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RESEARCH ARTICLE

Zinc content and prediction of bio-availability of zinc in some locally grown rice (*Oryza sativa* L.) varieties in Sri Lanka

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Abstract: Rice is the staple food in Sri Lanka and the country has a large number of traditional and improved rice varieties. Since their zinc content and bio-availability has not been studied systematically, the present study focused on the zinc content in some traditional rice varieties with high demand and also some improved rice varieties, and their predictable bio-availability.

Thirty nine rice varieties from Bombuwala and Bathalagoda Regional Agricultural Research and Development Centres, grown during *Yala* (March - August, 2006) and *Maha* (September - March, 2006 ⁄2007) seasons were analysed for stable high zinc rice varieties. Mean zinc content (mg/100 g, on dry weight basis) in the varieties from Bathalagoda varied from 2.17 (Masuran) to 4.49 (Wanni Dahanala), while in the varieties from Bombuwala it varied from 2.46 (Bg 352) to 3.71 (Dahanala) with average values of 3.19 ± 0.55 and 3.11 ± 0.32, respectively. Overall mean zinc content (mg/ 100 g, on dry basis) in the two locations varied from 2.51 (Masuran) – 3.91 (Kalu Bala Wee) with an average value of 3.18 ± 0.45. The mean zinc contents varied significantly ($p \leq 0.05$) with varieties. A significant variation ($p \leq 0.05$) was observed with respect to the site, season, variety, site*var and ses*var in two way ANOVA, while site*ses*var showed a significant variation in three way ANOVA. The reduction of zinc and phytic acid contents in the selected fifteen polished rice varieties (at polishing rate 8 – 10 %) were 18.2 – 60.7 % and 18.8 – 40.8 %, respectively and no significant correlation was observed between zinc and phytic acid. A moderate bio-availability of zinc was shown by the molecular ratio of zinc:phytic acid and these values ranged from 8.3 – 12.5 and 9.3 – 18.9 in brown rice and polished rice, respectively.

Keywords: Rice, zinc, zinc bio-availability.

INTRODUCTION

Zinc has been recognised as an essential nutrient in animals since the early 1900s (Wardlaw, 1999). Cereals are a good source of zinc and globally people rely on cereals for protein, energy and zinc (Hemalatha *et al*., 2007). Adequate zinc intake is necessary to support many bodily functions such as nucleic acid synthesis and functioning, protein metabolism, wound healing, growth, immune functions, development of sexual organs and bones as well as storage, release and functions of insulin (Wardlaw, 1999; Wikramanayake, 2002).

The adult recommended daily allowance (RDA) of zinc is 15 mg/day for men and 12 mg/day for women (Gazette, 1998; FAO/WHO, 2001) based on the absorption of 20 % of zinc.

The effect of phytic acid on mineral bio-availability has been reported in many studies (Cosgrave, 1980; Harland, 1989; Reddy *et al*., 1989; Reddy & Sathe, 2002), revealing that in humans the bio-availability of minerals decreases due to phytic acid forming complexes with divalent ions (e.g. Ca^{2+}, Mg^{2+}, Cu^{2+}, Fe^{2+}, Fe^{3+}, Zn^{2+}, Co^{2+}, Mn^{2+}), proteins and starch (Raboy, 2000).

Currently in Sri Lanka there is a high prevalence of micronutrient deficiencies especially iron and vitamin A, which has been well documented (Jayatissa & Hossaine, 2010). Although data on the zinc contents in foods and their intake are scarce, the high-phytate cereal-based diet and low consumption of animal-based foods in Sri Lanka

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suggests that a high proportion of the population could have inadequate zinc intake and therefore could face the risk of zinc deficiency. The objective of the present study was to determine the zinc content in some locally grown rice varieties and their predictable bio-availability with the intension of determining high zinc local rice varieties for consumption and breeding.

METHODOLOGY

Materials

Thirty nine rice varieties (Table 1) grown using a complete randomised block design (CRBD) in the Low Country Wet Zone at Bombuwala and Low Country Intermediate Zone-1 at Bathalagoda in two plots during *Yala* (March - August 2006) and *Maha* (September - March 2006 / 2007) seasons were used for screening purposes to identify high zinc rice varieties. Paddy was harvested at the stage of experimental maturity and stored in cold rooms at 4 – 8 °C until used for the analysis.

Samples were dehusked, and polished using a polishing machine (model: Satake THU35B, Satake Corporation, Hiroshima-shi, Kokutaiji, Japan) prior to analysis.

Chemicals

Zinc standard stock solution (1000 mg/L) Spectrosol was purchased from BDH, England to plot a calibration curve of zinc.

Anion exchange resin (AGI-X4, Chloride form, 100 – 200 mesh) from Bio-Rad Laboratories, USA was used for purification purposes in phytic acid analysis.

All chemicals used were of analytical grade unless otherwise specified.

Determination of moisture content

The moisture content of rice grains was determined by oven drying at 130 °C for 2 hrs (AOAC, 2000; method 925.10).

Determination of zinc content

Zinc content of the rice varieties was determined using atomic absorption spectrophotometer according to the method (999.11) specified by the Association of Official Analytical Chemists (AOAC, 2002). Working conditions of the flame atomic absorption spectrophotometer (model: Varian Fast Sequential SpectrAA - AA220FS, equipped with graphite furnace, Mulgrave Victoria, Australia): lamp current - 5 mA, fuel - acetylene, flame stoichiometry - oxidising, support - air, wave length - 213.9 nm, slit width - 0.1 nm, flow rate - 1 mL/s.

Table 1: Rice varieties used for screening their grain size and colour

Varietal name	Grain size and colour
Traditional Rice Varieties	
Kalu Bala Wee	INR
Wanni Dahanala	INR
Rathu Heenati	SMR
Dahanala	INR
Rathal	SMW
Kalu Heenati	INR
Herath Banda	INR
Devaraddari	INR
Suwanda samba	SMW
Madathawalu	INR
Goda Heenati	INR
Dik Wee	LNR
Hondarawala	INR
Pachchaperumal	INR
Rath Suwandal	INR
Sulai	INR
Beheth Heenati	SMR
Sudu Heenati	INR
Kottayar	INR
Kahata Wee	INR
Gonabaru	INR
Batapolal	INR
Suduru Samba	SMW
Kattamanjal	SMW
Masuran	INR
Newly Improved Varieties	
At 307	LNW
At 306	LNW
Basmati 370	LNW
Bg 358	INW
Bw 272-6b	SMR
Bg 359	INW
Bg 360	SMW
Bg 300	INW
Bw 267-3	INR
Bg 379-2	INW
At 354	INW
Bw 361	INR
Bg 406	INR
Bg 352	INW

INW - intermediate grain white; INR - intermediate grain red; SMW - small grain white; SMR - small grain red; LNW - long grain white; LNR - long grain red

The samples in working standards were acid digested and aspirated into the air acetylene flame at a flow rate of 1 mL/s to enhance the atomisation and a 6 point standard curve was obtained by diluting the zinc standard stock solution.

Determination of phytic acid

The phytic acid content in rice varieties was determined on an eluted acid extracted fraction using the anion exchange chromatographic technique followed by wet digestion and quantified spectrophotometrically using ammonium-molybdate as specified in method 986.11 (AOAC, 2000).

Selection of rice varieties for analysis of polished rice

Fifteen rice varieties (10 varieties with high zinc contents and 5 varieties with low zinc contents than the overall mean zinc content) were selected and they were polished to 8 – 10 % degree of polishing.

Prediction of bio-availability

Corresponding molar ratio of phytic acid/zinc in each variety was calculated as a predictor of zinc bio-availability and a critical value was set as 15, above which the zinc absorption is severely compromised (i.e. molar ratio of (PA)/(Zn) < 5 = high, 5 – 15 = moderate and > 15 = low) (Turnland *et al*., 1984).

Statistical data analysis

Data analysis was carried out using Statistical Analysis System (SAS Vr. 6.1 package). Data were expressed as the mean (M) with standard error of the mean (SEM). Mean comparison was done by analysis of variance (ANOVA) followed by the Duncan's multiple range test (DNMRT) and source of variation was given by two-way and three-way ANOVA.

RESULTS AND DISCUSSION

Zinc content in rice varieties

Thirty nine rice varieties grown in eight replicates obtained during the *Yala* season (2 replicates) and *Maha* season (2 replicates) from the two experimental plots (R1 and R2) at Bathalagoda and Bombuwala, Rice Research Institutes were analysed for the zinc content to determine the effect of varietal difference, seasonal variation (*Yala* and *Maha*) and variation of location. Zinc concentration of the soil at both locations was the same and it ranged between 0 – 5 ppm (personal communications, 22 April 2006). Samples from the two Rice Research Institutes were selected for the analysis so that the zinc content in the soil from where the paddy was harvested as well as the conditions used in cultivation practices were approximately constant.

Zinc content in rice varieties from Bombuwala

The mean zinc content (mg/100 g) in each rice variety obtained from Bombuwala during both *Yala* and *Maha* seasons varied from 2.46 (Bg 352) – 3.74 (Dahanala) with an overall mean value of 3.11 ± 0.32 (Table 2). Twenty two rice varieties (56.4 %) out of the thirty nine rice varieties from Bombuwala had higher zinc contents than the overall mean value of zinc (3.11 ± 0.32 mg/100 g). The highest value for the zinc content was obtained for Dahanala among the varieties analysed from Bombuwala. In general most of the traditional varieties had higher zinc contents than the newly improved varieties from Bombuwala.

The mean value for zinc content in rice varieties obtained during the *Maha* season (3.28 ± 0.36 mg/100 g) was higher than those during the *Yala* season (2.91 ± 0.41 mg/100 g) from Bombuwala (Table 2). Most rice varieties analysed had similar or higher zinc contents in samples obtained during the *Maha* season (76.9 %) than those obtained during the *Yala* season. The results of the present study showed that the rice varieties having a red pericarp and an intermediate grain size had a higher range of zinc content than the other varieties analysed (Table 3).

Statistical analysis by two way ANOVA (season *vs*. variety) indicated a significant variation in the zinc content with respect to variety ($p = 0.0001$), season ($p = 0.0001$) and ses*var ($p = 0.0001$) at 95 % confident interval. By analysing the zinc content in rice from Bombuwala, it was observed that even when the zinc content in the soil is the same (~5 ppm) there is a variation in zinc content with respect to season and variety. This may be due to the absorption of zinc from the soil being predominantly varietal dependant.

Zinc content in rice varieties from Bathalagoda

The mean zinc content (mg/100 g) in rice varieties obtained from Bathalagoda during *Yala* and *Maha* seasons (Table 2) varied from 2.17 (Masuran) to 4.49 (Wanni Dahanala) with the mean value for the zinc content being 3.19 ± 0.55. The mean zinc content of twenty out of thirty nine rice varieties (51.28 %) from Bathalagoda had higher zinc contents than the overall mean value of zinc (3.19 ± 0.32 mg/100 g). The highest value for the zinc content was obtained from Wanni Dahanala.

Table 2: Zinc content in rice varieties from Bathalagoda and Bombuwala locations

Varietal name	Zn content in Bombuwala (mg/100 g)			Zn content in Bathalagoda (mg/100 g)			p value	Overall mean zinc content in Bat and Bom (mg/100 g)
	Yala	*Maha*	Mean	*Yala*	*Maha*	Mean		
Kalu Bala Wee	3.29 ± 0.03	3.78 ± 0.05	3.54 ± 0.14	3.56 ± 0.29	5.02 ± 0.11	4.29 ± 0.44	0.203	$3.91^{a} \pm 0.15$
Wanni Dahanala	3.01 ± 0.05	3.60 ± 0.14	3.30 ± 0.48	5.14 ± 0.16	3.83 ± 0.72	4.49 ± 0.48	0.105	$3.89^{a} \pm 0.09$
Rathu Heenati	3.20 ± 0.11	3.34 ± 0.03	3.27 ± 0.06	4.76 ± 0.06	4.17 ± 0.30	4.47 ± 0.31	0.035	$3.87^{ab} \pm 0.36$
Dahanala	3.34 ± 0.03	4.08 ± 0.07	3.74 ± 0.26	3.69 ± 0.12	3.73 ± 0.12	3.71 ± 0.07	1.00	$3.70^{abc} \pm 0.32$
Rathal	3.37 ± 0.03	3.61 ± 0.09	3.48 ± 0.08	3.66 ± 0.09	3.85 ± 0.05	3.75 ± 0.06	0.054	$3.62^{abc} \pm 0.09$
Kalu Heenati	3.13 ± 0.06	3.65 ± 0.17	3.39 ± 0.17	3.74 ± 0.10	3.99 ± 0.10	3.87 ± 0.09	0.065	$3.57^{abc} \pm 0.13$
Herath Banda	3.03 ± 0.15	3.22 ± 0.14	3.12 ± 0.10	3.86 ± 0.04	3.91 ± 0.04	3.88 ± 0.38	0.006	$3.49^{cde} \pm 0.23$
At 307	ND	3.61 ± 0.02	3.61 ± 0.02	3.36 ± 0.08	3.33 ± 0.05	3.35 ± 0.06	0.143	$3.51^{bcd} \pm 0.15$
Devaraddari	3.54 ± 0.03	3.37 ± 0.02	3.48 ± 0.46	3.69 ± 0.05	3.31 ± 0.15	3.49 ± 0.13	0.841	$3.48^{cdef} \pm 0.10$
Suwanda Samba	2.75 ± 0.10	3.91 ± 0.02	3.33 ± 0.34	3.22 ± 0.30	3.74 ± 0.10	3.48 ± 0.24	0.718	$3.40^{defg} \pm 0.19$
Madathawalu	3.20 ± 0.07	3.65 ± 0.07	3.43 ± 0.14	3.39 ± 0.02	3.17 ± 0.09	3.28 ± 0.08	0.392	$3.35^{defg} \pm 0.08$
At 306	2.92 ± 0.07	3.23 ± 0.14	3.07 ± 0.17	3.86 ± 0.05	3.33 ± 0.17	3.62 ± 0.17	0.047	$3.33^{defg} \pm 0.15$
Goda Heenati	3.64 ± 0.06	3.17 ± 0.15	3.40 ± 0.15	3.20 ± 0.05	3.31 ± 0.30	3.25 ± 0.18	0.513	$3.32^{defgh} \pm 0.16$
Dik Wee	3.15 ± 0.05	3.50 ± 0.06	3.32 ± 0.10	3.46 ± 0.06	3.15 ± 0.03	3.31 ± 0.09	0.893	$3.31^{efgh} \pm 0.07$
Basmati 370	3.01 ± 0.19	3.69 ± 0.13	3.35 ± 0.22	3.09 ± 0.06	2.98 ± 0.06	3.03 ± 0.04	0.251	$3.19^{fghi} \pm 0.15$
Hondarawala	3.43 ± 0.06	3.24 ± 0.03	3.33 ± 0.63	3.08 ± 0.19	2.96 ± 0.44	3.02 ± 0.20	0.225	$3.18^{ghi} \pm 0.21$
Pachchaperumal	3.18 ± 0.14	3.10 ± 0.02	3.14 ± 0.09	3.07 ± 0.10	3.15 ± 0.19	3.11 ± 0.09	0.796	$3.13^{ghij} \pm 0.16$
Rath Suwandal	2.21 ± 0.15	3.47 ± 0.34	2.84 ± 0.39	3.44 ± 0.01	3.36 ± 0.10	3.40 ± 0.05	0.251	$3.12^{ghij} \pm 0.21$
Sulai	3.56 ± 0.11	2.89 ± 0.32	3.22 ± 0.24	3.79 ± 0.04	2.23 ± 0.20	3.01 ± 0.45	0.695	$3.12^{ghij} \pm 0.17$
Beheth Heenati	2.84 ± 0.06	3.64 ± 0.08	3.24 ± 0.23	1.62 ± 0.43	3.05 ± 0.66	2.83 ± 0.77	0.647	$3.04^{hijk} \pm 0.43$
Bg 358	2.42 ± 0.04	3.03 ± 0.13	2.70 ± 0.18	3.89 ± 0.04	2.66 ± 0.11	3.28 ± 0.36	0.244	$3.00^{hijk} \pm 0.43$
Bw 272-6b	3.29 ± 0.03	3.12 ± 0.04	3.20 ± 0.05	2.46 ± 0.04	3.09 ± 0.26	2.78 ± 0.21	0.150	$2.99^{ijk} \pm 0.15$
Sudu Heenati	2.38 ± 0.04	3.08 ± 0.06	2.78 ± 0.41	3.08 ± 0.06	3.38 ± 0.02	3.23 ± 0.09	0.090	$2.98^{ijk} \pm 0.07$
Kottayar	2.11 ± 0.17	3.30 ± 0.06	2.70 ± 0.35	3.01 ± 0.05	3.49 ± 0.27	3.25 ± 0.19	0.236	$2.98^{ijk} \pm 0.23$
Bg 359	2.41 ± 0.06	2.94 ± 0.29	2.67 ± 0.19	3.22 ± 0.03	3.31 ± 0.08	3.26 ± 0.04	0.061	$2.97^{ijkl} \pm 0.21$
Bg 360	2.98 ± 0.03	2.81 ± 0.21	2.89 ± 0.10	3.65 ± 0.10	2.26 ± 0.22	2.95 ± 0.41	0.901	$2.92^{ijklm} \pm 0.19$
Kahata Wee	3.08 ± 0.03	3.37 ± 0.22	3.22 ± 0.12	2.48 ± 0.80	2.74 ± 0.06	2.61 ± 0.08	0.009	$2.91^{ijklm} \pm 0.15$
Gonabaru	3.15 ± 0.07	3.86 ± 0.08	3.50 ± 0.21	1.39 ± 0.04	3.22 ± 0.27	2.31 ± 0.54	0.131	$2.90^{ijklm} \pm 0.27$
Batapolal	2.86 ± 0.04	3.49 ± 0.03	3.01 ± 0.18	2.17 ± 0.25	3.09 ± 0.02	2.63 ± 0.28	0.169	$2.89^{ijklm} \pm 0.12$
Suduru Samba	2.46 ± 0.34	3.08 ± 0.02	2.77 ± 0.23	3.47 ± 0.14	2.55 ± 0.13	3.01 ± 0.28	0.545	$2.87^{ijklm} \pm 0.23$
Bg 300	2.80 ± 0.22	2.80 ± 0.15	2.84 ± 0.13	3.51 ± 0.35	ND	3.51 ± 0.35	0.387	$2.88^{ijklm} \pm 0.37$
Kattamanjal	2.66 ± 0.05	3.60 ± 0.23	3.13 ± 0.24	1.75 ± 0.04	3.39 ± 0.04	2.58 ± 0.51	0.396	$2.85^{jklmn} \pm 0.27$

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Varietal name	Zn content in Bombuwala (mg/100 g)			Zn content in Bathalagoda (mg/100 g)			p value	Overall mean zinc content in Bat and Bom (mg/100 g)
	Yala	*Maha*	Mean	*Yala*	*Maha*	Mean		
Bw 267-3	2.76 ± 0.24	2.80 ± 0.21	2.78 ± 0.17	2.91 ± 0.04	2.77 ± 0.16	2.84 ± 0.07	0.744	2.80^{klmn} ± 0.33
Bg 379-2	2.36 ± 0.27	3.04 ± 0.11	2.69 ± 0.23	3.76 ± 0.11	2.02 ± 0.33	2.89 ± 0.52	0.750	2.79^{klmno} ± 0.29
At 354	3.00 ± 0.04	3.04 ± 0.09	3.02 ± 0.05	2.69 ± 0.07	2.36 ± 0.04	2.53 ± 0.11	0.014	2.77^{klmno} ± 0.13
Bw 361	2.89 ± 0.02	2.87 ± 0.10	2.88 ± 0.04	2.66 ± 0.12	2.25 ± 0.19	2.46 ± 0.15	0.072	2.67^{lmno} ± 0.15
Bg 406	2.50 ± 0.17	2.54 ± 0.08	2.51 ± 0.08	2.59 ± 0.03	2.89 ± 0.09	2.74 ± 0.09	0.117	2.64^{mno} ± 0.13
Bg 352	2.03 ± 0.16	2.90 ± 0.15	2.46 ± 0.26	2.98 ± 0.09	2.44 ± 0.05	2.71 ± 0.16	0.468	2.58^{no} ± 0.14
Masuran	2.68 ± 0.06	3.04 ± 0.02	2.86 ± 0.11	1.18 ± 0.06	3.16 ± 0.07	2.17 ± 0.57	0.318	2.5^{o} ± 0.14
Mean ± SEM	2.91 ± 0.41	3.28 ± 0.36	3.11 ± 0.32	3.15 ± 0.04	3.19 ± 0.04	3.19 ± 0.55		3.18 ± 0.45

Results were expressed as mean ± SEM of four replicates on dry weight basis. Bat – Bathalagoda; Bom - Bombuwala
p values were determined by student t -test in comparison with Bombuwala and Bathalagoda.
Significant difference based on $p \leq 0.05$, ND - not determined

The mean zinc content in rice varieties analysed during the *Maha* season (3.19 ± 0.04 mg/100 g) was comparable to those obtained during the *Yala* season (3.15 ± 0.04 mg/100 g). Most rice varieties analysed had higher or similar zinc contents in samples obtained during the *Maha* season (58.9 %) compared to those obtained from the *Yala* season. The present study revealed that most rice varieties with a red pericarp and an intermediate grain size had a higher range of zinc content than other analysed varieties (Table 3).

Statistical analysis by two-way ANOVA (season *vs*. variety) on the variation of zinc content in thirty nine varieties from Bathalagoda indicated that there was a significant difference at 95 % confident interval with respect to variety (p = 0.0001) and that there was no significant difference with respect to season (p = 0.5468), while ses*var interaction was significant (p = 0.0001).

By analysing the zinc content of rice varieties obtained from Bathalagoda, it was observed that even if the zinc level in the soil is low (~5 ppm) there is a variation in the zinc content in the grain with respect to variety.

Overall analysis of zinc content in rice varieties obtained from Bathalagoda and Bombuwala

The overall mean zinc content (mg/100 g) in each rice variety was obtained from pool analysis of zinc contents in the two locations, which varied from 2.51 (Masuran) to 3.91 (Kalu Bala Wee). Overall mean value for the zinc content (mg/100 g) of the thirty nine varieties analysed was 3.18 ± 0.45 (Table 2). Kalu Bala Wee and Wanni Dahanala had significantly higher ($p \leq 0.05$) overall mean zinc contents among the other studied varieties.

In general most of the rice varieties that had a red pericarp had a higher overall mean zinc content (Table 3), but there was an exception in Masuran that had the lowest zinc content. The size of the grain did not show the above effect with respect to the overall zinc content.

Most rice varieties obtained from Bathalagoda had a high zinc content (Table 2) compared to those from Bombuwala. Statistical analysis of the mean zinc content in every variety with respect to sites (i.e. Bathalagoda and Bombuwala) (Table 2) by student's t test (p value) showed a significant difference at 95 % confident interval in rice varieties Rathu Heenati, Herath Banda, At 306, Kahata Wee and At 354.

Table 3: Ranges and mean zinc contents in rice varieties analysed from Bathalagoda and Bombuwala locations

Parameters analysed	Bathalagoda (mg /100 g)	Bombuwala (mg/100 g)	Overall mean (mg/100 g)
Range of zinc content	2.17 (Masuran) – 4.49 (WD)	2.46 (Bg 352) - 3.71 (Dahanala)	2.51 (Masuran - 3.91 (KBW)
Zinc (Mean)	3.19 ± 0.55	3.11 ± 0.32	3.18 ± 0.45
Colour of pericarp			
Red pericarp	2.17 – 4.49	2.51 – 3.71	2.51 – 3.91
White pericarp	2.61 – 3.60	2.46 – 3.35	2.58 – 3.40
Grain size			
Long grain size	3.03 – 3.51	3.32 – 3.61	3.3 – 3.51
Intermediate grain size	2.17 – 4.49	2.46 – 3.71	2.5 – 3.51
Small grain size	2.58 – 3.75	2.77 – 3.48	2.87 – 3.87

KBW and WD represent Kalu Bala Wee and Wanni Dahanala, respectively

Table 4: Zinc content in brown rice from different countries

Country	Zinc content (mg/ 100 g)	Mean (mg/ 100 g)	Reference
China	0.8 – 7.7	–	Liang, 2007
China	1.29 – 3.87	2.28	
Vietnam	2.6 – 3.8	2.65	
Australia	1.5 – 2.4	1.9	
	2.5 – 8.4	3.7	
USDA collection	1.7 – 6.2		
IRRI	–	3.9	
Sri Lanka			Karunaratne *et al*., 2008
(polished)	0.54 – 1.46	1.14	
(parboiled)	0.54 – 1.23	0.75	
India		0.9	

Values of zinc content were given in dry weight basis

Statistical analysis by two-way ANOVA (season *vs* variety) indicated that there is a significant variation with respect to site (p = 0.0001), season (p = 0.0001), variety (p = 0.0001), site*var (p = 0.0006) and ses*var (p = 0.0001). Three-way ANOVA (season *vs* variety *vs* site) showed that there was a significant difference between site* ses* var (p = 0.0001).

The overall mean value for zinc content (3.18 ± 0.45 mg/100 g) at both locations when compared with those reported from other countries (Table 4), shows that the results of the present study are slightly lower than those from Australia and the International Rice Research Institute (IRRI), while it is slightly higher than in certain other countries including those previously reported by Karunaratne *et al*. (2008) in Sri Lanka. This may be due to the fact that in the study by Karunaratne *et al*. (2008) the degree of polishing was not specified and only a few varieties were analysed (NIV only).

Predictable bio-availability in selected brown and polished rice

The zinc content (mg/ 100 g) in polished rice of fifteen selected varieties (Table 5) varied from 1.41 (Bg 358) to 2.52 (Suduru samba) at 8 – 10 % degree of polishing, whereas the value of brown rice varied from 3.03 (Bg 358) to 4.07 (Dahanala). The percentage reduction in zinc content during polishing varied from 18.2 – 60.7 % (Table 5).

The lowest percentage reduction of zinc was in Suduru Samba (18.2 %) that had the highest zinc content after polishing. Hence Suduru Samba is suitable for polishing as it retained the highest amount of zinc. Although Dahanala contained the highest zinc content in brown rice, on polishing the percentage reduction of zinc was the highest (60.7 %).

The present study showed that the phytic acid content (mg/ 100 g) in polished rice varied from 214.5 (Bg 358) to 302.6 (Suwanda Samba), whereas in brown rice it varied from 301.1 (Kattamanjal) to 429.3 (Suwanda Samba) (Table 5). The percentage reduction of phytic acid content in polished rice was lower than the percentage reduction of zinc and it varied from 18.8 % (Pachchaperumal) to 40.8 % (Kalu Heenati). The lowest percentage reduction of phytic acid was in Pachchaperumal (18.8 %) that had a phytic acid content of 276.4 mg/100 g in the endosperm, while the highest percentage reduction of phytic acid (40.8 %) was in Kalu Heenati that had a phytic acid content of 232.8 mg/100 g.

Table 5: Content of zinc, phytic acid and molar ratios of (PA)/(Zn) in brown rice and polished rice

Vartietal name	Zn in BR (mg/100 g)	Zn in PR (mg/100 g)	% Reduction of Zn	PA in BR (mg/100 g)	PA in PR (mg/100 g)	% Reduction of PA	(PA)/(Zn) MRs in BR	(PA)/(Zn) MRs in PR
Suwanda Samba	3.91 ± 0.01	1.58 ± 0.11	59.6	429.3 ± 6.6	302.6 ± 12	29.6	10.9	18.9
Suduru Samba	3.08 ± 0.03	2.52 ± 0.29	18.2	389.1 ± 15.16	265.3 ± 6.6	31.9	12.5	10.4
Basmati 370	3.69 ± 0.09	2.26 ± 0.16	38.8	378.5 ± 10.7	257.4 ± 7.0	32.1	10.2	11.3
Kattamanjal	3.60 ± 0.12	2.21 ± 0.08	38.6	301.1 ± 7.3	236.6 ± 08	21.6	8.3	10.6
Rathal	3.61 ± 0.06	2.01 ± 0.07	44.4	322.1 ± 10.6	261.2 ± 8.5	18.9	8.8	12.9
At-307	3.67 ± 0.02	1.91 ± 0.19	48.0	312.2 ± 15.2	223.5 ±7.0	30.9	8.4	11.6
Kalu Heenati	3.64 ± 0.12	2.50 ± 0.03	31.3	392.3 ± 7.2	232.8 ± 7.5	40.8	10.7	9.2
Rathu Heenati	3.34 ± 0.02	1.96 ± 0.16	41.4	305.8 ± 6.1	236.7 ± 4.0	22.9	9.1	11.9
Kalu bala Wee	3.79 ± 0.04	2.41 ± 0.02	36.4	420.6 ± 12.6	294.2 ± 5.5	30.2	11.0	12.1
Wanni Dahanala	3.61 ± 0.10	2.13 ± 0.09	40.8	408 .4 ± 13.7	292.7 ± 7.0	28.4	11.2	13.6
Sudu Heenati	3.08 ± 0.05	1.96 ± 0.37	36.4	327.5 ± 16.3	251.1 ± 3.0	23.4	10.5	12.7
Madathawalu	3.65 ± 0.03	2.33 ± 0.36	36.1	388.2 ± 11.9	264.6 ± 6.5	32.1	10.5	11.2
Pachchaperumal	3.11 ± 0.01	1.89 ± 0.07	39.1	340.1 ± 8.3	276.4 ± 7.0	18.8	10.9	14.5
Dahanala	4.07 ± 0.25	1.62 ± 0.08	60.7	395.6 ± 11.5	247.3 ± 7.5	31.2	9.6	15.3
Bg 358	3.03 ± 0.09	1.41 ± 0.04	53.5	314.7 ± 9.3	214.5 ± 4.0	31.9	10.3	15.1
Mean SEM	**3.52 ± 0.16**	**2.04 ± 0.72**	**41.55 ± 5.2**	**361.9 ± 22.5**	**257.11 ± 13.2**	**28.31 ± 3.0**	**10.18 ± 0.86**	**12.8 ± 1.22**

Results were expressed as Mean ± SEM of triplicates. BR - brown rice; PR - polished rice; PA - phytic acid; MRs - molar ratios

The adverse effect of phytic acid on zinc absorption in cereal-based diets has been confirmed by several *in vivo* studies and the relationship has been well established (Turnland, 1982; Turnland *et al*., 1984; WHO,1998). Hence the level of phytic acid is an important factor to predict the bio-availability of zinc.

The results of the present study showed that in brown rice, the molar ratios of (PA)/(Zn) were in the range of 8.3 (Kattamanjal) to 12.5 (Suduru Samba) (Table 5) and this ratio falls below the value (15) stipulated by the World Health Organisation (WHO). Therefore all the brown rice varieties analysed could be categorised as food with a moderate bio-availability of zinc.

The molar ratio obtained for (PA)/(Zn) in rough raw rice as 13.9 ± 2.6 by Karunaratne *et al*. (2008) is in agreement with our values for brown rice. The values obtained by Liang *et al*. (2007) in China for the molar ratio of (PA)/(Zn) in brown rice varied from 27.0 – 66.6 with a mean value of 42.9 and is higher than the results in the present study (range 8.3 – 12.5 and mean 10.1). Also it has been reported that this ratio was much higher than that of wheat measured in India (Grewal *et al*., 1999).

The molar ratio of (PA)/(Zn) in polished rice varied from 9.23 – 18.9, while that in the brown rice varied from 8.3 – 12.5 showing that there is no significant change due to polishing as most of the zinc is bound to the large number of enzymes and other proteins in the endosperm of the rice grain.

The molar ratios (PA)/(Zn) obtained in the present study (i.e. 9.23 – 18.9 in polished rice) are lower than those previously reported by Karunaratne *et al*. (2008) (i.e. 8 – 42).

CONCLUSION

The present study showed that Kalu Bala Wee and Wanni Dahanala had significantly ($p \leq 0.05$) higher zinc contents in overall analysis irrespective of the location, and they could be used for consumption and breeding studies in order to obtain zinc-dense rice varieties.

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REFERENCES

1. Association of Official Analytical Chemists (AOAC) (2000). Phytate in foods. *Official Methods of Analysis*, 17th edition. Association of Official Analytical Chemists, Washington DC, USA.
2. Association of Official Analytical Chemists (AOAC) (2002). Determination of Pb, Cd, Cu, Fe and Zn in foods. *Official Methods of Analysis*, 18th edition. Association of Official Analytical Chemists, Washington DC, USA.
3. Christein H. (2009). The potential to improve zinc status through bio-fortification of staple food crop with zinc. *Food and Nutrition Bulletin* **30**: S172 – S178. DOI: http://dx.doi.org/10.1177/15648265090301S109
4. Cosgrave D.J. (1980). Inositol hexakis phosphates. *Inositol Phosphates: Their Chemistry, Biochemistry and Physiology* (ed. D.J. Cosgrave), pp. 26 – 43. Elsevier Scientific Publications, The Netherlands.
5. FAO⁄WHO (2001). *Human Vitamin and Mineral Requirements*. Report of a Joint FAO⁄WHO Expert Consultation, Bangkok, Thailand. Food and Agriculture Organisation/ World Health Organisation, Rome, Italy.
6. Gazette Extraordinary of the Democratic Socialist Republic of Sri Lanka (1998). *Recommended Dietary Allowances for Sri Lanka, based on WHO Recommendation*. 13 April 1998.
7. Grewal H.K., Hira C.K. & Kawatra B.L. (1999). Zinc, calcium and iron availability using molar ratios in processed and cooked wheat products. *Journal of Food Science and Technology* **36**: 453 – 456.
8. Harland B.F. (1989). Dietary fibre and mineral bio-availability. *Nutrition Research Review* **2**: 133 – 147. DOI: http://dx.doi.org/10.1079/NRR19890011
9. Hemalatha S., Platel K. & Srinivasan K. (2007). Zinc and iron contents and their bio-accessibility in cereals and pulses consumed in India. *Food Chemistry* **102**: 1328 – 1336. DOI: http://dx.doi.org/10.1016/j.foodchem.2006.07.015
10. Jayatissa R. & Hossaine S.M.M. (2010). *Report on Nutrition and Food Security Assessment in Sri Lanka*, pp. 1 – 3. Medical Research Institute, P.O. Box 527, Dr Danister De Silve Mawatha, Colombo 08.
11. Karunaratne A.M., Amerasinghe P.H., Sadagopa Ramanujam V.M., Sand-stead H.H. & Perera P.A.J. (2008). Zinc, iron and phytic acid levels of some popular foods consumed by rural children in Sri Lanka. *Journal of Food Composition Analysis* **21**: 481 – 487. DOI: http://dx.doi.org/10.1016/j.jfca.2008.02.006
12. Liang L. (2007). Iron, zinc and phytic acid in rice from china: wet and dry processing towards improved mineral bio-availability. *Ph.D thesis*, Wageningen University, Wageningen, The Netherlands.
13. Raboy V. (2000). Low-phytic grains. *Food and Nutrition Bulletin* **21**: 423 – 427. DOI: http://dx.doi.org/10.1177/156482650002100416
14. Reddy N.R. & Sathe S.K. (2002). *Food Phytates*. CRC Press, Boca Raton, New York, Washington DC, USA.

15. Reddy N.R., Pierson M.D., Sathe S.K. & Salunkhe S.K. (1989). *Phytates in Cereals and Legumes*. CRC Press, Boca Raton, USA.
16. Turnland J.R. (1982). Bio-availability of selected minerals in cereals food products. *Cereal Food World* **27**: 152 – 157.
17. Turnland J.R., King J.C., Keyes W.R., Gong B. & Michel M.C. (1984). A stable isotope study of zinc absorption in young men: effects of phytate and alpha cellulose. *American Journal of Clinical Nutrition* **40**: 1071 – 1077.
18. Wardlaw G.M. (1999). Trace minerals. *Perspective of Nutrition* (ed. G.M. Wardlaw), 4th edition, pp. 504 – 535. MA:WCB/McGraw-Hill, Boston, USA.
19. World Health Organization (WHO) (1998). *Complementary Feeding of Young Children in Developing Countries. A Review of Current Scientific Knowledge*. World Health Organization, Geneva, Switzerland.
20. Wikramanayake T.W. (ed.) (2002). Minerals. *Food and Nutrition*, 3rd edition, pp. 111 – 140. Hector Kobbekaduwa Agrarian Research and Training Centre, Wijerama Mawatha, Colombo 07.