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Communication

Preliminary Evaluation of Minor Cereals as Non-Traditional Brewing Raw Materials

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Abstract: Recently, "minor" cereals have been gaining interest due to their distinctive characteristics, not only in terms of nutritional and health potential, but also because of their hardiness. To date, the use of several of these cereals for the production, both at artisan and industrial level, of foods such as pasta and bakery products has already been well established, whereas their investigation for the production of malt and beer has been more limited. In this work, a preliminary analysis of the malting aptitude of einkorn, tritordeum, food-grade sorghum and teff was evaluated. Grain quality parameters that influence the processes of malting and transformation into alcoholic beverages were evaluated, i.e., thousand-kernel weight, test weight, total protein and starch content, falling number, germination capacity, germination energy and amylase activity. Grain analyses showed, on average, satisfactory values for alcoholic fermented beverage production in all the cereal species examined (mainly in tritordeum), whereas the amylase activity of the malts produced was lower than that revealed in barley malt. Fermented drinks derived from these minor cereals, therefore, could be interesting for the light and gluten-free beer markets.

Keywords: malt; einkorn; sorghum; teff; tritordeum

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1. Introduction

Today, the food sector is going through a new trend characterized by the challenges of reconciling innovation and tradition, promoting plant and food biodiversity, and offering development opportunities to local producers. Over the last few years, there has been a notable spread of beer culture accompanied by a growing offer of craft beers and the launch of numerous micro-breweries, brew pubs and beer firms [1]. In light of this, a strong boost to the brewing sector could be derived from the cultivation of unconventional cereals if used as an alternative to or in mixture with barley malt in order to create innovative fermented beverages. Although barley (*Hordeum vulgare* L.) remains the first-choice grain used in brewing Western-style beers, the recent interest in "underutilized" cereals and pseudocereals, such as oat, einkorn, sorghum, teff, millet, buckwheat, quinoa and amaranth [2,3], has also spread to the brewing sector due to their possible contribution to new beer flavors and quality, as well as their potential effect on health issues. Indeed, in consideration of the notable increase in the prevalence of gluten-related disorders such as celiac disease and wheat sensitivity, gluten-free cereals or cereal species characterized by less structured and more digestible gluten could be suitable for the production of low-gluten or gluten-free fermented beverages [4]. The properties of the malt from non-traditional cereals are, in general, poor compared to barley malt, and brewing generally requires the use of exogenous enzymes, mainly due to the different structure of starch and the higher subsequent temperature of gelatinization that is required in comparison to the optimal value for amylolytic activity, resulting in lower fermentable sugar content [4,5]. Though alcoholic drinks do not represent a primary source of nutrients, human well-being encompasses a number of food and social items which are not only able to satisfy physiological needs, but which are also important for the quality of social lives [6]. Beer is one of these products that is consumed throughout the world on a large scale. Therefore, it is important that individuals that opt against gluten are also able to safely consume and purchase good-tasting gluten-free beers. In this context, several "minor cereals" characterized by good antioxidant capacity, high vitamin and mineral content, and low or no gluten index (such as einkorn wheat (*Triticum monococcum* spp. *monococcum*), tritordeum (x Tritordeum Ascherson and Graebner), sorghum (*Sorghum bicolor*) and teff (*Eragrostis tef*)) [7–9] can represent a suitable raw material for the production of unconventional beers in anticipation of the expansion of the craft beer market [10,11]. *Triticum monococcum* is a diploid, hulled wheat that has been cultivated for a thousand years and progressively replaced by free-threshing and higher yielding wheat species. Naked varieties have an economic advantage because no de-hulling process is required before milling to produce flours. On the contrary, in barley brewing, the presence of glumes is exploited for wort filtration after mashing. Nowadays, einkorn has been reintroduced in different geographical areas thanks to its adaptation to poor soils and low-input agriculture. Despite having more digestible gluten with respect to the most cultivated wheats, einkorn shows good technological and organoleptic properties along with a distinctive nutritional value [12]. Tritordeum is an amphiploid species produced by crossing wild barley with either durum or common wheat. These hybridizations produce hexaploid and octoploid tritordeum, respectively [8]. Tritordeum could be a good novel raw material for the production of health-promoting foods. In addition, it has been shown to have fewer gluten immunogenic peptides in comparison with wheat [13]. Sorghum is the fifth most widely grown cereal crop after wheat, rice, corn and barley. Due to its C4 nature, sorghum has higher photosynthetic nitrogen and water use efficiencies than C3 plants, hence exhibiting good drought tolerance and adaptation to tropical and subtropical conditions [14]. It is a major human food source in Africa and Asia for more than 300 million people [15], and it could represent a valuable crop in the context of climate changes worldwide. It is mainly used for feed and ethanol production, and only 50% of total world production is used for human consumption [16]. However, the development of food-grade white sorghum, deprived of tannins possessing antinutritional properties, has significantly increased sorghum cultivation and consumption in Western countries. Sorghum shows a great concentration of bioactive compounds (i.e., phenolic acids, anthocyanins, phytosterols) and good technological properties [16,17] and could contribute to the development of healthy gluten-free foods and beverages. The use of sorghum as a brewing material is popular in Africa, and nowadays it is both largely used as an adjuvant and malted for gluten-free beer production worldwide [18–21].

Teff is a minor cereal crop worldwide, whereas in Ethiopia it constitutes the staple food for more than half of the Ethiopian population. Currently, it is being grown more widely in India, Australia, Canada, the United States and South Africa. Three types of teff are grown: brown, white and mixed-seed varieties. This niche gluten-free cereal can constitute a promising raw material for enhancing diversification in nutrition, contributing to the development of healthier foods and more sustainable agriculture [9]. In this work, a preliminary evaluation of the malting aptitude of einkorn, sorghum, teff and tritordeum was carried out, mainly through assessment of the germination characteristics and enzymatic activity of the different kernels in order to individuate potential alternative raw materials for the manufacturing of low-alcohol and low-gluten or gluten-free fermented beverages.

2. Materials and Methods

2.1. Grain Quality Parameters

Grains from five cereal species were used in this work: one commercial barley variety 'Tea', two einkorn cultivars, one naked 'Hammurabi' and one hulled 'Norberto', one advanced breeding line of tritordeum, one sorghum hybrid selected for human nutrition (food-grade) and two commercial varieties of teff, white and brown grains, for a total of seven samples. Grain quality parameters important for brewing aptitude were considered in this work, i.e., germination capacity (GC), germination energy (GE), 1000-kernel weight (TKW), test weight (TW), protein and total starch (TS) content, falling number (FN) and grain moisture. Seed size selection is essential for homogeneous germination during malting. Before performing the analyses and the malting process, the kernels were graded by grain size into four different categories by using a sieving equipment: larger than 3.7 mm, from 3.7 to 3.5 mm, from 3.5 to 2.6 mm and smaller than 2.6 mm (Carter Dockage Tester, Seedburo, Des Plaines, IL, USA). Broken grains and grains of lower than 2.6 mm width were removed. The kernel size between 3.7 and 3.5 mm was selected for all cereals, except for teff because of its very small grain size (0.8 mm, on average). To evaluate germination capacity and germination energy, one hundred kernels from each sample were sterilized by washing in a 1% NaClO solution, followed by two subsequent rinses with sterile distilled water. The kernels were germinated in 110 mm Petri dishes with two layers of filter paper (Whatman No. 1, Cytiva, Malborough, MA, USA) wetted with 4 mL H_2O. The samples were placed in a dark thermostat at 20 °C, except for sorghum, which was incubated at 25 °C [22] (Figure 1).

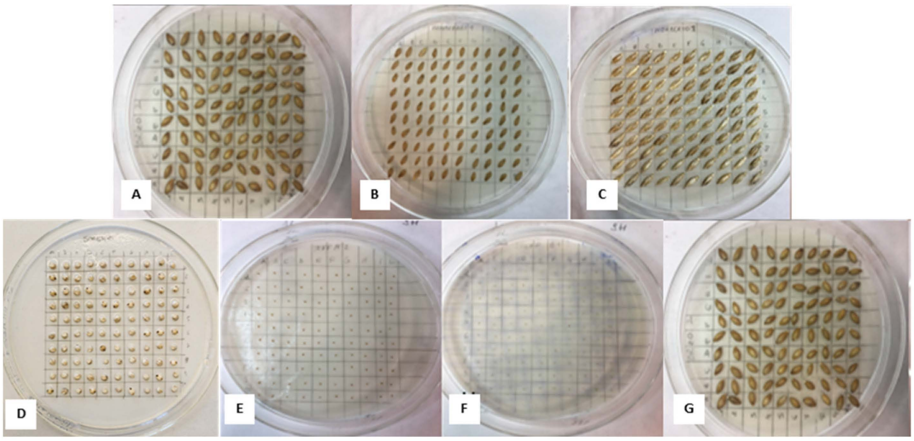

Figure 1. Germination test of barley (**A**), einkorn cv. Hammurabi (**B**), einkorn cv. Norberto (**C**), sorghum (**D**), brown teff (**E**), white teff (**F**) and tritordeum (**G**).

Germinated seeds were counted after 24, 48, 72, 96 and 120 h. For each sample, three replicates of 100 seeds were performed. The germination capacity and the germination energy were calculated using the equations below [23]:

$$\text{Germination Capacity (GC)} = \text{total germinated seeds after 5 days/total seeds sown} \times 100/1$$

$$\text{Germination Energy (GE)} = \text{germinated seeds after 3 days/total germinated seeds after 5 days} \times 100/1$$

Moisture content was assessed by the ICC 110/1 method [24] modified according to ASAE Standards [25]; in detail, intact kernels were incubated at 130 °C for 20 h for barley, 19 h for einkorn and tritordeum, 18 h for sorghum and teff. Thousand-kernel weight and test weight were evaluated by ISO 520:2010 [26] and ISO 7971-1:2009 [27] methods, respectively. All samples were milled to wholemeal flour using a laboratory mill (Cyclotec, Tecator/Hoganas, Sweden) with 0.5 or 1.0 mm sieve, depending on the requirements of each analysis, and kept at 4 °C until their use. Moisture content in flour was measured using the thermobalance (Sartorius MA 40, Göttingen, Germany) at 120 °C just before the chemical analyses. All analyses were performed in triplicate on two independent aliquots of each sample, and the data were expressed as dry basis. Protein content was determined according to the ICC 105-2 method [28], using as conversion factor N × 5.7 for einkorn cultivars, 5.85 for barley and 6.25 for other cereal species. Total starch was measured using the enzymatic method by the Megazyme (Bray, Ireland) kit K-TSTA according to AOAC methods 996.11 [29]. The falling number was assessed by AACC 56-81B method [30] using the Perten 1500 system (Hagersten, Sweden).

2.2. Malting Procedures

About 2 kg of grain samples was used for the malting process carried out using a customized micro-malting plant. The automated micro-malting pilot apparatus with a capacity of 1–10 kg consisted of a stainless steel tank in which steeping, germination and kilning stages were performed. The tank was equipped with a perforated cylindrical container placed on two rollers adapted to rotate the cylinder (1 revolution/min) to prevent compacting of the grain and to allow the aeration of the mass. Malting conditions were programmed and controlled by PLC system. Throughout steeping and germination, the air on, air off and temperatures were continuously monitored and logged. Each sample was washed vigorously using tip water to remove the dirt before the steeping step. The malting conditions for each cereal are summarized in Table 1. Malting procedures for sorghum, teff, barley and tritordeum followed the methods described by Djameh et al. [31], Di Ghionno et al. [32], Turner et al. [33] and Yding et al. [34], respectively, with slight modifications (Table 1). The einkorn malting process was performed according to the results of previous trials carried out to study the variability of einkorn amylase activity under different malting regimes. De-culming of all cereals was performed manually by rubbing immediately after the drying step, except for the einkorn cv. Norberto, which was de-hulled and de-culmed mechanically using a rice huller FC4S (Otake Co., Ltd., Oharu, Japan) after the drying step of the malting process. Indeed, the einkorn de-hulling before malting significantly affects the germination rate because of the extreme softness of einkorn kernels [35,36], leading to a very high percentage of broken kernels. The moisture content of the malts was determined immediately at the end of the kilning. The malting loss was determined as a percentage value reflecting the difference in the weight of 1000 grains (as dry base) measured before and after the malting process.

Table 1. Malting program of barley, einkorn, sorghum, teff and tritordeum.

Species	Steeping	Moisture after Steeping	Germination	Kilning
Barley	10 h wet, 19 h dry, wet 6 h, dry 8 h, wet 4 h (total 47 h), 15 °C	45%	96 h, 15 °C	2 h, 30 °C; 6 h, 40 °C; 15 h, 50 °C; 5 h, 60 °C (total 28 h)
Einkorn cv. Hammurabi	2 h wet, 19 h dry, wet 2 h (total 23 h), 15 °C	42%	96 h, 15 °C	6 h, 40 °C; 15 h, 50 °C; 5 h, 60 °C (total 26 h)
Einkorn cv. Norberto	4 h wet, 19 h dry, wet 2 h (total 25 h), 15 °C	42%	72 h, 15 °C	6 h, 40 °C; 20 h, 50 °C; 5 h, 60 °C (total 31 h)
Sorghum	4 h wet, 2 h dry, wet 4 h, dry 2 h, wet 4 h (total 16 h), 28 °C	45%	96 h, 28 °C	1 h, 30 °C; 1 h, 35 °C; 15 h, 40 °C; 2 h, 50 °C; 2 h, 60 °C (total 21 h)
Teff	3 h wet, 2 h dry, wet 2 h, (total 7 h), 24 °C	48%	96 h, 24 °C	6 h, 30 °C; 10 h, 40 °C; 5 h, 60 °C (total 21 h)
Tritordeum	6 h wet, 18 h dry, wet 6 h (total 30 h), 20 °C	42%	72 h, 20 °C	2 h, 30 °C; 12 h, 40 °C; 5 h, 60 °C (total 19 h)

2.3. Amylase Activity

The amylase activity of the malted grains was determined using the Ceralpha assay kit (Megazyme) for α-amylase activity, as previously described by McCleary and Sheehan [37], and the Betamyl assay kit (Megazyme) for β-amylase activity, as described by McCleary and Codd [38]. One unit of α-amylase activity is defined as the amount of enzyme, in the presence of excess thermostable α-glucosidase, required to release one micromole of *p*-nitrophenol from *p*-Nitrophenyl-α-D-maltoheptaoside (BPNG7) in 1 min under the defined assay conditions and is termed as Ceralpha® Unit; with regard to β-amylase activity, one unit of activity is defined as the amount of enzyme, in the presence of excess thermostable β-glucosidase, required to release one micromole of *p*-nitrophenol from *p*-Nitrophenyl-β-

D-maltotrioside (PNPβ-G3) in 1 min under the defined assay conditions and is termed as Betamyl-3® Unit.

2.4. Statistical Analysis

Results of all the analyses were expressed as means ± SD. Past 4.03 software was used to perform one-way multivariate analysis of variance (one-way ANOVA) employing the Kruskal–Wallis test to assess significant differences among the samples for each type of matrix ($p < 0.05$). ANOVA was followed up using univariate ANOVAs (Dunn's post hoc test).

3. Results and Discussion

3.1. Grain Quality

Germination capacity is the percentage of seeds that would normally germinate under optimal conditions of moisture and temperature for each species. Usually, values ≥ 96% indicate an excellent germination rate [39]. In the germination test (Figure 1), only barley, tritordeum and einkorn cv. Norberto showed excellent germination capacity, whereas the other samples showed values lower than 96%, particularly the brown teff, which showed only 90% of germinated seeds (Figure 2). The differences observed between the two einkorn cultivars could be ascribed to the free-threshing spike habit of cv. Hammurabi with respect to the hulled cv. Norberto. Indeed, this characteristic is linked to a partial sterility of the spikelet and poor seed germinability [40]. Concerning sorghum, the low germination capacity could be attributed to the amount of the water used (the same for all the species) in the germination test, which could represent a limiting factor for seed germinability, as also observed by [41], who found a germination capacity of 65% on average. Germination energy is a parameter that expresses the speed at which the seed germinates and, consequently, the ability of the kernel to overcome the dormancy phase. Seeds with good germination energy generally show homogeneous sprout, which is fundamental in the malting process. A germination energy as high as 100% was obtained in the samples of teff, tritordeum and einkorn cv. Hammurabi, whereas sorghum showed the lowest value (48.4%) amongst the cereals analyzed (Figure 2). The lowest value observed in sorghum with respect to the literature data [42] suggested that more days are required by this sorghum genotype to overcome the dormancy phase with respect to the other species analyzed. As a matter of fact, the germination energy was recorded after 3 days of incubation, whereas sorghum showed 50% of germinated seeds between the first and third day and the remaining 50% between the fourth and fifth day, indicating a low seed germination homogeneity in this food-grade sorghum hybrid.

Thousand-kernel weight (TKW) is an important prerequisite for the quality of malting and brewing processes. Kernels with high TKW are plumper, malt and mill more evenly and have a greater proportion of endosperm than small kernels; thus, TKW is a valuable parameter to maltsters and millers [43]. This parameter is significantly influenced both by the genotype and the environmental conditions [44,45].

TKW values of tritordeum (33.5 g) and einkorn cv. Hammurabi (33.4 g) were higher than those obtained for barley (26.0 g), used as reference (Table 2). The two teff varieties, as expected, showed the lowest values (0.3 g). Kernel test weight (TW) is a quality parameter that indicates the degree of filling of the kernel, and it is mainly correlated with starch content [46]. According to the European Brewery Convention (EBC), the test weight of brewing barley must range from 65 to 75 kg/hL, as stated by [47]. Indeed, high plump kernels, determined by starch, non-starch polysaccharides (NSP), lipids and proteins content in the endosperm [48], are desirable as they indicate high starch density and, consequently, high malt yield. The highest TW value was found in white and brown teff genotypes (88.9 and 86.9 kg/hL, respectively), followed by tritordeum (82.7 kg/hL), whereas sorghum showed the lowest value (72.6 kg/hL) amongst the species analyzed (Table 2). The TKW and TW values were in line with the literature data reported for tritordeum, einkorn, teff and sorghum [4,9,49–51].

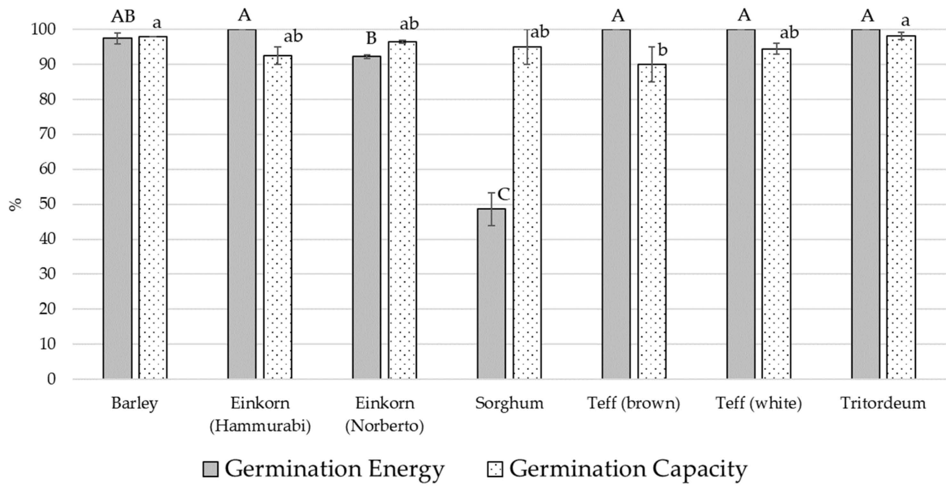

Figure 2. Germination capacity and germination energy of barley, einkorn cv. Hammurabi, einkorn cv. Norberto, sorghum, brown teff and white teff and tritordeum genotypes. Different letters (uppercase for germination energy and lowercase for germination capacity) indicate significant differences as determined by Dunn's post hoc test ($p < 0.05$).

Table 2. Kernel quality parameters of barley, einkorn, sorghum, teff and tritordeum genotypes.

	TKW g	TW kg/hL	TS g/100 g	Protein g/100 g	FN s
Barley	26.0 ± 0.1 ^{ab}	73.5 ± 0.4 ^{b}	64.4 ± 0.1 ^{ab}	11.3 ± 0.1 ^{b}	303 ± 7 ^{b}
Einkorn cv. Hammurabi	33.4 ± 0.4 ^{a}	79.4 ± 0.3 ^{b}	54.9 ± 0.2 ^{b}	19.0 ± 0.1 ^{a}	414 ± 2 ^{ab}
Einkorn cv. Norberto	23.8 ± 0.7 ^{ab}	80 ± 1 ^{b}	51.9 ± 0.2 ^{b}	19.9 ± 0.2 ^{a}	356 ± 14 ^{b}
Sorghum	24.2 ± 0.4 ^{ab}	72.6 ± 0.6 ^{b}	79.5 ± 0.9 ^{a}	10.5 ± 0.3 ^{b}	473 ± 11 ^{ab}
Teff (brown)	0.26 ± 0.02 ^{c}	86.9 ± 0.3 ^{ab}	77.3 ± 0.4 ^{a}	11.6 ± 0.1 ^{b}	431 ± 1 ^{ab}
Teff (white)	0.27 ± 0.01 ^{c}	88.9 ± 0.2 ^{a}	79 ± 1 ^{a}	11.0 ± 0.1 ^{b}	623 ± 15 ^{a}
Tritordeum	33.5 ± 0.9 ^{a}	82.7 ± 0.7 ^{ab}	61.9 ± 0.7 ^{ab}	17.5 ± 0.1 ^{ab}	383 ± 6 ^{b}

TKW: thousand-kernel weight; TW: test weight; TS: total starch; FN: falling number. Results are expressed as the mean value and standard deviation (SD) for 3 replications. Values in the same column followed by a different letter are statistically different ($p < 0.05$) according to Dunn's post hoc test.

Protein content is an important attribute in assessing grain quality for malting, but, in the two-row malting barley genotypes, the suitable value should not exceed 12% [52,53]. Indeed, it is known that, in beer production, excessive protein content counteracts the amount of starch in the endosperm, decreasing extracts available to the brewer and causing haze formation and a mash runoff problem [52,53]. Moreover, grains with high protein content are undesirable because it limits the enzymatic breakdown of starch by obstructing access of hydrolytic enzymes, thus leading to a poor malt extract and longer steeping time [54,55]. Higher protein content also affects mouthfeel and foam stability in beer [48,52]. However, lower protein content impairs brewing because of poor amino acid nutrition to yeast. The results of this research (Table 2) highlighted very high protein content in the two varieties of einkorn, Hammurabi (19.3%) and Norberto (19.9%), and in tritordeum (17.5%), whereas the lowest values were found in sorghum (10.5%) and in white teff (11.0%). As previously mentioned, high protein grains are generally not thought of as good for brewing, hence, the potential use of einkorn and tritordeum as raw material for brewing should take into account strategies to overcome this drawback, such as the use of exogenous proteases, like ficin and papain, used as chill-proof enzymes able to hydrolyze the proteins that cause the chilling haze [56], longer steeping [55], and protein rest during mashing and silica adsorbent treatment during beer filtration [57]. High starch content is an important requisite for the production of malt as it correlates with the quantity of fermentable sugars that will be used by the yeast during fermentation and, consequently, with the alcohol content of the resulting beverage. As reported in Table 2, sorghum and teff showed the highest starch content, 79.4% and 79.0%, respectively. Nevertheless, the content of fermentable sugars in the wort depends on the starch-degrading enzymes present in the malt of each species. Falling number is used for the indirect assessment of the flour α-amylase activity, and they are inversely proportional [58]. It is based on the viscosity change of a hot flour paste where an increased α-amylase activity leads to faster liquefaction of the paste and, thus, a shorter falling time. The FN values of the cereals analyzed were all found to be higher than 300 s (Table 2), an indication of low enzymatic activity of the α-amylase in the crude grain. It is noteworthy that barley and tritordeum showed the lowest FN value, confirming the well-known better malting aptitude of barley, whose germplasm is present also in the tritordeum genome.

3.2. Malting

The steeping step conditions applied to the different cereal species were related to kernel size, endosperm texture and the presence of the glumes [59], as in barley and einkorn cv. Norberto. Indeed, the longest wet steeping phase was applied to barley, whereas the shortest to einkorn and teff (Table 1), which showed small and soft-textured caryopsis. A floury endosperm adsorbs water more easily than a vitreous one and requires a shorter steeping time for the complete hydration of the kernel [59]. The total malting loss is affected by the decrease in the grain weight associated with the modifications resulting from seed germination, i.e., respiration and roots and shoot removal [60]. With respect to barley, which showed a total malting loss of 8.0%, lower values (6.5%) were recorded in grains of tritordeum and einkorn cv. Norberto, whereas higher values were found in sorghum (18.6%) followed by teff (11.0%) and einkorn cv. Hammurabi (8.8%). The longer duration of the malting process adopted for einkorn cv. Hammurabi and sorghum (Table 1) led to an increased total loss of kernel weight because of the growth of greater numbers of roots and shoots upon germination. In teff, the relative high malting loss percentage could be ascribable also to the considerable length of the radicles (1 cm) compared to the extremely reduced kernel size. Optimal malting loss should not exceed 10% since lower values are an index of low amylase activity and, consequently, a low fermentable sugar content in the wort. Conversely, high values of malting loss are a consequence of a more extended germination step and hence ineffective from an economic point of view due to an increased kernel weight loss without an improvement in the quality of the wort [60].

3.3. Amylase Activity

The main starch-hydrolyzing enzymes in malt are α- and β-amylase, the first being synthetized upon germination, and the second being accumulated in a bound form during kernel development and cleaved during the malting. The latter contributes the most to the production of fermentable sugars during mashing, which will be used by yeast during fermentation for the production of ethanol and CO_2 [61]. Previous research on the usage of various gluten-free grains as brewing ingredients has shown that their malts are generally lower in β-amylase and α-amylase contents when compared to barley [62]. Sorghum and white teff malts showed the highest α-amylase activity (78.7 and 74.3 CU/g, respectively), though less than half in comparison to that of the barley used as reference, while the highest value of β-amylase activity was recorded in tritordeum (27.8 B3U/g) (Figure 3). Regarding β-amylase activity, einkorn showed values comparable to those of barley and tritordeum even higher. Differently, sorghum and teff showed the lowest values of β-amylase activity, but, on the other hand, the alpha-amylase activity, for the white seed teff only, was significantly higher than in the other species examined. The low amylolytic activity of these cereals could be counterbalanced by mashing procedures tailored to the enzymatic and physical properties of these malts or by the set-up of optimal pH and temperature mashing conditions [62] or by the supplement of barley malt or exogenous amylase [63].

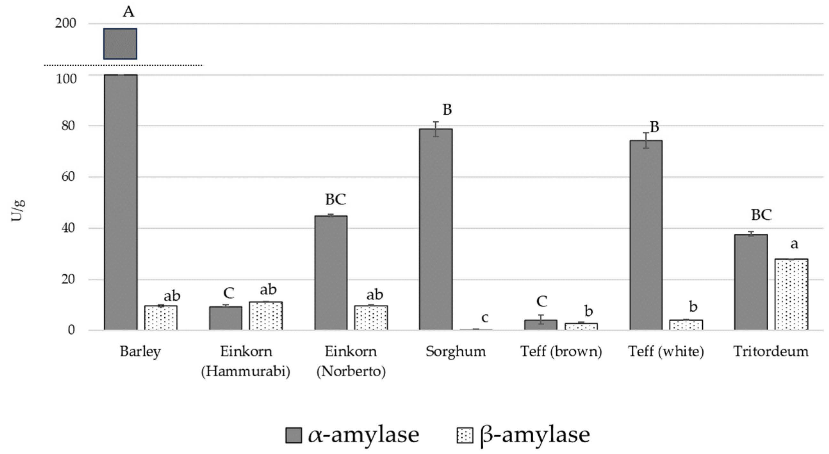

Figure 3. Amylase activity of malt from: barley, einkorn cv. Hammurabi, einkorn cv. Norberto, sorghum, brown teff and white teff and tritordeum genotypes. Different letters (uppercase for α-amylase activity and lowercase for β-amylase activity) indicate significant differences as determined by Dunn's post hoc test ($p < 0.05$).

4. Conclusions

The renewed interest in the use of cereals as an alternative to barley from the brewing industry and home and small craft brewers has stimulated the research to explore the aptitude of new germplasms to be brewed. From these preliminary analyses aimed at evaluating the malting aptitude of minor cereals, tritordeum was the species with the best characteristics in terms of germinability, malting loss and β-amylase activity, followed by einkorn. Nevertheless, both species are characterized by a very high protein content that could affect beer quality. This drawback could be overcome by technological expedients during brewing, such as exogenous proteases, longer steeping and protein rest, or by a focused varietal choice, selecting genotypes with lower protein content. Amongst gluten-free cereals, white teff was better than sorghum in terms of germination energy, test weight and β-amylase activity, even though the former is definitively less widespread, also because of restrictive teff export Ethiopian policies. Minor cereals could be used not only for light or gluten-free beer production, but also as source of extract, in order to impart distinctive flavors in specialty fermented beverages production. Though the brewing aptitude of these cereals cannot be compared to that of barley, the use of minor cereals could provide several benefits in terms of employment of local plant resources, reducing supply costs and environmental impacts and strengthening connection with territories, in line with the sustainable development of the food system and the exploitation and preservation of agro-food biodiversity.

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Data Availability Statement: The authors confirm that the data supporting the findings of this study are available within the article.

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