Available online at www.elixirpublishers.com (Elixir International Journal)

Food Science

Elixir Food Science 41 (2011) 6051-6054

ISSN: 2229-712X

The inhibitory effect of phytate on the bioavailability of calcium, iron and zinc in raw commonly consumed sorghum and maize cultivars

Yankey R K[1], Amartey E O[1], Achel DG[2], Adaboro RM[2], Saalia K[3], Duncan AE[4] and R Zugle[4]

[1]National Nuclear Research Institute, Ghana Atomic Energy Commission, P.O. Box LG 80, Legon, Accra.

[2]Radiological and Medical Sciences Research Institute, Ghana Atomic Energy Commission, P.O. Box LG 80, Legon, Accra.

[3]Department of Food Science and Nutrition, University of Ghana, Legon, P.O. Box P.O. Box LG 25, Legon, Accra, Ghana.

[4]Department of Chemistry, University of Cape Coast, Cape Coast, Ghana.

ARTICLE INFO

Article history:
Received: 24 October 2011;
Received in revised form:
15 December 2011;
Accepted: 28 December 2011;

Keywords
Phytate,
Mineral,
Molar ratio,
Bioavailability,
X-ray fluorescence.

ABSTRACT

Energy dispersive X-ray fluorescence (EDXRF) has been used to determine the Ca, Fe and Zn content in eight sorghum and maize cultivars. The phytate content is also determined together with the phytate/mineral molar ratios in order to estimate the inhibitory effect of phytate on the bioavailability of these minerals. The results obtained indicated high phytate/mineral molar ratio and suggest thus that reduced and possible non-bioavailability of the minerals may be incited. Nonetheless the [CaxPh]:Zn ratios suggests that the cereal cultivars are a good source of the minerals and that processing of the cereals would improve bioavailability of the mineral.

Introduction

The quality of our diet depends on the nutrient content and the bioavailability of its nutrients. Bioavailability of nutrients is about how the little bits of food e.g. amino acids, fatty acids, minerals, simple sugars and vitamins are made available to our bodies for use. The bioavailability of nutrients present in food can vary substantially and is determined by: nutrient content of the food, food processing, the physical state of the person, interactions among components of the diet and the presence of anti-nutritional factors such as phytates, oxalates, tannins and polyphenols in foods, (Paul, Turner & Ross, 2004).

Minerals that are needed by the body in small amounts are referred to as micronutrients. Though needed in small amounts, deficiencies in these minerals can have a major impact on health such as depression, hormonal imbalance, anemia, poor concentration and osteoporosis that commonly occur in both developing and developed countries. The cause of mineral deficiency is commonly due to its low bioavailability in the diet. The importance of a foodstuff as a source of dietary mineral depends upon both the total mineral content and the level of other constituents in the diet that affect mineral bioavailability. Phytate may reduce the bioavailability of dietary zinc and calcium by forming insoluble mineral chelate at physiological pH.

Phytates are generally found in fibre-rich food such as wheat bran, whole grains and legumes (Lori, Thava & James, 2001). Due to evidence showing that food rich in fibre protect against diseases such as cardiovascular disease, breast and colon cancer, more people are now adopting a dietary pattern containing high fibre foods.

Phytate, also known as myoinositol hexakisphosphate (IP6), is a phosphorus containing compound that binds with minerals and inhibits their absorption. The presence of phytate in food has been associated with reduced mineral absorption. The ability of phytate to bind with minerals is attributed to its structure. Phyate has a high density of negatively charged phosphate groups (Figure 1) which form very stable complexes with mineral ions causing non-availability for intestinal absorption (Walter *et al*., 2002).

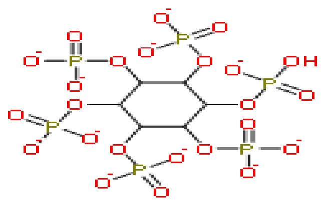

Figure1: Structure of phytate.
(http://www.chemspider.com/Search.aspx?q=phytate)

For example the inhibitory effect of phytate on mammalian zinc absorption is been recognized for over forty years (O'Dell BL, 1960 and Oberleas D et al, 1962), and there is considerable experimental (Sandstrom B, Sandberg AS, 1992; Turnlund JR et al, 1984 and Larsson M et al, 1996) and epidemiologic (Gibson RS, 1994 and Bindra GS et al 1968) evidence that dietary phytate has a negative effect on the bioavailability of dietary zinc in humans.

The inhibitory effect of phytate on mineral absorption has been quantified by the molar ratios of phytate to mineral in the diet (Morris & Ellis, 1989). The proportion of samples with ratios above the suggested critical values has been calculated: phytate: calcium > 0.24 (Morris & Ellis, 1985), phytate: iron > 1 (Hallberg, Brune & Rossander, 1989), phytate : zinc > 15 (Turnlund *et al*.,1984; Sandberg *et al*., 1987; Morris & Ellis, 1989). Similarly, phytic acid and mineral ratios have also been used for the purpose of determining mineral bioavailabilty. For

Tele:
E-mail addresses: rkyankey@gmail.com

example Erdal *et al*. (1998b) considered PA:Zn molar ratio, especially in cereals and legumes, to be a good criterion for assessment of Zn adsorption with PA:Zn of 25-30 as critical values in foods. Gibson *et al*. (1998) reported that PA:Zn molar ratio of 12 or higher caused a decrease in Zn absorption. According to WHO (1996) 55% of Zn content of foods is expected to be absorbed if PA:Zn ratio of foods is less than 5; whereas it would be 35% if the ratio is 5-15 and only 15% if it is higher than 15. Fordyce et al. also reported that zinc bioavailability, measured from growth and tibia zinc concentrations of rats, was better predicted by the (phytate x calcium):zinc ratio than the phytate:zinc ratio. The thrust of this study focused on the determination of phytate, calcium, iron and zinc contents and their molar ratios in commonly consumed raw cereal food in Ghana in order to estimate the inhibitory effect of phytate on the bioavailability of these minerals especially zinc.

Materials and Methods

Sample preparation

The samples were obtained from the Savanna Agriculture Research Institute (SARI). Each of the samples was air dried for two weeks and then pulverized and homogenized into a very fine powder using a grinding mill (FRITSCH Pulverisette 2, Germany). Dried powdered samples were extracted at room temperature by percolation with double distilled water. In this study water is been used for extraction as per the way the meal is prepared from the cultivars. The extracts were stored in refrigerator for laboratory analysis.

Sample analysis

The phytate content was determined by the method of Maga, (1982) with modification. This method depends on the ability of standard ferric chloride to precipitate phytate from the extract.

The elemental concentrations were determined using energy dispersive X-ray fluorescence (EDXRF) with a secondary target excitation arrangement. An 800W maximum power X-Ray Generator (Compact 3K5, Italy) EDXRF spectrometer with a Mo target and KETEK Silicon Drift detector of resolution 136eV for 5.9KeV X-ray energy was used.

Three hundred milligram (300mg) of each powdered samples were pelletized using a hydraulic press (hydraulic Specac press, USA) with an applied load of 10 metric tons tons/cm^2 to produce an intermediate thick pellet sample. The pellet produced was kept in a desiccator for 28 h to get rid of moisture in the sample.

Samples pellets were irradiated with tube X-ray of 45 kV and 10 mA power. The incident and take-off angles were 45, with a Be window thickness of 12.5 µm. The distance between the sample (exposed diameter of 22 mm) and the detector was 4.5 cm. Applied voltage and current are chosen to acquire the require K" or L" energies line. The current was to maintain similar portions of live detection time. MCDWIN- (MC-A (1)) software was employed for data collection. Irradiations were made for each sample, being the intermediate thick sample target for spectrum collection life time of 1500s. Linear least squares fitting of the axils software programme was used for the spectrum de-convolution (IAEA, 2005). Emission- transmission method in QXAS package was used to convert spectrum peak areas into concentrations.

Results and Discussions

The results of the analysis of the sorghum and maize cultivars for phytate and mineral content as well as their molar ratios are presented by way of figures and tables below.

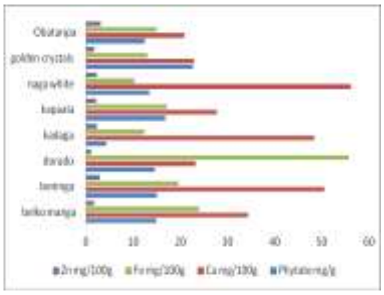

Figure 2: phytate and mineral content in cultivars

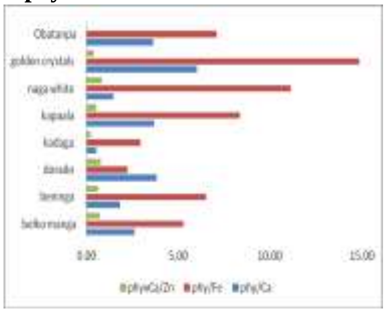

Figure 3: phytate:mineral ratio in the cultivars

Sorghum cultivars (S*i*)

Phytate contents ranged from 4.29 mg/g for *kadaga* to 16.89 mg/g for *kapaala*. For calcium content, the highest value obtained was 56.17 mg/100g for *naga white* and the lowest was 23.24 mg/100g for *dorado*. The range of iron content in the sorghum cultivars was between 10.27 mg/100g *naga white* to 55.74 mg/100g for *dorado*, whilst the zinc content ranged from 1.07mg/100g for *dorado* to 2.89mg/100g for *beninga*.

The molar ratios of phytate/calcium of the sorghum cultivars ranged between 0.54-3.81 with a mean value of 2.31 (i.e > 0.24) whilst that for phytate/iron ranged 2.22-11.11 with a mean of 6.09 (> 1.00). These ratios predict that all the food samples from these sorghum cultivars could have poor bioavailability of iron and calcium. For phytate/zinc molar ratio values ranged 18.21-134.44 with a mean of 70.47. All the sorghum cultivars had their molar ratios far above the critical phytate/zinc value of 15.

Maize cultivars (M*i*)

Phytate contents ranged from 12.52 mg/g for *obatanpa* to 22.68 mg/g for *golden crystals*. For calcium content, comparable values of 20.88 mg/100g for *obatanpa* and 22.87mg/100g for *golden crystals* was obtained. The range of iron content in the maize cultivars was between 12.96 mg/100g *golden crystals* to 14.98 mg/100g for *obatanpa*, whilst the zinc content ranged from 1.77mg/100g for *golden crystals* to 3.10mg/100g for *obatanpa*.

The molar ratios of phytate/calcium of the maize cultivars ranged 3.63-6.01 with a mean of 4.82 (i.e > 0.24) whilst that for phytate/iron ranged 7.09-14.85 with a mean of 10.97 (> 1.00) was obtained. These ratios predict that all these food samples from these maize cultivars could have poor bioavailability of iron and calcium. The phytate:zinc molar ratio ranged 39.77-126.20 with a mean of 82.9. Phytate/zinc ratios of between 18-40 have been reported for some maize hybrids (Hambidge *et al*, *2004*)

Although the mineral content of the maize and sorghum cultivars could meet the mineral needs of consumers, the high phytate/mineral ratio would suggest that reduced and possible non-bioavailability of the minerals may be incited.

For example only 15% of the Zn content may be available to consumers since the phytate/zinc molar ratio of both the sorghum and maize is higher than 15 (WHO 1996). Nonetheless the *kadaga* sorghum and the *obatanpa* maize cultivars will present and be a good source of the minerals because of their high calcium and zinc content coupled with relatively low phyate content. This assertion is buttressed further by the low near critical value of 0.22 and 0.21 (cf. 0.20, Ellis et al 1987) of their Phy:Ca /Zn ratio for *kadaga* and the *obatanpa* respectively.

Fordyce et al. (1987) reported that zinc bioavailability, measured from growth and tibia zinc concentrations was better predicted by the (phytate x calcium):zinc ratio rather than the phytate:zinc ratio. The phytate:Ca/Zn ratio was highest in *naga white* and *golden crystals* (0.82 and 0.72 mol g^{-1} in sorghum and maize respectively) whilst *kadaga* and *obatanpa* had the lowest phytate:Ca/Zn ratio of 0.22 and 0.21 respectively (Table 2).

In addition processing may improve the bioavailability of the minerals. For example it is reported that the phytate content in bread was lowered when the amount of yeast or the fermentation time was raised (Harland & Harland, 1980). Similarly the phytate content in locust bean seeds was reportedly lowered from 0.51 mg/g to 0.31 mg/g by fermentation (Eka, 1980). Natural lactic fermentation of maize meal decreased phytate phosphorus by 78% (Chompreeda & Fields, 1984). The reduction of phytate content during dough fermentation for whole grain flour was about 50% (Roos *et al*., 1990).

The bioavailability of these minerals (Ca, Fe and Zn) and by extension the nutritive value of these cereal cultivars could be enhanced by processing. This is because although the phytate mineral ratios were higher than critical the [CaxPh]:Zn ratios suggests that the cereal cultivars are a good source of the minerals and that their consumption could be encouraged.

References

Bindra GS, Gibson RS, Thompson LU. Phytate, calcium, zinc ratios in Asian immigrant lacto-ovo vegetarian diets and their relationship to zinc nutrition. Nutr Res. 1968; 6:475–83.

Chompreeda PT & Fields ML. Effects of heat and fermentation on the extractability of minerals from soybean meal and corn meal blends. *Journal of Food Science* 1984; 49: 566-568.

Eka OU (1980): Effect of fermentation on the nutrient status of locust beans. *Food Chemistry* 5, 303-308.

Ellis, R., Kelsay, J. L., Reynolds, R. D., Morris, E. R., Moser, P. B. and Frazier, C. W. Phytate: Zinc and Phytate×Calcium: Zinc Milimolar Ratios in Self Selected Diets of Americans, Asian Indians and Nepalese. *J.Am. Dietary Assoc.*, 1987; 87: 1043-1047.

Erdal, I., Torun, B., Karanlik, S., Ekis, H. and Cakmak, I. Determination of Zinc and Phytic Acid and Bioavailability of Zinc in Wheats Grown in Turkey. *The First National Zinc Congress*, 1998b; Ankara, Turkey.

Fordyce EJ, Forbes RM, Robbins KR, Erdman JW Jr. Phytate x calcium/zinc molar ratios: are they predictive of zinc bioavailability? J Food Sci 1987; 52:440–4.

Gibson RS. Content and bioavailability of trace elements in vegetarian diets. Am J Clin Nutr 1994; 59(suppl):1223S–32S.

Gibson, R. S., Yeudall, F., Drost, N., Mitimuni, B. and Cullinan, T. Dietary Interventions to Prevent Zinc Deficiency. *Am. J. Clin Nutr.*, 1998; 68: 484-487.

Hallberg L, Brune M & Rossander L. Iron absorption in man: ascorbic acid and dose-dependent inhibition by phytate. *American J Clin Nutr* 1989; 49:140-144.

Harland BF & Harland J. Fermentative reduction of phytate in rye, white, and whole wheat breads. *Cereal Chemistry* 1980; 57, 226-229.

Hambidge K M, Huffer J W, Raboy V, Grunwald G K, Westcott J L, Sian L, et al. Zinc absorption from low-phytate hybrids of maize and their wild-type isohybrids *Am J Clin Nutr* 2004;79:1053–9

Larsson M, Rossander-Hulthen L, Sandstrom B, Sandberg AS. Improved zinc and iron absorption from breakfast meals containing malted oats with reduced phytate content. Br J Nutr 1996; 76:677–88.

Lori O, Thava V & James HH (2001). Phytic acid. *Food Rev Int* 17: 419-431.

Maga, J. A. Phytate: Its chemistry, occurrence, food interaction, nutritional significance and methods of analysis. *J. Agric. Food Chem.*1982; 30: 1-9

Morris ER & Ellis R. Bioavailability of dietary calcium-effect of phytate on adult men consuming non-vegetarian diets. In: *ACS Symposium Series 75: Nutritional Bioavailability of Calcium.* Kies C (eds), 1985; p. 63. American Chemical Society: Washington, DC, USA.

Morris ER &Ellis R. Usefulness of the dietary phytic acid/zinc molar ratio as an index of zinc bioavailability to rats and humans. *Biol Trace Elem Res* 1989; 19: 107-117.Oberleas D & Harland

O'Dell BL, Savage JE. Effect of phytic acid on zinc availability. Proc Soc Exp Biol Med 1960;103:304–6.

Oberleas D, Muhrer ME, O'Dell BL. Effects of phytic acid on zinc availability and parakeratosis in swine. J Anim Sci 1962;21:57–61.

Paul I, Turner RE, Ross D. Nutrition. 2004; Jones and Barlett Publishers.

Roos U, Caneva P, Escher F & Amadò R. Influence of fermentation on the phytic acid content of conventionally produced bread. *Processing and Quality of Foods, Vol. 2, Food Biotechnology:Avenues to Healthy and Nutritious Products*. ed. Z. e. al. ISBN 1 85166 496 3, 1990; pp 2.105 2.110.

Sandberg AS, Anderson H, Carlesson NG & Sandstrom B. Degradation products of bran phytate formed during digestion in the human small intestine: effects of extrusion cooking on digestibility. *J Nutr* 1987; 117: 2061-2065.

Sandstrom B, Sandberg AS. Inhibitory effects of isolated inositol phosphates on zinc absorption in humans. J Trace Elem Electrolytes Health Dis 1992;6:99–103.

Turnlund JR, King JC, Keyes WR, Gong B & Michel MC. A stable isotope study of zinc absorption in young men: effects of phytate and α-cellulose. *Am Clin Nutr* 1984;40: 1071-1077.

Turnlund JR, King JC, KeyesWR,Gong B, Michel MC.Astable isotope study of zinc absorption in young men: effects of phytate and alphacellulose. Am J Clin Nutr 1984;40:1071–7.

Walter HL, Fanny L, Charles C & Christian R. Minerals and phytic acid interaction: is it a real problem for human nutrition. *Int J Food Sc Tech* 2002; 37:727-739.

WHO. Trace Elements in Human Nutrition and Health. 1996. WHO, Geneva.

Table 1. Phytate, calcium, iron, and zinc content of samples

sample	Common Name	Phytate mg/g	Ca mg/100g	Fe mg/100g	Zn mg/100g
S1	*belko manga*	14.91	34.42	23.94	1.75
S2	*beninga*	15.07	50.5	19.65	2.89
S3	*Dorado*	14.61	23.24	55.74	1.07
S4	*Kadaga*	4.29	48.45	12.342	2.32
S5	*kapaala*	16.89	27.79	17.19	2.18
S6	*naga white*	13.45	56.17	10.27	2.26
M7	*golden crystals*	22.68	22.87	12.96	1.77
M8	*Obatanpa*	12.52	20.88	14.98	3.10

Table 2. The molar ratio between phytate and minerals of samples

sample	Common Name	Phytate /Ca	Phytate /Fe	Phytate /Zn	Phytate:Ca /Zn
S1	*belko manga*	2.63	5.29	83.94	0.72
S2	*beninga*	1.81	6.51	51.35	0.65
S3	*dorado*	3.81	2.22	134.44	0.78
S4	*kadaga*	0.54	2.95	18.21	0.22
S5	*kapaala*	3.68	8.33	76.28	0.53
S6	*naga white*	1.45	11.11	58.60	0.82
M7	*golden crystals*	6.01	14.85	126.20	0.72
M8	*Obatanpa*	3.63	7.09	39.77	0.21