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Phytate, Calcium, Iron, and Zinc Contents and Their Molar Ratios in Foods Commonly Consumed in China

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A total of 60 food samples commonly consumed in China were analyzed for phytate using the anion-exchange method and for calcium, iron, and zinc using atomic absorption spectrophotometry. The foods analyzed included those based on cereal grains and soybean. Phytate contents expressed on a wet weight basis ranged from 0 for foods made from starches to 1878 mg/100 g for dried stick-shaped soybean milk film. The calcium contents were between 2.08 mg/100 g for ground corn and 760.67 mg/100 g for diced fried soybean curd. The lowest values of iron and zinc were 0.04 mg/100 g for Panjin pearl rice cooked with discarding extra water and 0.08 mg/100 g for potato and bean starches, while the highest values of iron and zinc were observed in dried stick-shaped soybean milk film. Although many foods were relatively rich in calcium, zinc, and iron, many also contained a higher level of phytate. Of the 60 food samples, 34 foods had a phytate/calcium molar ratio >0.24, 53 foods had a phytate/iron molar ratio >1, 31 foods had a phytate/zinc molar ratio >15, and only 7 foods had a phytate × calcium/zinc >200. Phytate in foods impair the bioavailability of calcium, iron, and zinc, which to some extent depends upon food processing and cooking methods.

KEYWORDS: Phytate; calcium; zinc; iron; bioavailability; China

INTRODUCTION

The diets of people in China are based on plant foods, which provide at least 50% of the dietary energy and nutrients (*1*). Plant-food-based diets are rich in bioactive compounds, which are believed to be beneficial for the prevention of noncommunicable chronic diseases, such as cancer, diabetes mellitus, etc. However, on the other hand, plant-food-based diets are also rich in phytate. Phytate can decrease the bioavailability of critical nutrients such as zinc, iron, calcium (*2*, *3*), and magnesium (*4*) because of its high binding affinities to minerals; on the other hand, phytate may act as an antioxidant and anticarcinogen (*5*).

Phytate exerts its inhibitory effect on the absorption of minerals by forming insoluble and undigestable complexes (*6*). The effect of phytate on the bioavailability of minerals depends upon not only the amount of phytate and minerals in the diets but also the ratio of phytate/minerals. The relative bioavailability of minerals can be predicted from the molar ratio of phytate/minerals in the food and diet (*7*−*13*).

There have been studies on the phytate contents of different foods and diets in other countries (*14*−*16*). However, these data may not suitable for use in assessing the phytate intake of people in China because of the fact that large discrepancies exist in food variety, food processing, cooking methods, and food consumption between China and other countries. For this reason, the phytate contents and its inhibitory effect on the bioavailability of minerals have never been assessed in the foods and diets of people in China because of the lack of data in the China Food Composition Table (*17*). Therefore, the purpose of this study is, first, to examine the phytate content in foods commonly consumed in China and provide basic data for the China Food Composition Table; second, to assess the inhibitory effect of phytate on the bioavailability of calcium, iron, and zinc in foods commonly consumed; and last, to compare the phytate contents and its possible inhibitory effect on the bioavailability of minerals in China with other studies.

MATERIALS AND METHODS

Samples Selection and Collection. The information on food consumption from the 2002 China National Nutrition and Health Survey (*1*) was used for food sample selection. A total of 60 kinds of food samples including 18 wheat flour and products, 14 soybean products, 9 rice products, 8 corn products, 6 other grains, and 5 starch products were selected. A total of 5 different samples of each kind of food were purchased from 5 supermarkets in Beijing, China. Panjin pearl rice was cooked with four methods in the lab of the National Institute for Nutrition and Food Safety, Chinese Center for Disease Control and

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Prevention. Tap water were added with a ratio of 1.5:1 (weight/weight) before cooking. Rice was cooked for 10 min after boiling and discarding extra water and then steamed for 20 min. Rice was cooked with an electric pot for 40 min after boiling. Rice was steamed with a pot for 40 min after boiling. Rice was cooked with a pressure pot for 10 min after boiling. The same amount of each of the 5 samples was ground (Phillip Model HR2839), mixed, and transferred into a screw-capped plastic bottle and was stored at −20 °C until analysis.

Determination of Phytate, Calcium, Iron, Zinc, and Moisture. The anion-exchange method (*18*) was used for determination of the phytate content.

Samples were accurately weighed (∼1.00−2.00 g) and transferred into 100 mL conical flasks. A total of ∼40−50 mL of Na_2SO_4 (100 g/L)-HCl (1.2%) were added. Flasks were capped and shaken vigorously for 2 h on a rotator at ambient laboratory temperature. The supernatant solutions were then filtered through qualitative filter paper. In some instances, i.e., rice and oat cereals, a gel formed in the flask, and therefore, the sample was hard to filter. In those cases, the supernatant was centrifuged (Beckman TJ-6R, Lynchburg, VA) before filtration.

A total of 10 mL of filtered extract was diluted to 30 mL with distilled water after mixing with 1 mL of 30 g/L NaOH and then passed through an anion resin column (resin, AG1-X4, ∼100−200 mesh, Bio-Rad Laboratory, Inc., CA; column, 0.8 × 10 cm, Beijing Glass Instrumental Factory). The column was washed before use with 20 mL of 0.5 mol/L NaCl solution and deionized water until no Cl^- can be detected.

The column was washed with 15 mL of distilled water and 20 mL of 0.05 mol/L NaCl solution after sample application. The eluate from the resin was eluted with 0.7 mol/L NaCl to 25 mL. The postcolumn reagent was made up as a 0.03% $FeCl_3$ solution containing 0.3% sulfosalicylic acid. A total of 4 mL of the reagent was added into 5 mL of collected eluate and then centrifuged at 3000 rps for 10 min. The absorbance of the supernatant was measured at 500 nm using a spectrophotometer (LKB 4053, U.K.).

A calibration curve for the colorimetric method was obtained by using phytate standards (P-8810 Sigma Co.). The phytate content of samples was calculated using the standard curve.

The contents of calcium, iron, and zinc in foods were measured by atomic absorption spectrophotometry (Perkin−Elmer 1100B, Norwalk, CT). Spectrophotometry measurements were calibrated using commercial standards (National Center for Standard Substance, Beijing, China). The standard curves were controlled using chloride solutions of the metals. Relative standard deviations were less than 10%.

Quality Control. Duplicate sample solutions from each food sample were analyzed. The measurement was repeated until the relative standard deviation (RSD, %) was within 10%. Recovery experiments were done in every batch (6 samples) by adding 1 mL of 10 mg/mL standard phytate (P-8810 Sigma Co.) to the extracting samples. The average recovery rate of the standard sample was 100.49% ($n = 10$, RSD = 1.30).

Statistical Analysis. The means and standard deviations of the phytate, calcium, iron, and zinc content of foods were calculated. The analysis results were expressed as M ± SD. A comparison of the difference in phytate contents between each two kinds of foods was applied using ANOVA factorial analysis with a Turkey post-hoc comparison. Differences were considered significant at $p < 0.05$. All statistical analysis was done with the SAS Statistical Package (SAS 8.2e for Windows, SAS Institute, Inc.).

RESULTS AND DISCUSSION

Rice and Products. Rice is the staple food, especially for people from southern regions of China. On average, people consume 238 g of rice and its products per day in China (*1*).

A total of 8 samples of rice and products were analyzed. The phytate, calcium, iron, and zinc content of the foods are presented in **Table 1**. Phytate contents ranged from 55 mg/100 g for Thailand rice to 183 mg/100 g for Heilongjian rice, while calcium contents ranged from 2.52 mg/100 g for Panjin pearl rice to 4.74 mg/100 g for Tianjin Xiao Zhan rice. The range of iron contents was between 0.12 mg/100 g for Thailand rice and 0.19 mg/100 g for Heilongjiang rice, whereas that of zinc was between 1.09 mg/100 g for Tianjin Xiao Zhan rice and 1.76 mg/100 g for Thailand rice. Variations were found in phytate and minerals contents between different brands of commercial rice. The variability of the phytate content of rice was also found in other studies, which ranged from 6 to 60 mg/100 g (*19*−*21*).

The most common methods for cooking rice in China are boiling and steaming with or without discarding the excessive water. To study the effect of different cooking methods on the phytate content, Panjin pearl rice was cooked with 4 different methods, i.e., steamed after boiling and discarding the excessive water and steamed, boiled, and cooked with a pressure pot without discarding the cooking water. Significant differences in phytate contents were found between uncooked and cooked rice for each cooking method ($p < 0.001$). Rice steamed after boiling and discarding the excessive water had a greater degree of phytate reduction (78.6%) than cooked with a pressure pot (48.7%), boiled (43.7%), and steamed (40.3%) without discarding the cooking water. No significant differences in the phytate content were found between steamed, boiled, and cooked with a pressure pot. The result from the present study was similar to that of Almana (*22*), who reported that discarding excessive water in cooking rice may result in phytate degradation of ∼37−65%, while retaining the water only results in degradation of 12%. The influence on the minerals content was also found with different cooking methods. Both the iron and zinc content of rice with four methods decreased compared with the raw material, while the calcium content increased, which might be caused by the high content of calcium in the cooking water (*23*).

Because phytate is heat-stable, significant reduction during cooking or any conventional heat-processing method is not expected unless the cooking water is discarded, because some nutrients will be solved in the cooking water (*24*). Discarding cooking water will also result in a certain loss of nutrients at the same time. This method may not be effective in improving the bioavailability of minerals.

Studies in humans indicate that the absorption of zinc and iron from a meal corresponds directly to its phytate content (*25*, *26*). The phytate/minerals molar ratios are used to predict its inhibitory effect on the bioavaiability of minerals. The phytate/calcium molar ratio >0.24 will impair calcium bioavailability (*8*). The phytate/iron molar ratio >1 is regarded as indicative of poor iron bioavailability (*27*). Zinc absorption is greatly reduced and results in a negative zinc balance when the phytate/zinc molar ratio is 15 (*10*). When diets are high in both phytate and calcium, phytate × calcium/zinc is a more useful assessment of zinc bioavailability than the phytate/zinc molar ratio (*13*).

Table 2 summarized the molar ratios of phytate/minerals of foods. The molar ratios of phytate/calcium of all rice were >0.24 except for rice that was steam-cooked with discarding the cooking water, which was 0.11. All ratios of phytate/iron were >1, while that of phytate/zinc and phytate × calcium/zinc were below the critical values. These ratio indices indicated that the bioavailability of calcium and iron but not zinc would be impaired by phytate in rice and products.

Wheat and Products. Wheat and wheat products are another staple food, especially for people from northern regions of China. On average, people consume 140 g of wheat and its products per day (*1*).

Phytate contents ranged from 3 mg/100 g for fresh wheat noodle to 420 mg/100 g for standard wheat flour, while calcium contents ranged from 11.1 mg/100 g for wheat flour (50%

Table 1. Phytate, Calcium, Iron, and Zinc Content of Cereal-Based Foods[a]

food type	moisture (g/100 g)	phytate (mg/100 g)	calcium (mg/100 g)	iron (mg/100 g)	zinc (mg/100 g)
rice and products (9)					
Thailand rice	13.4	55 ± 2	3.77 ± 0.19	0.12 ± 0.04	1.76 ± 0.11
Tianjin Xiao Zhan	17.2	92 ± 3	4.74 ± 0.25	0.19 ± 0.02	1.09 ± 0.02
Heilongjiang rice	13.3	183 ± 4	2.56 ± 0.06	0.19 ± 0.01	1.63 ± 0.02
Panjin pearl rice	14.1	131 ± 0	2.52 ± 0.19	0.16 ± 0.01	1.15 ± 0.06
Panjin pearl rice, steamed after half boiling, discard extra water	61.4	14 ± 1	7.71 ± 0.69	0.04 ± 0.00	0.44 ± 0.01
Panjin pearl rice, boiling	59.2	35 ± 1	9.06 ± 0.56	0.10 ± 0.02	0.56 ± 0.00
Panjin pearl rice, steamed	58.6	38 ± 0	7.08 ± 0.47	0.10 ± 0.01	0.51 ± 0.00
Panjin pearl rice, cooked with pressure pot	53.4	38 ± 0	9.07 ± 0.69	0.16 ± 0.00	0.56 ± 0.03
rice noodle, dried	12.4	14 ± 3	14.01 ± 0.63	0.72 ± 0.03	0.46 ± 0.01
wheat and products (18)					
wheat flour, 85% extraction rate	12.0	420 ± 0	21.56 ± 1.36	1.35 ± 0.05	0.78 ± 0.02
wheat flour, 75% extraction rate	12.3	117 ± 3	18.38 ± 0.79	1.27 ± 0.05	0.57 ± 0.01
wheat flour, 50% extraction rate	12.7	37 ± 4	11.12 ± 1.06	0.41 ± 0.01	0.52 ± 0.04
twisted wheat roll, steamed	37.3	77 ± 3	20.01 ± 1.20	0.68 ± 0.07	0.60 ± 0.01
wheat bread, steamed	37.0	38 ± 0	15.87 ± 0.06	0.75 ± 0.04	0.53 ± 0.02
whole wheat bread, steamed	42.6	173 ± 11	16.12 ± 0.06	1.00 ± 0.02	0.85 ± 0.02
wheat bread, white, baked	31.3	20 ± 2	35.68 ± 0.15	0.68 ± 0.02	0.73 ± 0.01
whole wheat bread, baked	32.0	176 ± 3	29.17 ± 1.55	0.88 ± 0.03	1.25 ± 0.12
wheat pancake, unleavened	39.6	14 ± 0	14.17 ± 0.76	0.89 ± 0.12	0.47 ± 0.00
wheat pancake, leavened	35.3	7 ± 1	23.74 ± 1.21	0.78 ± 0.04	0.58 ± 0.03
wheat noodle, fresh	28.1	3 ± 0	22.12 ± 0.16	1.15 ± 0.08	0.57 ± 0.06
wheat noodle, dried	11.7	158 ± 14	27.73 ± 0.80	1.87 ± 0.54	0.79 ± 0.02
instant noodle	3.6	103 ± 3	15.83 ± 0.92	1.15 ± 0.26	0.55 ± 0.04
spaghetti	10.7	248 ± 5	24.55 ± 1.31	0.87 ± 0.03	0.75 ± 0.03
whole wheat biscuit	1.3	304 ± 21	39.32 ± 1.40	1.63 ± 0.15	0.71 ± 0.06
wheat flake	2.4	138 ± 8	250.25 ± 7.29	3.22 ± 0.25	0.76 ± 0.02
wheat gluten, fresh	63.1	134 ± 2	20.54 ± 0.33	3.02 ± 0.03	2.75 ± 0.04
wheat gluten, fried	7.2	266 ± 4	27.19 ± 0.52	5.41 ± 0.39	1.98 ± 0.07
corn and products (8)					
fresh corn	57.9	300 ± 4	6.38 ± 0.02	0.34 ± 0.03	0.12 ± 0.00
fresh corn, boiled	49.3	196 ± 7	2.71 ± 0.12	2.58 ± 0.25	0.13 ± 0.02
ground corn	13.4	100 ± 3	2.08 ± 0.03	0.43 ± 0.00	0.63 ± 0.08
corn flour	12.1	310 ± 6	5.01 ± 0.42	1.03 ± 0.02	0.63 ± 0.01
corn flake	13.1	275 ± 0	2.58 ± 0.08	1.65 ± 0.01	0.79 ± 0.01
baked corn bread, unleavened	41.8	18 ± 0	16.64 ± 0.26	0.61 ± 0.02	0.61 ± 0.00
steamed corn bread, unleavened	41.1	61 ± 6	18.41 ± 0.62	0.83 ± 0.01	0.46 ± 0.03
steamed corn bread, leavened	42.3	76 ± 2	20.62 ± 0.41	0.70 ± 0.00	0.54 ± 0.00
other grains (6)					
buckwheat noodle, dried	12.2	223 ± 5	54.29 ± 0.26	1.69 ± 0.05	1.69 ± 0.11
oat flake	9.2	871 ± 44	45.83 ± 0.06	2.34 ± 0.39	1.26 ± 0.05
millet	11.4	522 ± 18	10.70 ± 0.24	2.54 ± 0.09	1.80 ± 0.03
sorghum	11.1	427 ± 9	6.48 ± 0.45	0.94 ± 0.09	0.41 ± 0.02
black sesame powder	4.0	440 ± 22	327.74 ± 77.32	1.67 ± 0.35	0.84 ± 0.08
seed of Job's tears	9.9	1419 ± 41	5.88 ± 0.10	1.85 ± 0.08	2.74 ± 0.13

[a] Data are expressed as mean ± SD on a wet weight basis.

extraction rate) to 250.3 mg/100 g for wheat flake. The range of iron contents was between 0.41 mg/100 g for wheat flour (50% extraction rate) and 5.41 mg/100 g for fried wheat gluten, whereas that for zinc was between 0.47 mg/100 g for unleavened wheat pancake and 2.75 mg/100 g for fresh wheat gluten. Variations were found in both phytate and minerals contents between different foods made from wheat flour (**Table 1**). The phytate content in wheat gluten was comparable to that reported by Wallace and Satterlee (*28*).

The phytate content reported in other studies also shows a wide variation depending upon the flour extraction rate, flour types, and cooking method. The values reported for wheat flour were between 154 and 1750 mg/100 g (*14*, *15*, *29*−*32*). The phytate content in the present study is within the above range.

Because phytate is distributed in larger proportions in external covers in the pericarp and in the aleurone layer of wheat (*33*), therefore, simple dehulling or milling may be effective in removing significant amounts of phytate. However, it should be noticed that food processing and cooking will also result in the loss of minerals to some extent (*34*). In the present study, we have found that the phytate content of two refined flours decreased significantly as compared with the standard refined flour. At the same time, a certain amount of minerals loss was observed. A similar result can be seen in other reports (*31*, *35*); an 80% extraction rate resulted in a reduction of ∼30−40% of phytate in comparison to the raw material.

People consume plenty of foods made from wheat flour. Steamed bread and pancake with and without the fermentation process and noodles are the most favorable foods for people in China. Studies indicated that the phytate contents varied considerably because of different preparation and cooking methods. During bread making, the content of phytate decreases as the action of phytases as well as the high temperature (*36*). Other factors affect phytate hydrolysis, including the type and extraction rate of flour and fermentation techniques (*22*, *37*, *38*).

Table 2. Molar Ratios of Phytate to Calcium, Iron, Zinc, and Phytate × Calcium/Zinc of Cereal-Based Foods

food type	phytate/ calcium	phytate/ iron	phytate/ zinc	phytate × calcium/ zinc
rice and products (9)				
Thailand rice	0.88	39.40	3.07	0.29
Tianjin Xiao Zhan	1.18	40.46	8.29	0.98
Heilongjiang rice	4.32	83.27	11.01	0.71
Panjin pearl rice	3.15	69.67	11.27	0.71
Panjin pearl rice, steamed after half boiling, discard extra water	0.11	29.16	3.09	0.59
Panjin pearl rice, boiling	0.24	29.89	6.20	1.40
Panjin pearl rice, steamed	0.32	31.97	7.28	1.29
Panjin pearl rice, cooked with pressure pot	0.25	20.02	6.64	1.51
rice noodle, dried	0.06	1.64	2.96	1.04
wheat and products (18)				
wheat flour, 85% extraction rate	1.18	26.46	80.23	43.24
wheat flour, 75% extraction rate	0.39	7.81	14.74	6.78
wheat flour, 50% extraction rate	0.20	7.63	6.47	1.80
twisted wheat roll, steamed	0.23	9.61	12.60	6.31
wheat bread, steamed	0.14	4.24	7.05	2.80
whole wheat bread, steamed	0.65	14.68	20.06	8.08
wheat bread, white, baked	0.03	2.47	2.69	2.40
whole wheat bread, baked	0.37	17.00	13.91	10.15
wheat pancake, unleavened	0.06	1.37	3.02	1.07
wheat pancake, leavened	0.02	0.79	1.24	0.74
wheat noodle, fresh	0.01	0.24	0.58	0.32
wheat noodle, dried	0.35	7.16	19.80	13.72
instant noodle	0.40	7.64	18.37	7.27
spaghetti	0.61	24.12	32.63	20.03
whole wheat biscuit	0.47	15.87	42.29	41.56
wheat flake	0.03	3.64	17.98	112.52
wheat gluten, fresh	0.39	3.76	4.80	2.46
wheat gluten, fried	0.59	4.17	13.25	9.01
corn and products (8)				
fresh corn	2.85	75.79	243.97	38.90
fresh corn, boiled	4.39	6.45	149.68	10.13
ground corn	2.91	19.68	15.61	0.81
corn flour	3.75	25.48	48.18	6.03
corn flake	6.44	14.15	34.18	2.21
baked corn bread, unleavened	0.07	2.54	2.98	1.24
steamed corn bread, unleavened	0.20	6.24	13.11	6.04
steamed corn bread, leavened	0.22	9.23	13.85	7.14
other grains (6)				
buckwheat noodle, dried	0.25	11.21	13.04	17.70
oat flake	1.15	31.59	68.14	78.04
millet	2.96	17.46	28.53	7.63
sorghum	3.99	38.60	103.21	16.72
black sesame powder	0.20	22.33	51.83	169.05
seed of Job's tears	14.62	65.07	51.03	7.51

In the present study, we found that the whole wheat bread had a higher phytate value than white bread no matter whether it is baked or steamed, while the leavened pancake had only 50% of the phytate content as that of the leavened pancake (7 versus 14 mg/100 g). This showed the effect of the processing and cooking on phytate hydrolysis. Similar results have been seen in other studies (*7, 14, 38*).

Of the 18 wheat and products, 16 had a phytate/iron molar ratio >1, 10 had a phytate/calcium ratio >0.24, and only 7 had a phytate/zinc molar ratio above the critical value. The molar ratios of phytate × calcium/zinc of foods were all below 200. The bioavailability of iron was more likely to be affected by phytate in this kind of food.

Corn and Corn Products. Although less corn and products are consumed in comparison to rice and wheat, they are still frequently consumed foods, especially for people in some poor rural areas of China.

Phytate contents were between 18 mg/100 g for unleavened baked corn bread and 310 mg/100 g for corn flour, while calcium contents ranged from 2.08 mg/100 g for ground corn to 20.62 mg/100 g for leavened steamed corn bread. The phytate content of corn flour in the present study is much lower than 1078 mg/100 g reported by Garcia-Estepa et al. (*14*, *29*). The range of iron contents was between 0.34 mg/100 g for fresh corn and 2.58 mg/100 g for boiled fresh corn, whereas that of zinc was between 0.12 mg/100 g for fresh corn and 0.79 mg/100 g for corn flake.

Unlike for wheat and rice, 88% of phytate is present in the germ of corn (*39*); therefore, removing the germ portion is an effective way to remove a significant amount of phytate form corn. We have found that, on average, corn products had lower phytate values than those in corn and corn flour. This result indicated that phytate degrades to a certain degree during food processing and cooking.

The molar ratio of phytate/iron of all corn and products was >1, while that of phytate × calcium/zinc was <200. The molar ratios of phytate/calcium and zinc of corn and products were above the critical levels, except for unleavened baked corn bread and two corn bread (**Table 2**). This is indicated that phytate in most corn and products affect the bioavailability of minerals.

Other Grains. In general, the phytate content of other grains was higher than that of rice, wheat, and corn. Seed of Job's tears had the highest value of phytate, 1419 mg/100 g; zinc, 2.74 mg/100 g; and the lowest calcium content, 5.88 mg/100 g, while dried buckwheat noodle had the lowest phytate value, 223 mg/100 g. The highest values of calcium and iron were observed in black sesame powder. Sorghum had the lowest amounts of zinc and iron content as 0.41 and 0.94 mg/100 g, respectively (**Table 1**).

All of the molar ratios of phytate/minerals were above the critical values, excepts phytate/calcium for black sesame powder and phytate/zinc for buckwheat dried noodle (**Table 2**), which hence predicts a low bioavailability of calcium, iron, and zinc for these foods.

Soybean Products. Soy products are commonly consumed all over China. There are more than a hundred kind of soy products made by different methods. Soy and its products are good sources for both protein and minerals, and they are also the major source of phytate because of the high content.

Table 3 presents the phytate and minerals contents of soy foods. Soy food products had the highest content of phytate as well as calcium, zinc, and iron as compared with other foods, although a wide variation was found. The ranges of phytate contents were between 130 mg/100 g for lactonic soybean curd and 1878 mg/100 g for dried soybean milk film. The range of calcium was between 12.55 mg/100 g for lactonic soybean curd and 760 mg/100 g for diced fried soybean curd. The iron contents ranged from 0.37 mg/100 g for lactonic soybean curd to 6.13 mg/100 g for dried soybean milk film, whereas that of zinc was from 0.37 mg/100 g for lactonic soybean curd to 3.50 mg/100 g for dried soybean milk film. The phytate content of soy products was lower than reported by other studies (*40*−*42*).

The production of soy products undergoes soaking, grinding, and boiling. Phytate will be degraded throughout the procedures. Soaking may remove ∼6−28% phytate, and the longer the periods of soaking, the greater losses in the phytate content (18). Grinding enables endogenesis phytase to come into contact with more phytate and thus catalyzes the hydrolysis procedure. Boiling or pressure boiling may also cause a certain loss of phytate. Then, different curdle reagents are added, and the curd may experience various squeeze methods and cooking methods, which may result in various degradations of phytate. However,

Table 3. Phytate, Calcium, Zinc, and Iron Content of Soybean Foods[a]

food type	moisture (%)	phytate (mg/100 g)	calcium (mg/100 g)	iron (mg/100 g)	zinc (mg/100 g)
lactonic soybean curd	91.6	130 ± 2	12.55 ± 0.20	0.37 ± 0.02	0.37 ± 0.02
soybean curd, South	88.6	211 ± 2	217.45 ± 1.11	0.39 ± 0.01	0.58 ± 0.07
soybean curd, North	79.5	446 ± 6	80.73 ± 0.71	1.43 ± 0.02	0.72 ± 0.06
soybean curd slab	69.0	592 ± 6	137.33 ± 6.67	2.92 ± 1.42	1.30 ± 0.05
soybean curd slab, soy sauce flavored	47.8	912 ± 20	377.96 ± 18.33	3.03 ± 0.03	2.25 ± 0.29
soybean curd, chicken flavored	71.4	736 ± 1	523.39 ± 21.31	3.98 ± 0.00	1.07 ± 0.02
fried soybean, shrimp flavored	2.2	1253 ± 5	216.03 ± 6.45	4.27 ± 0.03	2.32 ± 0.00
smoked soybean curd	66.6	769 ± 16	245.65 ± 7.44	3.19 ± 0.18	1.96 ± 0.13
fried soybean curd, diced	45.7	819 ± 11	760.67 ± 13.72	1.13 ± 0.02	1.50 ± 0.14
flavored soybean curd slab	59.9	889 ± 16	118.47 ± 1.82	3.16 ± 0.48	1.82 ± 0.12
thin sheets of bean curd	61.3	987 ± 12	97.03 ± 4.20	2.86 ± 0.02	1.65 ± 0.04
soybean curd strip	61.1	987 ± 5	109.21 ± 5.95	1.77 ± 0.02	1.86 ± 0.21
dried soybean milk film, stick shaped	8.0	1878 ± 23	223.09 ± 0.18	6.13 ± 0.43	3.50 ± 0.06
soybean powder	3.6	800 ± 2	306.18 ± 11.46	2.81 ± 0.13	1.53 ± 0.03

[a] Data are expressed as mean ± SD on a wet weight basis.

Table 4. Molar Ratios of Phytate to Calcium, Iron, Zinc, and Phytate × Calcium/Zinc of Soybean Foods

food type	phytate/calcium	phytate/iron	phytate/zinc	phytate × calcium/zinc
lactonic soybean curd	0.63	29.73	34.72	10.89
soybean curd, South	0.06	46.06	35.61	193.59
soybean curd, North	0.33	26.54	60.84	122.80
soybean curd slab	0.26	17.21	44.74	153.59
soybean curd slab, soy sauce flavored	0.15	25.53	39.83	376.38
soybean curd, chicken flavored	0.09	15.68	68.06	890.49
fried soybean, shrimp flavored	0.35	24.90	53.11	286.85
smoked soybean curd	0.19	20.43	38.73	237.83
fried soybean curd, diced	0.07	61.35	53.90	1025.07
flavored soybean curd slab	0.45	23.88	48.02	142.22
thin sheets of bean curd	0.62	29.31	58.76	142.54
soybean curd strip	0.55	47.24	52.22	142.57
dried soybean milk film, stick shaped	0.51	25.98	52.85	294.76
soybean powder	0.16	24.20	51.46	393.93

the study indicated that food processing also lead to the decrease of minerals and vitamins content of foods (*24*, *38*).

Table 4 lists the molar ratios of phytate/minerals of soy products. The ranges of phytate to calcium, iron, zinc, and phytate × calcium/zinc molar ratios were 0.06−0.63, 15.68−61.35, 34.72−68.06, and 10.89−1025.07, respectively. A total of 8 of 14 soy products had the phytate/calcium molar ratio above the critical level. All of the soy products had phytate to iron and zinc ratios above the critical values. A total of 7 of 14 soy products had phytate × calcium/zinc molar ratio were >200. When the four ratios are taken into account together, the phytate in soy products will inhibit the absorption of calcium, iron, and zinc.

Food Made from Starch. Table 5 presents the phytate and minerals contents of foods made from different starches. It shows that foods made of starch contained no detectable phytate. The calcium contents ranged from 5.58 mg/100 g for cornstarch to 63.09 mg/100 g for lotus starch, while the range of iron contents was from 0.38 mg/100 g for potato starch to 3.79 mg/100 g for sweet potato starch vermicelli. Potato and bean starch vermicelli had the lowest zinc value of 0.08 mg/100 g, while sweet potato starch vermicelli had the highest value at 0.14 mg/100 g.

Table 5. Phytate, Calcium, Iron, and Zinc Content of Foods Made of Starch[a]

food type	moisture (g/100 g)	phytate (mg/100 g)	calcium (mg/100 g)	iron (mg/100 g)	zinc (mg/100 g)
corn starch	12.2	0 ± 0	5.58 ± 0.55	0.57 ± 0.05	0.11 ± 0.01
lotus starch	10.7	0 ± 0	63.09 ± 0.67	1.25 ± 0.06	0.13 ± 0.01
potato starch	15.5	0 ± 0	20.38 ± 1.90	0.38 ± 0.02	0.08 ± 0.01
bean starch vermicelli	14.4	0 ± 0	24.69 ± 0.83	0.84 ± 0.11	0.08 ± 0.01
sweet potato starch vermicelli	13.5	0 ± 0	36.04 ± 1.01	3.79 ± 0.12	0.14 ± 0.01

[a] Data are expressed as mean ± SD on a wet weight basis.

Because foods made of starch have undetectable phytate, the effect of phytate on the bioavailability of minerals in this kind of food can be neglected.

Although a dietary pattern has changed in recent years in China, the diets of people are plant-based. Rice, wheat, and their products are staple foods for most people, while corn and corn products are staple foods for a few people living in rural areas. Grains are the main source of phytate. Both the phytate contents of grains and the molar ratios of phytate/minerals imply that phytate in the diet of people in China impair the bioavailability of iron and calcium.

In conclusion, variations of phytate contents are found in foods commonly consumed in China and can be observed in the same kind of food prepared by different processing and cooking methods. The indices of molar ratios of phytate/minerals predict that phytate shows the inhibitory effect on the bioavailability of minerals in those foods to a certain extent; therefore, optimal food processing and cooking methods should be chosen to minimize this effect.

LITERATURE CITED

(1) Wang, L. *Report of China National Nutrition and Health Survey 2002 (1): Summary Report*; People's Medical Publishing House: Beijing, China, 2005; pp 18−45.

(2) Gibson, R. S. Zinc nutrition in developing countries. *Nutr. Res. Rev.* **1994**, *7*, 151−173.

(3) Weaver, C. M.; Kannan, S. Phytate and mineral bioavailability. In *Food Phytate*; Reddy, N. R., Sathe, S. K., Eds.; CRC Press: Boca Raton, FL, 2002; pp 211−223.

(4) Pallauf, J.; Pietsch, M.; Rimbach, G. Dietary phytate reduces magnesium bioavailabiltiy in growing rats. *Nutr. Res.* **1998**, *18*, 1029−1037.

(5) Jeanb, M.; Thompsonm, L. U. Role of phytic acid in cancer and other diseases. In *Food Phytate*; Reddy, N. R., Sathe, S. K., Eds.; CRC Press: Boca Raton, FL, 2002; pp 225−248.

(6) Wise, A. Phytate and zinc bioavailability. *Int. J. Food Sci. Nutr*. **1995**, *46*, 53−63.

(7) Fordyce, E. J.; Forbes, R. M.; Robbins, K. R.; Erdman, J., Jr. Phytate × calcium/zinc molar ratios (in soybean products): Are they predictive of zinc bioavailability? *J. Food Sci*. **1987**, *52*, 440−444.

(8) Morris, E. R.; Ellis, R. Bioavailability of dietary calcium-effect of phytate on adult men consuming nonvegetarian diets. In *ACS Symposium Series 275: Nutritional Bioavailability of Calcium*; Kies, C., Ed.; Amerian Chemical Society: Wagenington, DC, 1985; p 63.

(9) Morris, E. R.; Ellis, R. Usefulness of the dietary phytic acid/zinc molar ratio as an index of zinc bioavailability or rats and humans. *Biol. Trace Elem. Res*. **1989**, *19*, 107−117.

(10) Turnlund, J. R.; King, J. C.; Keyes, W. R.; Gong, B.; Michel, M. C. A stable isotope study of zinc absorption in young men: Effects on phytate and α-cellulose. *Am. J. Clin. Nutr*. **1984**, *40*, 1071−1077.

(11) Sandberg, A. S.; Anderson, H.; Carlesson, N. G.; 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.

(12) Davies, N. T.; Carswell, A. J. P.; Mills, C. F. The effect of variation in dietary calcium intake on the phytate−zinc interaction in rats. In *Trace Elements in Man and Animals TEMA-5*; Mills, C. F., Bremner, I., Chesters, J. K., Eds.; CAB: Wallingford, U.K., 1985; pp 456−457.

(13) Bindra, G. S.; Gibson, R. S.; Thompson, L. U. [Phytate] × [calcium]/[zinc] ratios in Asian immigrant lacto-ovo vegetarian diets and their relationship to zinc nutriture. *Nutr. Res*. **1986**, *6*, 475−483.

(14) Garcia-Estepa, R. M.; Guerra-Hernandez, E.; Garcia-Villanova, B. Phytci acid content in milled cereal products and breads. *Food Res. Int*. **1999**, *32*, 217−221.

(15) Harland, B. F.; Smikle-Williams, S.; Oberleas D. High performance liquid chromatography analysis of phytate (IP6) in selected foods. *J. Food Compos. Anal*. **2004**, *17*, 227−233.

(16) Umeta, M.; West, C. E.; Fufa, H. Content of zinc, iron, calcium, and their sbsorption inhibitors in foods commonly consumed in Ethiopia. *J. Food Compos. Anal*. **2005**, *18*, 803−817.

(17) Yang Y.; Wang, G.; Pan X. *China Food Composition Table 2002*; Beijing Medical University Publishing House: Beijing, China, 2002; pp 1−343.

(18) Harland, B. F.; Oberleas, D. Anion-exchange method for determination of phytate in foods: Collaborative study. *J. Assoc. Off. Anal. Chem*. **1986**, *69*, 667−670.

(19) Toma, R. B.; Tabekhia, M. M. Changes in mineral elements and phytic acid contents during cooking of three California rice varieties. *J. Food Sci*. **1979**, *44*, 619−621.

(20) Graf, E.; Dintzis, F. R. Determination of phytic acid in foods by high performance liquid chromatography. *J. Agric. Food Chem.* **1982**, *30*, 1094−1097.

(21) Mameesh, M. S.; Tomar, M. Phytate content of some popular Kuwaiti foods. *Cereal Chem.* **1993**, *70*, 502−503.

(22) Almana, H. A. Extent of phytate degradation in breads and various foods consumed in Saudi Arabia. *Food Chem*. **2000**, *70*, 451−456.

(23) Zeng, Y.; Shao, S. S.; Wang, J. S.; Hu W. X. The determination of calcium and magnesium in the water of Beijing and Luoyang. *Mod. Instrum*. **1999**, *3*, 36−39.

(24) Lestienne, I.; Icard-Vernière, C.; Mouquet, C.; Picq, C.; Trèche, S. Effects of soaking whole cereal and legume seeds on iron, zinc, and phytate contents. *Food Chem*. **2005**, *89*, 421−425.

(25) Brune, M.; Rossander-Hultén, L.; Hallberg, L.; Gleerup, A.; Sandberg, A. S. Iron absorption from bread in humans: Inhibiting effects of cereals fibre, phytate, and inositol phosphates with different numbers of phosphate groups. *J. Nutr*. **1992**, *122*, 442−449.

(26) Nävert, B.; Sandstöorm, B.; Cederblad, Å. Reduction of phytate content of bran by leavening in bread and its effect on zinc absorption in man. *Br. J. Nutr*. **1985**, *53*, 47−53.

(27) Hallberg, L.; Brune, M., Rossander, L. Iron absorption in man: Ascorbic acid and dose-dependent inhibition by phytate. *Am. J. Clin. Nutr*. **1989**, *49*, 140−144.

(28) Wallace, G. W.; Satterlee, L. D. Calcium binding and its effects on the properties of several food protein sources. *J. Food Sci*. **1977**, *42*, 473−476.

(29) Harland, B. F. Phytate contents of foods. In *CRC Handbook of Dietary Fiber in Human Nutrition*, 2nd ed.; Spiller, G. A., Ed.; CRC Press: Boca Raton, FL, 1993; pp 617−623.

(30) Oberleas, D.; Harland, B. F. Phytate content of foods: Effect on dietary zinc bioavailability. *J. Am. Diet. Assoc.* **1981**, *79*, 433−436.

(31) Febles, C. I.; Arias, A.; Hardisson, A.; Rodriguez-Alvarez, C.; Sierra, A. Phytic acid level in wheat flours. *J. Cereal Sci*. **2002**, *36*, 19−23.

(32) Francois, P. Phytic acid and zinc contents of cereal products: Relation to the manufacturing process. *J. Food Compos. Anal*. **1988**, *1*, 146−151.

(33) Cheryan, M. Phytic acid interactions in food systems. *Crit. Rev. Food Sci. Nutr*. **1980**, *13*, 297−335.

(34) Duhan, A.; Khetarpaul, N.; Bishnoi, S. Content of phytic acid and HCl-extractability of calcium, phosphorus, and iron as affected by various domestic processing and cooking methods. *Food Chem*. **2002**, *78*, 9−14.

(35) Mahgoub, S. E. O.; and Elhag, S. A. Effect of milling, soaking, malting, heat-treatment and fermentation on phytate level of four Sudanese sorghum cultivars. *Food Chem*. **1998**, *61*, 77−80.

(36) Plaami, S.; Kumpulainen, J. Inositol phosphate content of some cereal-based foods. *J. Food Compos. Anal*. **1995**, *8*, 324−335.

(37) Türk, M.; Carlsson, N. G.; Sandberg, A. S. Reduction in the levels of phytate during wholemeal bread making; effect of yeast and wheat phytases. *J. Cereal Sci.* **1996**, *23*, 257−264.

(38) Hotz, C.; Gibson, R. S. Assessment of home-based processing methods to reduce the phytate content and phytate/zinc molar ratio of white maize (*Zea mays*). *J. Agri Food Chem*. **2001**, *49*, 692−698.

(39) Morris, E. R.; Ellis, R. Bioavailability to rats of iron and zinc in wheat bran: Response to low-phytate bran and effect of the phytate/zinc molar ratio. *J. Nutr*. **1980**, *110*, 2000−2010.

(40) Kasim, A. B.; Edwards, H. M. The analysis of inositol phosphate forms in feed ingredients. *J. Sci. Food Agri*. **1998**, *76*, 1−9.

(41) Poneros, A. G.; Erdman, J. W. Bioavailability of calcium from tofu, tortillas, non-fat dry milk, and mozzarella cheese in rats: Effect of supplemental ascorbic acid. *J. Food Sci*. **1988**, *53*, 208−210.

(42) Thompson, D. B.; Erdman, J. W., Jr. Phytic acid determination in soybeans. *J. Food Sci*. **1982**, *47*, 513−517.

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