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ARTICLE

Bioaccessible Mineral Content of Malted Finger Millet (*Eleusine coracana*), Wheat (*Triticum aestivum*), and Barley (*Hordeum vulgare*)

KALPANA PLATEL,* SUSHMA W. EIPESON, AND KRISHNAPURA SRINIVASAN

Department of Biochemistry and Nutrition, Central Food Technological Research Institute, CSIR, Mysore 570 020, India

Malted grains are extensively used in weaning and geriatric foods. Malting generally improves the nutrient content and digestibility of foods. The present investigation examined the influence of malting of finger millet, wheat, and barley on the bioaccessibility of iron, zinc, calcium, copper, and manganese. Malting increased the bioaccessibility of iron by >3-fold from the two varieties of finger millet and by >2-fold from wheat, whereas such a beneficial influence was not seen in barley. The bioaccessibility of zinc from wheat and barley increased to an extent of 234 and 100%, respectively, as a result of malting. However, malting reduced the bioaccessibility of zinc from finger millet. Malting marginally increased the bioaccessibility of calcium from white finger millet and wheat. Whereas malting did not exert any influence on bioaccessibility of copper from finger millet and wheat, it significantly decreased (75%) the same from barley. Malting did increase the bioaccessibility of manganese from brown finger millet (17%) and wheat (42%). Thus, malting could be an appropriate food-based strategy to derive iron and other minerals maximally from food grains.

KEYWORDS: Bioaccessibility; barley; finger millet; malted cereals; minerals; wheat

INTRODUCTION

Deficiencies of micronutrients, especially minerals such as iron, zinc, and calcium, are widespread in developing countries and are a cause for concern. Although many factors including inadequate dietary intake of these micronutrients are responsible for the onset of iron and zinc deficiencies, their poor bioavailability from plant foods is probably the most likely cause (*1*, *2*). Therefore, evolving dietary strategies to maximize the bioavailability of these micronutrients is one of the ways in which this public health problem can be overcome. Food processing methods such as heat treatment, germination, and fermentation have been evidenced to enhance the bioaccessibility of iron and zinc from cereal grains (*3*, *4*). Germination and fermentation of grains are generally practiced food-processing methods in India. Some of the cereals so processed also form foods for infants and older adults. Malting of cereals and pulses is one of the traditional methods of food processing, which is extensively used in the preparation of weaning and geriatric foods and beverages. The process of malting involves germination, followed by heat treatment. Malting generally improves the nutritional quality of foods by increasing their nutrient content and digestibility. The content of vitamin C is particularly enhanced during the process of germination, which is the initial stage of the malting procedure. Germination can bring about a 2-fold increase in bioavailability of iron, whereas malting of minor millets brings about a 5−10-fold increase in the same (*5*). Most weaning foods are prepared from cereals or starchy roots, commonly reconstituted with water. Such foods become highly viscous when reconstituted and are difficult to feed to infants. Due to the small stomach capacity of infants, they cannot consume adequate amounts of bulky foods, resulting in inadequate intakes of vital nutrients. Hence, it is important to increase the calorie density of such weaning foods to the extent possible. Malting is known to reduce the viscosity of foods through amylolytic breakdown of starch, thus reducing bulk (*6*). Such malted foods, when used in the preparation of weaning foods, have the advantage of increased calorie density as a result of reduced viscosity. Such low-viscosity foods would also find application in the preparation of geriatric foods. During the process of aging, there is a reduction in gastrointestinal motility, thus making it difficult for the elderly to digest foods (*7*). Thus, foods of low viscosity and easy digestibility are desirable for these age groups. Information on the effect of malting of food grains on mineral bioavailability, however, is limited. In Latin American countries, household food-processing methods such as fermentation and germination are used in formulating infant foods (*8*). In view of this, the present investigation was carried out to examine the influence of malting of finger millet, wheat, and barley on the bioaccessibility of iron, zinc, calcium, copper, and manganese.

*Corresponding author (e-mail kalpanaplatel@gmail.com; fax +91-821-2517233; phone +91-821-2514876).

MATERIALS AND METHODS

Materials. The cereals, finger millet (*Eleusine coracana*) and wheat (*Triticum aestivum*), were procured locally, and barley (*Hordeum vulgare*) was procured from the University of Agricultural Sciences, Dharwad, India. The grains were cleaned and used for the study. Pepsin, pancreatin, and bile extract, all of porcine origin, were from Sigma Chemical Co., St. Louis, MO. Reference mineral standard solutions for atomic absorption spectrometry (AAS) were procured from Sisco Research Laboratories,

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Table 1. Mineral Contents of Malted Grains

food grain	mineral content[a] (mg/100 g)				
	iron	zinc	calcium	copper	manganese
finger millet, white					
unmalted	2.12 ± 0.02	1.44 ± 0.05	331.1 ± 1.28	0.20 ± 0.10	3.73 ± 0.05
malted	2.01 ± 0.00	1.38 ± 0.07	295.7 ± 1.25	0.16 ± 0.02	3.40 ± 0.04
finger millet, brown					
unmalted	2.36 ± 0.05	1.56 ± 0.03	339.3 ± 0.53	0.37 ± 0.03	5.98 ± 0.51
malted	2.20 ± 0.02	1.55 ± 0.11	306.8 ± 0.75	0.38 ± 0.01	5.35 ± 0.14
wheat					
unmalted	3.45 ± 0.02	1.61 ± 0.01	36.4 ± 1.45	0.53 ± 0.03	2.16 ± 0.03
malted	3.65 ± 0.11	1.44 ± 0.05	34.2 ± 2.32	0.44 ± 0.03	2.17 ± 0.06
barley					
unmalted	2.00 ± 0.08	3.08 ± 0.11	38.91 ± 1.46	2.93 ± 0.50	0.93 ± 0.02
malted	2.14 ± 0.16	3.10 ± 0.29	37.83 ± 2.22	3.03 ± 0.20	0.91 ± 0.03

[a] Values are mean ± SEM of five independent determinations.

Mumbai, India. All other chemicals used here were of analytical grade. Triple-distilled water was employed during the entire study. Acid-washed glassware was used throughout the study.

Malting of Food Grains. Two varieties of finger millet, namely, a brown variety and a white variety, wheat, and barley were used in this study. Hundred gram portions of the finger millet and wheat samples (taken in five replicates) were initially soaked for 24 h at room temperature; these grains were spread on a cloth and maintained moist by periodic sprinkling of water for 48 h. The sprouted grains were then sun-dried for 2 h, and the sprouts were removed physically by applying gentle pressure and sieving. The grains were then toasted in an open pan at around 80 °C for 3−4 min until a pleasant aroma developed. The toasted grains were ground to a fine powder in a stainless steel blender. In the case of barley, after the initial soaking, the grains were germinated at 23 °C for 3 days and dried at 55 °C for 2 h. The rootlets were then removed physically, and the grains were tempered by adding 7% moisture and ground to a powder. The method adopted for malting was similar to that commonly practiced in Indian households.

Determination of Total Mineral Content. The above samples were ashed in a muffle furnace at 550 °C for 10 h, and the ash was dissolved in concentrated HCl. Mineral contents (iron, zinc, calcium, copper, and manganese) were determined by atomic absorption spectrometry (Shimadzu AAF-6701). In the case of calcium, lanthanum chloride (0.2% of the final volume) was added to the mineral solution to avoid interference from phosphorus. Calibration of measurements was performed using commercial standards. All measurements were carried out with standard flame operating conditions as recommended by the manufacturer. The reproducibility values were within 2.0% for all of the minerals.

Determination of Bioaccessibility of Minerals. Bioaccessibility of minerals from the malted samples was determined by an in vitro method described by Luten et al. (*9*) and involving simulated gastrointestinal digestion with suitable modifications. Briefly, the freeze-dried samples were subjected to simulated gastric digestion by incubatiion with pepsin at pH 2.0 for 2 h. Segments of dialysis tubing (MW cutoff = 10 kDa) containing a solution of sodium bicarbonate in concentrations equimolar to sodium hydroxide as determined by titratable acidity were inserted into the gastric digesta, and incubation was continued further in the presence of a pancreatin−bile extract mixture (4 g of pancreatin and 25 g of bile extract in 1 L of 0.1 M sodium bicarbonate solution), to simulate intestinal digestion. The dialyzable fraction of the mineral, which represents that which is bioaccessible, was quantitated by AAS. Bioaccessibility was calculated as follows: bioaccessibility (%) = $100 \times Y/Z$, where Y is the element content of the bioaccessible fraction (mg of mineral element/100 g of grain) and Z is the total zinc or iron content (mg of mineral element/100 g of grain).

Statistical Analysis. All determinations were made in five replicates, and the average values are reported. Statistical analysis of analytical data was done employing t tests by using Origin software.

RESULTS AND DISCUSSION

The contents of iron, zinc, calcium, copper, and manganese in the raw and malted cereal grains are presented in **Table 1**. All of the cereal grains examined had similar iron contents, ranging from 3.45 mg/100 g in wheat to 2.00 mg/100 g in raw barley. Barley had the highest amount of zinc (3.08 mg/100 g), whereas the zinc content of the other three grains ranged from 1.44 to 1.61 mg/100 g. As expected, both varieties of finger millet had significantly high contents of calcium, being 339.3 and 331.1 mg/100 g in the brown and white varieties, respectively. Wheat and barley contained 36.4 and 38.9 mg of calcium/100 g, respectively. Copper content of the grains ranged from 0.20 mg/100 g in white finger millet to 0.53 mg/100 g in wheat. Barley had significantly higher copper content, being 2.93 mg/100 g. Manganese content was highest in the brown variety of finger millet (5.98 mg/100 g), whereas it ranged from 0.93 to 3.73 mg/100 g in the other three grains. As expected, malting of the grains did not influence their mineral content, except for bringing about a slight decrease in the copper content of wheat.

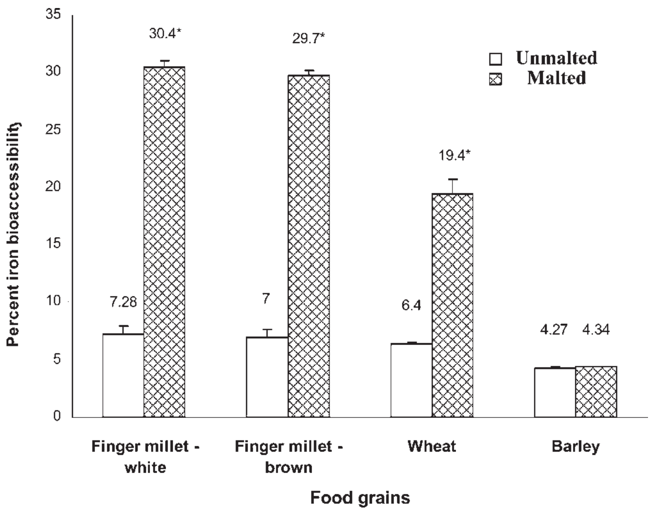

Figure 1. Effect of malting of grains on the bioaccessibility of iron. Values are mean ± SEM of five replicate determinations. ∗, value significantly ($p < 0.05$) higher than that of unmalted grain.

The effect of malting on iron bioaccessibility from the two varieties of finger millet, wheat, and barley is presented in **Figure 1**. Malting brought about an enormous improvement in the bioavailability of iron from both the varieties of finger millet and wheat. The extent of increase was nearly 4-fold in the two varieties of finger millet and around 3-fold in the case of wheat. Malting, however, did not bring about a similar enhancing effect on the bioaccessibilty of iron from barley (Figure.**1**).

The bioaccessibility of zinc from wheat and barley was enormously increased as a result of malting (**Figure 2**). The increase was 3-fold and 2-fold those in wheat and barley, respectively.

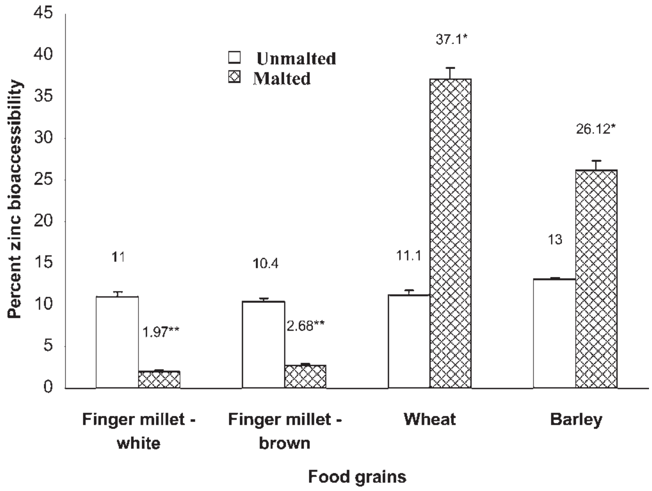

Figure 2. Effect of malting of grains on the bioaccessibility of zinc. Values are mean ± SEM of five replicate determinations. ∗, value significantly ($p < 0.05$) higher than that of unmalted grain; ∗∗, value significantly ($p < 0.05$) lower than that of unmalted grain.

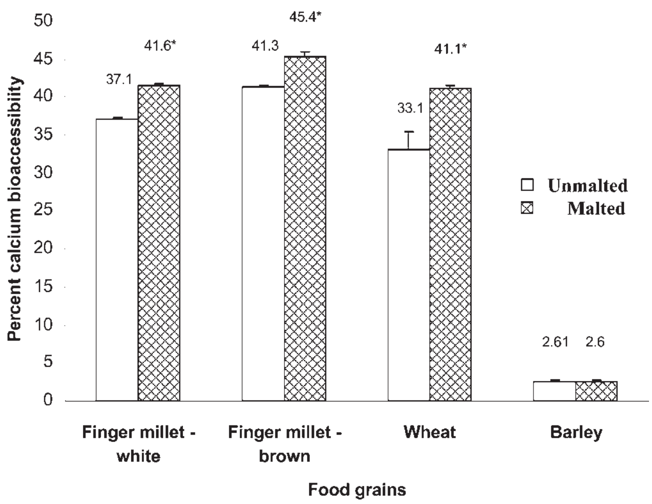

Figure 3. Effect of malting of grains on the bioaccessibility of calcium. Values are mean ± SEM of five replicate determinations. ∗, value significantly ($p < 0.05$) higher than that of unmalted grain.

Contrary to this, malting significantly decreased the bioaccessibility of zinc from the two varieties of finger millet examined (Figure.**2**), the percent decreases being 82 and 74 in the white and brown finger millets, respectively.

Malting brought about a slight increase in calcium bioaccessibility from white finger millet and wheat, the extent of increase being 12 and 24%, respectively (**Figure 3**). Such a beneficial effect of malting on the bioaccessibility of calcium was not evident in the case of barley. Thus, the beneficial influence of malting on the bioaccessibility of calcium was similar to that of iron, being restricted to finger millet and wheat.

Whereas malting did not exert any influence on bioavailability of copper from finger millet and wheat, it brought about a significant decrease in the same from barley (**Table 2**), the percent decrease in this case being 30.

The bioaccessibility of manganese from wheat was significantly increased as a result of malting, the percent increase being 42 (**Table 2**). Although malting had no effect on the bioaccessibility of manganese from white finger millet and barley, it brought about a 17% increase in the bioaccessibility of manganese from brown finger millet. Similar to that of iron and calcium, malting

Table 2. Effect of Malting of Grains on the Bioaccessibility of Copper and Manganese

grain	% bioaccessibility[a] unmalted	malted
Copper		
finger millet, white	45.1 ± 7.20	48.2 ± 5.00*
finger millet, brown	35.6 ± 1.53	39.2 ± 1.01*
wheat	35.9 ± 2.14	36.3 ± 2.19
barley	4.91 ± 0.35	3.40 ± 0.24**
Manganese		
finger millet, white	33.3 ± 0.64	34.3 ± 0.53
finger millet, brown	34.1 ± 1.99	39.9 ± 1.45*
wheat	27.1 ± 1.90	38.6 ± 2.34*
barley	11.4 ± 0.80	10.2 ± 0.75

[a] Values are mean ± SEM of five replicate determinations: *, value significantly ($p < 0.05$) higher than that of unmalted grain; **, value significantly ($p < 0.05$) lower than that of unmalted grain.

did not have a beneficial influence on manganese bioaccessibility from barley.

Thus, malting generally improved the bioaccessibility of the minerals examined. This beneficial influence of malting was enormous in the case of iron bioaccessibility from three of the four grains examined. On the other hand, whereas malting brought about a significant increase in zinc bioaccessibility from wheat and barley, the same was significantly decreased in the two varieties of finger millet. The conspicuous contrasting influence of malting on iron and zinc bioaccessibility is evident only in the case of finger millet but not in wheat and barley. The reason for such differentiation of grains on the bioavailability of these two minerals needs to be elucidated further. The present study also suggests that malting of barley may form a good strategy to provide higher amounts of bioaccessible minerals, except zinc.

The beneficial effect of malting on iron and calcium bioaccessibility, which was evident in finger millet and wheat, may probably be attributed to the decrease in phytate content as a result of malting. The phytate content was highest in finger millet (612 mg/100 g), followed by wheat (417 mg/100 g) and barley (278 mg/100 g) (*10*, *11*). Barley, the intrinsic phytate content of which was relatively lower, did not find similar advantage of enhanced bioaccessibility of these minerals as a result of malting. Among the inhibitors of mineral bioaccessibility inherent in cereal grains, phytate has been observed to be dominant as compared to either dietary fiber or tannin (*10*). Moreover, these inherent components are subject to alterations as a result of food processing, such as the germination and heat treatment involved in malting.

Any beneficial effect of malting on the bioavailability of minerals is probably due to the combined effects of soaking, germination, and heat treatment. Studies from our laboratory revealed that germination and heat treatment of grains independently brought about an increase in the bioaccessibility of iron (*3*, *4*). A 20% increase in iron bioaccessibility from finger millet was seen at the end of 48 h of germination (*4*). Heat processing of finger millet has been earlier evidenced to enhance the bioaccessibility of iron by 10.4 and 85% in pressure-cooked and microwave-heated finger millet, respectively. Pressure-cooking and microwave-heating brought about 39 and 11.5% increases, respectively, in the bioaccessibility of iron from wheat (*3*). The magnitude of increase in iron bioaccessibility as a result of malting (which involves germination followed by roasting) of these grains is enormous and is more than the effects brought about by germination and heat processing put together.

Germination and heat treatment (pressure-cooking) of finger millet have been earlier evidenced to independently decrease the bioaccessibility of zinc, the percent decreases being 38 and 63, respectively (*3*, *4*). The present observation of decreased bioaccessibility of zinc in malted finger millet is consistent with this earlier observation.

It has been reported that during germination, de novo synthesis and activation of endogenous phytases with concomitant decrease in phytate content occurs in cereals and legumes (*12*, *13*). In the case of finger millet, phytate content was not affected by germination; however, the tannin, which is a known inhibitor of mineral bioavailability, was significantly (50%) decreased as a result of germination (*4*).

Roasting and malting of wheat, barley, and green gram in the preparation of weaning foods was found to increase the bioavailability of iron by 16−32%. This effect was more pronounced in malted weaning foods compared to roasted ones (*14*). It has been reported that using a malting process to decrease phytic acid in oats resulted in increased zinc and iron absorption in adult subjects (*15*).

Cereals and legumes are staple foods in the diet of populations in developing countries and are also the main sources of minerals such as iron and zinc. Mineral availability from these food grains being generally poor due to the presence of phytic acid, tannin, and dietary fiber, food-based strategies are needed to maximize the mineral absorbability from these sources. The much practiced heat processing, germination, and fermentation of grains as encountered during Indian culinary practices have been earlier evidenced to have beneficial influences on mineral bioaccessibility (*3*, *4*). Similarly, the beneficial influence of food acidulants commonly used in India on mineral bioaccessibility has also been documented (*16*). The present study is the first report on the beneficial influence of malting, a traditional process that is employed at both domestic and commercial levels, especially in the manufacture of weaning and geriatric foods, on mineral bioaccessibility. The magnitude of this beneficial effect of malting on the bioaccessibility of iron, zinc, and calcium in particular from these grains suitable for malting is far more than that brought about by any other processing method. Minerals such as calcium, iron, and zinc are important, especially during the weaning period and during aging. During weaning, the poor stomach capacity of infants will result in inadequate intakes of these vital nutrients, necessitating the inclusion of malted grains to lower the bulk of weaning foods. During the process of aging, atrophic gastritis, a condition characterized by a lack of hydrochloric acid and the intrinsic factor, will impair the digestion and absorption of nutrients, most notably vitamin B^{12} but also calcium, iron, and zinc (*7*). Thus, the beneficial influence of malting on mineral bioaccessibility is an additional advantage over and above the perceived easy digestibility achieved through lowered viscosity, rendering it ideal for geriatric and weaning formulations.

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