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Iron, zinc and phytic acid content of selected rice varieties from China

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Abstract: Rice is the major Chinese staple food (per capita approx 250 g day^{-1}) and, as such, is an important source of essential minerals. However, due to a number of factors the bio-availability of these minerals is limited. In this study, the variation of phytic acid (PA), iron (Fe) and zinc (Zn) levels in 56 varieties of Chinese rice was investigated. The samples included in this study were collected in proportion to the importance of the rice-growing regions in China. Fe levels showed the biggest variation (9–45 mg kg^{-1}) and were not related with PA content or grain shape although growing locations were identified yielding higher (25.2 mg kg^{-1}) and lower (14.2 mg kg^{-1}) Fe levels. Zn showed a moderate variability (13–39 mg kg^{-1}), which was narrower than for Fe, while broader than for PA (7.2–11.9 g kg^{-1}). Zn content is correlated ($R^2 = 0.5$; $P < 0.01$) with PA content, and shows a relation with growing region and kernel shape. Variation of PA content is the least among the three components. Molar ratios of PA to Fe and Zn ranged from 15 to 105 and 27 to 67, respectively. The results of the mineral contents and PA content can be interpreted in terms of expected bio-availability. This study shows that the mineral bio-availability of Chinese rice varieties will be <4%. Despite the variation in mineral contents, in all cases the PA present is expected to render most mineral present unavailable. We conclude that there is scope for optimisation of mineral contents of rice by matching suitable varieties and growing regions, and that rice products require processing that retains minerals but results in thorough dephytinisation.

Keywords: rice; iron; zinc; phytic acid; varieties

INTRODUCTION

Rice is the primary food source for more than half of the world population. In Asia, it serves as the major source of energy, protein, thiamine, riboflavin, niacin, iron (Fe) and calcium (Ca) in the diet.[1]

Rice is also the most important staple food in China. In 2004, the national production was estimated at 18.7 million tons,[2] with a per capita consumption of 251 g day^{-1}. This accounts for 30.4% of the supply of dietary energy, 19.5% of dietary protein, and 2.5% of dietary fat.[3] Rice is also the major source of intake of micro-nutrients such as zinc (Zn), iron, and vitamins for the Chinese, especially those who live in the southern countryside.

Unfortunately, rice does not supply minerals adequately. It only has limited contents of Fe and Zn, and moreover the loss of minerals, particularly of Fe, during rice milling is high.[4] In addition, rice contains phytic acid (PA), the most important anti-nutritional factor impeding availability of divalent minerals. It forms complexes with mineral ions, such as Fe, Zn and Ca, and ultimately affects their bio-availability.[5–7]

The bio-availability of minerals in rice could be improved by the selection of varieties with a high mineral content suitable for certain growing regions, by using plant breeding for high mineral content or low PA content, or by processing methods that either improve the mineral content and/or its bio-availability.[7–9]

Although rice is one of the most important cultivated cereals and has a significant effect on the nutritional status of the Chinese people, research on rice in China has until now been focussed mainly on yield, macro-nutrients such as protein and starch, and sensory quality.

Brown rice is the raw material for several rice-derived products like white rice, germinated rice, and rice noodles. Therefore, in this study we concentrated on brown rice and its potential to serve as a raw material for further processing, as a first requirement to improve mineral availability.

The objectives of this paper are (1) to investigate the variation of content of PA, Fe and Zn in selected Chinese rice varieties and (2) to analyse the effect of variety and rice-growing region on these parameters.

MATERIALS AND METHODS

Collection of rice samples

Samples of 56 rice varieties (1 kg per variety) were obtained from different growing regions in China. These regions and their classification are

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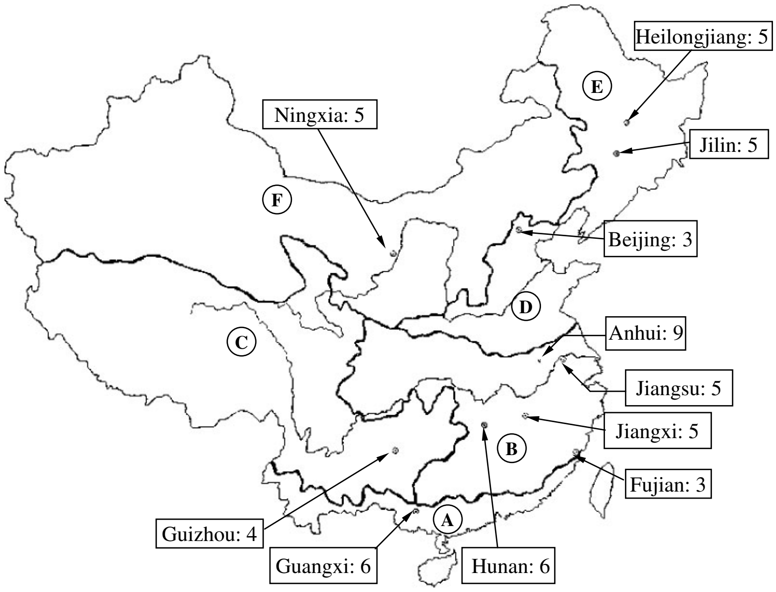

Figure 1. Rice-growing regions and locations where varieties were collected, with numbers of varieties collected.

based on climate, soil quality and agro technological infrastructure. Locations and numbers of varieties collected are shown in Fig. 1.

Currently, it is held that more than 50 000 varieties of rice exist in China, of which about 230 are grown on a commercial scale. For this study, we collected 56 varieties of commercial relevance harvested in 2003 with the assistance of the Institute of Crop Germplasm Resources of the China Academic Agriculture Sciences, and the College of Agronomy and Biotechnology of the China Agricultural University.

The importance of the growing regions was a major criterion for sample collection. For example, 61.8% of the sampled varieties originate from regions A and B, since these two regions occupy 78% of total planting area of the whole of China.[10] Five varieties of aerobic rice (origin Anhui) were included, as well as three 'special' varieties which are used for non-staple food preparations such as porridges.

Pre-treatment and processing of rice samples

Husks were removed with a laboratory-scale dehulling machine (JLGJ45, Zhejiang, China). The resulting brown rice was ground using two different protocols, depending on the purpose. For mineral analysis, the rice was ground using a Fritsch mill (Marius Instrumenten, the Netherlands; with a 0.5 mm sieve). For PA analysis, samples were first dried at 70 °C until constant weight, and were ground using a home blender (SG-280A, Shunde, China) to pass through a 1 mm sieve. Ground samples were sealed and stored in closed containers at 4 °C prior to analysis.

Measurement of kernel dimensions

The length and width of rice kernels were measured with a micro-ruler (accuracy: 0.01 mm). For every grain, the maximum length and width were measured. Twenty grains were measured for each variety, and the average was reported.

Fe and Zn contents

Fe and Zn contents were analysed with induced coupled plasma–atomic absorption spectrometry (ICP-AAS)[11] (ELAN 6000 spectrometer PerkinElmer, Wellesley, MA, USA). Samples were digested with HNO_3–H_2O_2–HF. Aliquots of 5.0 mL hydrofluoric acid and 5.0 mL nitric acid (65% w/w) were added to 0.3–0.4 g (±0.001 g) of sample and were allowed to react overnight at room temperature (21 °C). Then, samples were evaporated until almost dry at 120 °C. Another 5.0 mL nitric acid (65% w/w) and three times 1.0 mL hydrogen peroxide (H_2O_2) were added and samples were digested in a microwave oven using a heating programme of subsequently 1 min at 100 °C, 5 min at 125 °C, 5 min at 150 °C and 10 min at 175 °C. Fe and Zn in filtered digested solutions were measured with ICP–AAS. All varieties were analysed in triplicate.

Phytic acid content

The China National Standard Analysis Method (GB/T 17 406-1998)[12,13] was used, based on extraction, separation on anion exchange resin, and spectrophotometric detection of the reaction product with $FeCl_3$ and sulfosalicylic acid. All samples were analysed in triplicate.

Data analysis

Data were analysed by ANOVA and *t*-tests using the SPSS package (Sony DADC, version 12.0.1).

RESULTS

Phytic acid, iron and zinc content in rice in China

Table 1 summarises PA, Fe and Zn values determined in the Chinese varieties in comparison with data

Table 1. Comparison of Fe, Zn and phytic acid (PA) content of Chinese brown rice with international literature data

	China ($n = 56$), (dry mass)	Vietnam ($n = 25$)[21], (fresh weight basis)	Australia[a] A: ($n = 90$)[11] (at 14% moisture)	Australia[a] B: ($n = 22$)[27] (not mentioned)	Korea ($n = 68$)[26] (not mentioned)	India ($n = 16$)[4] (not mentioned)	IRRI[b] ($n = 7$)[14] (fresh weight basis)
Fe (mg kg^{-1})	18.2 (9.4–44.6)	12.0 (8.7–25.8)	13 (5–67)	26 (17–34)	7.4 (1.6–14)	21.6 (–)	12.4 (–)
Zn (mg kg^{-1})	22.8 (12.9–38.7)	26.5 (22.5–32.5)	16 (13–21)	32 (22–72)	19.1 (12.7–37.5)	14.3 (–)	22.4 (–)
PA (g kg^{-1})	9.6 (7.2–11.9)	– [c] (–)	– (–)	– (–)	12.6 (8.6–17.6)	– (–)	– (–)

Results are given as the mean and the range (in parentheses).
[a] Two different literature data sets, labelled as A and B.
[b] International Rice Research Institute, Philippines.
[c] Data not published.

obtained in other regions. In the Chinese set, the mean Fe content is 18 mg kg^{-1}, which is lower than that found in Indian and Australian group B, but higher than Vietnamese and Korean varieties. The Fe content in Chinese varieties ranged from 9 to 45 mg kg^{-1}. This variation is larger than that observed in the Vietnamese and Korean sets of rice samples. On the other hand, the set of Australian samples showed an even larger variation (5–67 mg kg^{-1}). As for Zn content, values obtained with Chinese rice were within the range of the other reported data. In our varieties, the variation of Zn content is smaller than that of Fe content. PA contents in Chinese rice also show some variation (7.2–11.9 g kg^{-1}). This variation is smaller than reported in Korean rice (8.6–17.6 g kg^{-1}). PA contents in rice from other countries were not available from published literature.

The differences between our samples and those from other studies could stem from both the type of samples included in these studies and the methods of analysis used. The latter differed among the reported studies. Atomic absorbance spectrophotometry (AAS) was used for Fe and Zn analysis in the Indian varieties, while energy-dispersed X-ray was used in the IRRI study.[14] Other studies (including this study) used the ICP–AAS method for mineral analysis. Procedures of pre-treatment of samples, their digestion and sensitivity limits of equipment might also affect the absolute levels of minerals reported in rice.

Molar ratios of phytic acid, iron and zinc in brown rice varieties from China

The molar ratios of PA to Fe and Zn, and Fe to Zn are presented in Table 2. In Chinese varieties, the mean value of molar ratios of PA/Fe in brown rice is 50. For comparison, this value is close to the ratio in brown rice reported previously.[15] This ratio is much higher than that of wheat measured in India, which was only 5.45.[16] The ratios of PA/Fe ranged from 15 to 105, which has a large variation. These ratios, even the lowest, are much higher than required to chelate more than 90% of Fe.[17] According to the model of Wolters,[15] the availability of Fe in Chinese brown rice would be 4.0–6.5% if we only take into account the effect of PA. Since brown rice also contains other complex forming substances, such as dietary fibre, and does not contain enhancers of Fe availability, the bio-availability of Fe in brown rice in China will probably be even lower.

Table 2. Molar Ratio of PA, Fe and Zn in Chinese brown rice ($n = 56$ varieties)

	PA/Fe	PA/Zn	Fe/Zn
Average	49.5 ± 16.0	42.9 ± 7.5	0.953 ± 0.354
Range	15–104.8	27.0–66.6	0.48–2.26
Correlation between the two components (R^2)	0.12	0.50*	0.24

* Significant ($P < 0.01$).

The mean molar ratio of PA to Zn in the Chinese varieties is 42.9, which is higher than that measured in brown rice in India.[17] There is some correlation ($R^2 = 0.50$, $P < 0.01$) between the levels of PA and Zn in brown rice. Molar ratios of PA to Zn in brown rice are also different from other cereals.[18] Davies and Olpin[19] mentioned that regardless of the absolute levels of Zn and PA, the ratios of PA to Zn would be the major determinant of Zn availability. Marginal Zn deficiency in rats appeared at a ratio of PA to Zn of 10–15. Similarly, as calculated for Fe, we can predict that the availability of Zn in Chinese rice is 2.4–3.9%, if PA is the only factor taken into account. These data suggest that molar ratio of PA to Zn in Chinese brown rice must be reduced significantly to increase bio-availability of Zn.

The mean value of molar ratio of Fe to Zn in Chinese rice is 0.95, which is similar to other cereals,[18] although a higher ratio of 3.85 was reported elsewhere[16]. The mean value of molar ratio of Fe to Zn in our study is close to that of Doesthale *et al.* (0.80): these authors also reported that the level of Fe in brown rice depends significantly on the level of Zn ($R^2 = 0.92$, $P < 0.01$).[4] The latter correlation was lower in our study.

Effect of the morphology of rice kernels on the content of PA, Fe and Zn

The distribution of minerals and PA in rice kernels is not homogenous. In general, the bran contains higher levels of Zn, Fe, as well as PA.[4] Since the kernel size and shape could also relate to the ratio of volume to

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Table 3. Morphology and other properties of rice varieties from China

Variety	PL[a]	GR[b]	Length (mm)	*L/W*[c]	TKW[d] (g)	YBR[e] (%)	YWR[f] (%)	MC[g] (%)
II You 838	Anhui	B	6.4	2.5	19.13	80.2	70.3	8.1
Tesanai 2	Anhui	B	5.5	1.9	20.38	81.2	72.1	9.7
Xieyou 9019	Anhui	B	7.0	3.0	20.21	81.4	70.0	10.4
Zhongxian 898	Anhui	B	7.1	3.1	21.48	78.9	69.0	9.4
Han 65 (aerobic rice)	Anhui	B	5.2	1.8	16.25	76.8	58.1	8.4
Han 277 (aerobic rice)	Anhui	B	5.0	1.7	17.33	68.2	61.3	8.7
Han 297 (aerobic rice)	Anhui	B	5.5	2.0	19.96	77.0	69.9	6.6
Han 502 (aerobic rice)	Anhui	B	6.0	2.0	21.86	73.7	66.6	7.6
Han No.9 (aerobic rice)	Anhui	B	5.0	1.8	17.35	76.1	68.4	7.8
Jiamu Zaozhan	Fujian	B	7.4	3.5	20.13	79.7	68.2	9.8
Jinshanyou No. 1	Fujian	B	6.8	3.0	20.95	79.2	69.0	8.9
Weiyou 77	Fujian	B	6.7	2.6	22.19	80.8	66.5	8.7
Boyou 253	Guangxi	A	6.0	2.5	17.58	74.1	68.4	7.5
Qiuyou 1025	Guangxi	A	6.3	3.0	14.54	74.4	69.2	7
Qiuyougui 99	Guangxi	A	6.6	3.0	15.93	73.6	68.6	9.8
Teyou 63	Guangxi	A	6.3	2.4	22.41	70.9	63.4	7.5
Teyou 706	Guangxi	A	6.4	2.5	22.35	77.8	71.5	7
Zhongyou 838	Guangxi	A	7.1	3.0	22.34	74.6	67.1	8
Bijing 37	Guizhou	C	5.1	1.8	18.24	75.2	68.9	7
Jinyou 431	Guizhou	C	6.3	2.4	19.21	66.3	59.5	7
Jinyou 527	Guizhou	C	7.4	3.0	23.59	70.3	62.2	7.5
Liangyou 363	Guizhou	C	7	3.0	20.95	71.8	65.5	7
Fushiguang	Heilongjiang	E	5.4	1.8	21.76	82.2	72.6	8.5
Hejiang 195	Heilongjiang	E	5.8	2.1	20.23	80.3	70.9	8.9
Xixuan No.1	Heilongjiang	E	5.7	2.0	19.70	81.1	72.6	10.4
Wuyoudao C	Heilongjiang	E	5.6	2.0	21.55	81.0	71.9	9.7
Wuyoudao No.1	Heilongjiang	E	5.7	2.0	18.95	79.2	70.2	9.7
Jinyou 207	Hunan	B	6.9	3.0	20.05	78.2	69.2	7.8
Jinyou 402	Hunan	B	7.4	3.1	22.15	81.5	67.3	8.6
R 981	Hunan	B	6.2	2.5	18.55	83.6	75.7	10.7
V 46	Hunan	B	6.2	2.2	23.39	79.3	70.6	7.8
Xiangwanxian No.11	Hunan	B	6.8	3.1	19.87	79.1	68.8	8.8
XiangzaoxXian No.31	Hunan	B	6.4	2.8	17.11	81.0	70.3	9.9
Nanjing 40	Jiangsu	B	5.2	1.7	21.15	84.7	76.2	7.2
Nanjing No.16	Jiangsu	B	7.3	3.2	21.18	74.6	68.8	7.4
Wuyujing No.3	Jiangsu	B	4.8	1.6	20.67	83.3	75.5	7.4
Wuyujing No.7	Jiangsu	B	5.0	1.6	20.99	83.5	76.4	6.6
Zhenjing 866	Jiangsu	B	6.7	2.9	20.30	75.2	68.9	6.2
Ganwanxian 30	Jiangxi	B	7.5	3.4	19.00	72.0	64.2	6.5
Ganzaoxian 49	Jiangxi	B	7.1	3.3	18.16	72.0	64.2	10.4
Jinyou 71	Jiangxi	B	6.7	3.1	17.16	70.0	61.7	7.6
Jinyou 402	Jiangxi	B	6.7	3.1	17.38	72.7	62.5	7.3
Zhongyou 752	Jiangxi	B	6.5	3.4	15.22	70.2	62.5	7.5
Changbai No.9	Jilin	E	5.2	1.7	21.89	84.8	76.2	8.9
Fengyou 307	Jilin	E	5.0	1.8	18.49	82.6	74.9	9.6
Qiuguang	Jilin	E	5.2	1.8	19.26	83.5	76.1	8.8
Tong 35	Jilin	E	5.2	1.8	20.76	83.1	74.7	9.5
Tong 95-74	Jilin	E	4.9	1.7	19.17	83.2	75.0	8.8
Ningjing 22	Ningxia	F	5.0	1.7	19.22	83.3	74.2	10.6
Ningjing 23	Ningxia	F	5.3	1.7	20.60	82.8	74.4	8.1
Ningjing 24	Ningxia	F	5.8	2.0	21.28	81.6	73.1	8.7
Ningjing 27	Ningxia	F	5.2	2.1	15.94	80.4	73.1	7.9
Ningjing No.5	Ningxia	F	4.9	1.7	19.21	81.4	72.1	9.6
Heinuomi 1568[h]	[i]	D	5.2	2.1	14.88	66.1	[j]	7.5
Jupei Xiangnuo 1574[h]	[i]	D	4.8	1.7	15.81	74.1	64.8	5.5
Tianhongmi 1571[h]	[i]	D	4.6	1.9	8.13	67.5	[j]	7.5

[a] Planting location.
[b] Growing region as shown in Fig. 1.
[c] Ratio of length to width.
[d] Thousand kernel weight (brown rice).
[e] Yield of brown rice from paddy.
[f] Yield of white rice from paddy.
[g] Moisture content of brown rice.
[h] Special varieties.
[i] Collected from the Chinese Academy of Agricultural Sciences.
[j] Impossible to obtain white rice from brown rice due to too small kernel size.

surface area, we analysed the possible effect of the morphology of rice kernel on the content of minerals and PA.

The morphology of a rice kernel can be described by several parameters, such as length, width, and thousand-kernel weight (TKW). The properties of the collected samples are presented in Table 3. According to the Industrial Standard of the Ministry of China Agriculture,[20] rice kernel length can be distinguished into three groups. These are long (>6.5 mm), medium (5.5–6.5 mm) and short grains (<5.5 mm). *Indica* rice (in China referred to as *Xian* or *Hsien*, long grains) is dominant in the south, while *japonica* rice (*Jing* or *Keng*, short grains) is widely planted in the north. In addition, aromatic, glutinous and other special types of rice are appreciated,[10] these are not used for milling and noodle making but for special dishes such as porridges. The rice varieties collected in this study represented the three groups by 33%, 29% and 38% respectively. The longest kernel was 7.5 mm, and the shortest was 4.6 mm. The shape of the kernel can also be characterised by the ratio of length to width. These ratios varied from 1.7 to 3.5. The TKW of brown rice ranged from 15.2 to 23.6 g, except for the special varieties. The yield of brown rice from paddy ranges from 66.1 to 84.8%, and the yield of white rice from paddy from 58.1 to 76.2% with the exclusion of the special varieties. The moisture content of the seeds was lower than 11%. This indicated that the varieties of Chinese rice differ greatly in morphology and processing properties.

PA, Fe and Zn levels in brown rice did not show a significant relation with TKW. On the other hand, PA, Fe and Zn levels had a significant relation with the ratio TKW/L at the 0.05 level. This ratio is a shape factor, instead of TKW alone. So, these results further confirmed that the shape of the kernels has a significant effect on the levels of PA, Fe and Zn in brown rice. We also observed a slight correlation between length, x, in millimetres, of brown rice kernels and yield factors, Y, in %, as follows:

$$Y_{\text{brown}} = -2.5225x + 93.143 (R^2 = 0.202)$$
$$Y_{\text{white}} = -2.8043x + 86.25 (R^2 = 0.2644)$$

where Y_{brown} and Y_{white} are the yields of brown and white rice, respectively.

The relation of PA, Fe and Zn levels with the kernel length is presented in Table 4 and shows that the mean value of PA content tends to increase with kernel length, although not statistically significant. Notwithstanding this, PA contents related significantly ($P < 0.05$) with the ratio kernel length/width (L/W) which were shown in Table 3. At L/W <2, the mean value of PA was 9.1, whereas L/W >2 had a mean PA value of 9.9.

Table 4 also demonstrates the wide variation of Fe content in Chinese rice. It appears that the variability in the short-grain rice is slightly lower than in the other groups.

The mean value of Zn levels in brown rice of different kernel lengths (Table 4) reveal average Zn contents of short-, medium- and long-grain rice to be 20.3, 22.8, and 24.6 mg kg^{-1}, respectively. The mean levels differ significantly ($P < 0.05$). The Zn content is also correlated with kernel length and L/W ratio ($P < 0.01$).

Table 4. Phytic acid, iron and zinc in short-, medium- and long-grain rice

Kernel shape	Length (mm)	Range of length (mm)	PA content (g kg^{-1})*	Range of PA content (g kg^{-1})	Fe content (mg kg^{-1})*	Range of Fe content (mg kg^{-1})	Zn content (mg kg^{-1})*	Range of Zn content (mg kg^{-1})
Short-grain	5.1 ± 0.2	4.9–5.4	9.2 ± 1.2^a	7.2–11.9	16.0 ± 4.4^a	9.4–24.6	20.3 ± 4.0^a	12.9–27.1
Medium-grain	6.1 ± 0.3	5.6–6.5	9.7 ± 0.9^a	8.3–11.5	19.7 ± 7.9^a	12.3–44.6	22.8 ± 3.8^b	15.8–28.6
Long-grain	7.0 ± 0.3	6.7–7.4	9.9 ± 1.4^a	7.1–11.7	19.2 ± 7.2^a	9.5–40.0	24.6 ± 3.4^c	17.1–31.3

* Different characters in same column indicate significant differences ($P < 0.05$).

Table 5. Natural conditions in major rice growing regions of China[24]

Growing region[a]	Major soil types	Average rainfall in growing period (mm)	Average temperature (cumulative temperature) (°C)	Cumulative sunshine in growing seasons (h)
A	Lateritic red soil, red earths, humid–thermo-ferralitic soils	700–1200	≥10 (5800–9300)	1000–1800
B	Lateritic red soil, yellow–cinnamon soils	700–1600	≥10 (4500–6500)	700–1500
C[b]	Yellow earth, yellow–brown earths, purplish soils, torrid red soils	500–1400	≥10 (2900–8000)	800–1500
D	Solonetzs, lime concretion black soils	580–1000	≥10 (4000–5000)	2000–3000
E	Chernozems, meadow soils	350–1100	≥10 (2000–3700)	2200–3100
F	Grey desert soils, meadow soils, cumulated irrigated soils	50–600	≥10 (2000–4250)	2500–3400

[a] See Fig. 1 for explanation of growing regions.
[b] Altitude of this region is 160–2700 m; the other regions are lower altitudes.

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Table 6. Phytic acid (PA), Fe and Zn content in brown rice according to growing regions (mean ± standard deviation)

Growing region	Locations	Varieties (*n*)	PA ($g\,kg^{-1}$)*	Fe ($mg\,kg^{-1}$)*	Zn ($mg\,kg^{-1}$)*
A	Guangxi	6	9.2 ± 0.6^a	19.6 ± 12.3^a	22.6 ± 1.1^a
B	Anhui	9	9.4 ± 1.8^a	17.9 ± 6.1^a	21.9 ± 5.2^a
B	Fujian	3	10.8 ± 0.5^b	14.2 ± 0.1^b	24.3 ± 2.4^a
B	Hunan	6	10.2 ± 0.8^b	18.3 ± 2.4^a	26.1 ± 2.7^a
B	Jiangsu	5	9.5 ± 0.8^a	14.7 ± 2.7^b	22.6 ± 3.1^a
B	Jiangxi	5	9.2 ± 1.7^a	25.2 ± 8.9^c	25.7 ± 3.6^a
C	Guizhou	4	9.6 ± 1.3^b	19.3 ± 5.4^a	18.6 ± 2.6^b
D	Special varieties	3	11.24 ± 0.8^c	16.5 ± 2.2^a	28.1 ± 1.7^c
E	Heilongjiang	5	9.9 ± 0.4^b	19.9 ± 6.4^a	22.6 ± 4.6^a
E	Jilin	5	8.5 ± 0.6^d	14.5 ± 6.2^b	17.7 ± 1.9^b
F	Ningxia	5	9.2 ± 0.5^a	17.2 ± 3.2^a	19.7 ± 2.4^b
	Total/Mean	56	9.58 ± 1.2^b	18.13 ± 6.6^a	22.55 ± 4.2^a

* Different characters in same column indicate significant differences ($P < 0.05$).

Effect of growing regions on the content of PA, Fe and Zn

It may be expected that the growing environment,[21] location and agricultural practice will influence mineral levels in rice. There are six rice-growing regions in China with different natural conditions and agrotechnological infrastructure. Table 5 presents some characteristics on soil types, rainfall, temperature and sunshine of the growing regions. Table 6 shows the differences of PA, Fe and Zn levels in rice from different growing regions. If all samples are taken into account, the growing regions did not have a significant effect ($P < 0.05$) on the PA and Fe levels. However, when comparing locations pair-wise by the *t*-test, we could distinguish ($P < 0.05$) groups with low, medium, and higher PA content. In particular, the special varieties have higher PA, and rice grown in Jilin had significantly lower PA levels. The level of Fe was significantly ($P < 0.05$) higher in the rice cultivated in Jiangxi, and lower in Fujian, Jiangsu and Jilin. Zn content in the rice from different growing regions was significantly different ($P < 0.05$). In particular, the special varieties had higher, and rice cultivated in Jilin, Guizhou and Ningxia had lower Zn levels than elsewhere.

The mean of PA content of aerobic rice varieties, cultivated in Anhui, was $7.93\,g\,kg^{-1}$ and differed significantly ($P < 0.05$) from those of irrigated varieties ($11.09\,g\,kg^{-1}$) in the same location. Mean values of Fe and Zn in aerobic rice were 17.15 and $19.46\,mg\,kg^{-1}$, and 22.05 and $25.69\,mg\,kg^{-1}$, respectively, for irrigated varieties which were not statistically significant.

DISCUSSION

We conclude that the levels of Fe, Zn and PA in Chinese varieties are very diverse. This can be explained by the genetic characteristics of varieties,[22] the different soil and climatic properties as were shown in Table 5, agricultural practices (such as irrigation and fertilisation), post-harvest conditions and handling.[3,21] Cultivation practice and variety both influence the seed morphology, and may also affect the levels of minerals mostly occurring in chelated form with PA.[23] This would suggest that there is scope for improvement of mineral content by selecting optimum varieties for specific regions. The big effect of agricultural practice is exemplified by the two groups of Australian rice that had been grown under different conditions: group A had been collected from farmers,[11] while group B had been cultivated in experimental plots.[14] Chinese rice cultivation conditions are diverse: of the six rice-growing regions (Fig. 1), regions A and B are dual-planting areas, region C is a dual-harvesting area, and the other three are single-season harvesting areas. Except for differences in planting and harvesting times, irrigation systems in these regions are also different. These differences may be expected to result in different properties of the seeds.[24] Because of the variations of soil and climatic conditions within growing regions, no firm conclusion may be drawn yet concerning the regional effect on PA levels. However, it appears that Fe contents are related to soil types, considering the different Fe levels in rice from region B. More agronomical research will be required to link environmental and agro-technological factors to processing characteristics of rice and its macro- and micro-nutrients.

Nutritional aspects

The intake of Fe and Zn from rice will contribute about 12–75% and 20–81% of RDIs for adult Chinese if we calculated on the basis of the recommendation of the Chinese Nutrition Society.[25] Regarding these percentages, three important aspects should be noted. First, the percentages of RDI were based on the consumption of brown rice, although Chinese people seldom consume brown rice in daily life. Second, an important amount (54–66%) of minerals is lost as a result of milling and polishing.[14] This indicates that the estimated contribution to RDI is over-optimistic and that although some rice varieties could provide most of RDIs of Fe and Zn for Chinese, there actually is still a big problem of Fe and Zn deficiency. Third, bio-availability of Fe and Zn in brown rice is much lower than recommended for the diet.[25] This implies that there is a need to minimise mineral losses during milling and polishing and to maximise the bio-availability of minerals by dephytinisation.

CONCLUSION

From this study we conclude that the levels of Fe and Zn in Chinese rice are very diverse. This is both due to varietal and environmental effects. In principle, brown rice has the potential to provide an adequate intake of Fe and Zn. However, the bio-availability of Fe and Zn is very low because of the presence of phytic acid, even in rice varieties with the lowest PA levels and highest levels of Fe and Zn. With white rice, the situation is even worse, since 70–80% of minerals may be lost with the bran during milling.

Our study suggests that improving bio-availability by optimising the combination of variety and growing conditions in terms of high Fe and Zn and low PA, will only have limited effect. Such procedures will have to be combined with post-harvest processing methods that retain essential minerals on the one hand and increase their bio-availability.

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