



## Zinc bio-fortification and kernel quality enhancement in elite *Basmati* rice (*Oryza sativa*) cultivars of south Asia through legume residue-recycling and zinc fertilization

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### ABSTRACT

Basmati-rice (*Oryza sativa* L.) is a geographical indication and most remunerative foreign-exchange earning crop in Indo-Gangetic-plains-region (IGPR). In current study, summer-mungbean residue-recycling (SMB–RR) and Zn-fertilization through zinc-sulfate-heptahydrate (ZSHH) significantly enhanced the grain yield in *basmati* rice genotypes by 11.8 and 8.4%, respectively over summer-fallow (SF) and control; besides higher hulling and head-rice recovery. Kernel-length before and after cooking enhanced by 3.79 and 5.03%, respectively by SMB–RR over SF. SMB–RR and ZSHH registered higher Zn concentration in rice grains (31.4, 32 mg/kg); besides total Zn uptake (1024.5; 1000.8 g/ha) and Zn harvest index (ZHI), indicating ZSHH offers vital solution to curtail Zn malnutrition. Among *basmati*-rice cultivars, Pusa–2511 exhibited highest grain yield (5.07 t/ha), hulling (70.9%), kernel-breadth before (0.17 cm) and after cooking (0.24 cm), and Zn concentration in grains (32.8 mg/kg); while Pusa 1121 exhibited highest kernel-length before (0.84 cm) and after cooking (1.6 cm), and kernel L: B ratio after cooking (7.85). The ZSHH supplied plots led to respective significant enhancement in ZHI to the tune of 7.69% over control plots. Overall, SMB–RR and Zn-fertilization assume great significance in improving productivity, kernel-quality and Zn bio-availability in *basmati*-rice cultivars having global repute as top-quality rice.

**Key words:** *Basmati* rice, Kernel quality, Mungbean residue-recycling, Zn bio-fortification, Zn-fertilization

*Basmati* is a geographical indication of speciality rice of south-Asian Indo-Gangetic plains-region (IGPR) especially India and Pakistan (APEDA 2006). *Basmati*-rice (*Oryza sativa* L.) has global repute as top-quality rice and known for its complex inherited key characteristics *viz.* distinctive and pleasant aromas, extra-long slender grain, extended elongation on cooking leading to fluffy cooked rice, nutty taste and delicate texture besides high yield potential (APEDA 2006, Pooniya *et al.* 2018). *Basmati*-rice acquires above quality traits only in prevailing agro-climatic conditions of south-Asian IGPR; thus, *Basmati*-rice is a major agricultural export-commodity in south-Asian countries like India and Pakistan (Shivay *et al.* 2010). It also provides strong industrial back-up to agro-based industry bestowing ample livelihood avenues to millions in the region. In general, rice is staple food in Asia and provides ~35–80% of total calorie intake (IRRI 1997). Due to changing dietary habits, the demand for *Basmati*-rice is also increasing in

middle-East, western countries, and Asia (Pooniya *et al.* 2018). On the other hand, the traditional *Basmati* rices in Indian sub-continent are low yielder ~1.5–2.0 t/ha (Shivay *et al.* 2010). Thus, replacement of low-yielder old/local *Basmati*-rice genotypes with promising *Basmati* cultivars can be a viable option to enhance rice productivity to meet growing global demands (Pooniya *et al.* 2018). The greatest challenge to rice productivity in IGPR is stagnant/declining productivity conglomerated by intensive cereal–cereal rotations, indiscriminate use of chemical fertilizers and poor soil organic matter posing a threat to its sustainability (Choudhary and Suri 2013, 2014, Paul *et al.* 2014, Pooniya *et al.* 2018). Therefore, the major challenge is to achieve higher productivity with better quality and soil health. In above context, cultivation of summer legumes, *viz.* mungbean (*Vigna radiata*), and cowpea (*Vigna unguiculata*) in summer window-period before rice transplanting either as green manuring or their *in situ* residue-recycling after pod-picking may add sufficient symbiotically fixed-N and biomass enhancing the bio-availability of plant nutrients and soil organic carbon (Pooniya *et al.* 2012, 2018). Legumes as green manure can recycle 60–143 kg N, 16–22 kg P<sub>2</sub>O<sub>5</sub> and 25–121 kg K<sub>2</sub>O/ha per season (Mishra and Prasad 2000). Legume-residues are also associated with decreased

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soil bulk density, reduced soil compaction and increased water stable aggregates, which ultimately improve the rice productivity (Pooniya *et al.* 2015, 2018). Thus, *in-situ* residue recycling of short duration mungbean after pod-picking can prove as boon for resource-poor IGPR farmers besides sustaining rice productivity and soil health (Pooniya *et al.* 2012, 2015, 2018).

Among micronutrients, zinc (Zn) deficiency is the major cause of concern among humans especially where rice is the staple food with ~one-third human population suffering from Zn deficiency (Alloway 2008). As per WHO report (WHO 2002), Zn nutrition need utter attention in humans and animals. The major soil factors affecting Zn availability to plants are low Zn content and organic matter, high pH, high calcite and high concentrations of Na, Ca, Mg and bicarbonates or in labile forms (Pooniya *et al.* 2012, Kumar *et al.* 2017). Another approach to enhance micronutrient biofortification in crop produce is the screening of nutrient responsive crop genotypes (Stein *et al.* 2007, Kumar *et al.* 2018). However, Zn fertilization to soil and onto foliage offers simple and effective solution to combat Zn deficiency in plants as it increases Zn content in major cereals especially rice which is inherently low in Zn (Stein *et al.* 2007). Response of rice to Zn in IGPR soils is highly expected as the critical level of DTPA extractable Zn for rice in alluvial soils of IGPR ranges between 0.38–0.90 mg/kg soil (Pooniya and Shivay 2015). Since, meagre work is done on combined effect of summer-mungbean residue-recycling (SMB–RR) and Zn fertilization on basmati rice. Thus, current study assessed the influence of SMB–RR and Zn fertilization in *Basmati* rice genotypes with respect to rice productivity, kernel quality, Zn bio-fortification and Zn-use efficiency in south-Asian IGPR.

#### MATERIALS AND METHODS

Field experimentation was carried-out during summer (April–May) – *khariif* (June–October) seasons 2013 and 2014 at Experimental Farm of IARI, New Delhi, India (28°58' N Latitude; 77°10' E Longitude; 228.6 m Altitude). The climate of this region is sub-tropical, semi-arid with an average annual rainfall of 650 mm, 80% of which is received through south–west monsoons during July–September, and

the rest is received during the western disturbances from December to February. The hottest months are May and June, with the mean daily maximum temperature varying from 40 to 46°C, whereas December and January are the coldest months, with the mean daily minimum temperature ranging from 5 to 8°C. The soil of the experimental field belongs to the major group of Indo–Gangetic alluvium (Typic Ustochrept). The soil (0–15 cm layer; taken initially before experimentation) of the experimental site was sandy-clay loam in texture having pH 7.9 [1:2.5 soil and water ratio (Rana *et al.* 2014)], Walkley–Black C oxidizable–SOC (Walkley and Black 1934) 0.55%, total–N 0.099% (Euro EA–CHNS analyser), alkaline KMnO<sub>4</sub> oxidizable–N (Subbiah and Asija 1956) 200.8 kg/ha, 0.5 M NaHCO<sub>3</sub> extractable–P (Olsen *et al.* 1954) 16.0 kg/ha, and 1 N NH<sub>4</sub>OAc extractable–K (Hanway and Heidel 1952) 282.4 kg/ha. The diethylene–triamine–penta–acetic acid (DTPA) extractable–Zn (Lindsay and Norvell 1978) in soil was 0.86 mg/kg. Response of rice to Zn was expected because the critical level of DTPA extractable Zn for rice in alluvial soils of IGPR ranges from 0.38–0.90 mg/kg (Pooniya and Shivay 2015).

In the study, two treatments, viz. Summer-mungbean residue-recycling (SMB–RR) and summer-fallow (SF) were considered as factor I; 4 promising *Basmati*/aromatic-rice genotypes (Pusa Basmati 1, Pusa 1121, Pusa 1401, Pusa 2511); and 2 Zn levels, viz. absolute control (only N) and 25 kg Zn [zinc-sulfate heptahydrate (ZSHH)] constituted as factor II and III, thereby, making 16 treatments. Selection of 4 *Basmati* genotypes was done keeping in view their yield potentiality and special characteristics for export potential (Table 1). The experiment was laid-out in split (main A, sub–B × C) plot design replicated thrice with plot size of 4.0 × 5.5 m for each sub-plot.

A representative SMB for biomass accumulation (t/ha) was taken from a quadrat (0.5 m<sup>2</sup>) at five places from each plot. The shoot parts were harvested with sickle and roots were taken from 0–30 cm soil layer. The fresh weight of shoot and roots was taken after properly washing initially with tap water and then with deionised water. After that, the samples were air-dried for 4 days and then dried in oven (60 ± 1°C) to assess dry-matter accumulation. SMB was

Table 1 Salient characteristics of promising *Basmati*/aromatic rice varieties developed by Indian Agricultural Research Institute, New Delhi, India as tested under current study

Variety and parentage	Duration (in days)	Average yield (t/ha)	Special characteristics
Pusa Basmati 1 (PB1)	135–140	5.0–5.5	First semi–dwarf basmati rice having pleasant aroma with superfine grain, soft texture and higher linear elongation on cooking. This variety led to enhanced production multi–folds.
Pusa Basmati 1121 (PS4)	140–145	4.0–4.5	Kernel length 8 mm with cooked grain length of ~ 20 mm, fetching premium price in international market. This cultivar has excellent global acceptability in Middle East, Iran, Australia, Africa, Europe, Canada and USA.
Pusa Basmati 6 (Pusa 1401)	140–145	5.0–5.5	Its grain during cooking has uniform shape and has < 4% chalky grains.
Pusa Sugandh 5 (Pusa 2511)	120–125	5.5–6.0	A semi–dwarf high yielding aromatic rice variety suitable for multiple cropping in IGPR in South Asia.

properly chopped with chopper *in situ* and their residue was incorporated into soil ~65 d of sowing. For chemical analysis, plant samples were collected at 10 days before incorporation and oven dried samples were sieved by passing through 40 mesh sieve. Plant samples were analyzed for total N using Kjeldahl's digestion unit, while total P and K were determined using di-acid digestion [Perchloric acid (HClO<sub>4</sub>) + Nitric acid (HNO<sub>3</sub>) in 3:10 ratio] as per standard procedure (Rana *et al.* 2014). The NPK and Zn uptake in SMB was also assessed using standard procedures.

The field was disk-ploughed and puddled twice with puddler in standing water (5 cm) and then levelled. At final puddling, 26 kg/P ha as single super phosphate and 33 kg K/ha as muriate of potash were broadcasted uniformly while 5.25 kg Zn/ha was applied as per treatments. Split N @ 110 kg/ha (½ at transplanting, ½ at panicle initiation) as prilled urea was applied in all treatments. In *Basmati*-rice, 25 days aged seedlings were transplanted (20 × 10 cm). SMB cv. Pusa Vishal was sown under residual fertility (no fertilizers) on 2<sup>nd</sup> fortnight of April in summer window-period and *in-situ* residue-recycled after pod-pickings before rice transplanting.

Tillers/hill were counted from a sampling unit, and 10 randomly selected panicles were used for number of grains/panicle. 1000-filled grains were taken from sampled panicles for counting and weighing. The harvested *Basmati*-rice and SMB pods were sun-dried for 3–4 days to bring moisture content ~14–17%. After threshing, grains were winnowed and yield was recorded at ~14% moisture content in grains. Rice grain and straw yields were expressed as t/ha.

Paddy samples (husked rice) from each plot were used to study physico-chemical and cooking quality parameters following standard procedures as given below:

Well sun-dried paddy samples weighing 100 g were hulled in a mini Satake Rice Mill and the weight of brown rice was recorded, hulling (%) was calculated as per formula suggested by Shivay *et al.* (2010):

$$\text{Hulling (\%)} = \frac{\text{Weight of brown rice (g)}}{\text{Weight of rough rice (g)}} \times 100$$

The milled produce was sieved with appropriate sieves to separate whole kernels from broken ones. A small proportion of whole kernels that passed along with broken ones were hand separated, and head rice recovery (%) was computed.

Before cooking, 10 milled kernels from each plot were taken randomly and measured on graph paper for their length and breadth using a photo enlarger with 3X magnification. Mean kernel length and breadth were expressed in cm. A sample of 10 kernels before cooking from each plot were taken separately in long-labelled test tubes and pre-soaked in 5 ml tap water for 30 minutes, then tubes were placed in water bath maintained at boiling temp. For 6–8 minutes. After cooking, the tubes were taken out to cool under running water for 2 min. Cooked kernels were taken out of the tubes and excess water was removed with a blotting paper. Length and breadth of cooked kernels were then measured. The

ratio of cooked kernel length to breadth before and after cooking was calculated accordingly.

Plant samples were collected 10 days prior to harvesting and dried in hot air oven (62±5°C) for 6–8 hr. These samples were then grind and sieved in 40 mesh sieve in Macro-Wiley Mill. From each treatment, 0.5 g dry matter (grain and straw) samples were taken for chemical analysis to determine Zn concentrations. N concentration was determined by modified Kjeldahl's method. Zn in grain and straw was determined by di-acid digestion on atomic absorption spectrophotometer (Rana *et al.* 2014).

The estimated partial factor productivity (PFP) of applied N/Zn, agronomic efficiency (AE) and nitrogen harvest index of applied N (NHI) and Zn harvest index of applied Zn (ZHI) were computed by the equations suggested by Fageria and Baligar (2003), and Pooniya and Shivay (2015):

$$\begin{aligned} \text{PFP} &= Y_t/N_a \text{ or } Z_n \\ \text{AE} &= (Y_t - Y_c)/Z_n \\ \text{NHI/ZHI} &= \text{GU}_{N/Zn}/U_{N/Zn} \end{aligned}$$

wherein, Y<sub>t</sub> and U<sub>N/Zn</sub> refer to grain yield (kg/ha) and total N/Zn uptake (kg/ha), respectively, of basmati rice in N/Zn applied plots; Y<sub>c</sub> refer to grain yield (kg/ha) in control (only N) plots; N<sub>a</sub>/Zn<sub>a</sub> refers to the Zn applied (kg/ha); GU<sub>N</sub> refers to N/Zn uptake (kg/ha) in grain.

Analysis of variance (ANOVA) was done to determine treatment effects through Tukey's honestly significant difference as a post hoc mean separation test ( $P \leq 0.05$ ) by using *Proc GLM in SAS 9.3* software. Tukey procedure was used only where ANOVA was significant.

## RESULTS AND DISCUSSION

### *Mungbean productivity and nutrient-recycling by mungbean residue-recycling*

In current study, after mature pod-picking of dual-purpose SMB, the SMB residues were recycled *in-situ* resulting in nutrient-recycling ranging between 83.6–88.4 kg N, 8.62–9.28 kg P<sub>2</sub>O<sub>5</sub>, 97.3–103.2 kg K<sub>2</sub>O kg/ha (2 year av.) besides improved SOC and N by atmospheric N-fixation. SMB, on an average, produced 0.96 t/ha grain yield during current study, thus, adding to the nutritional security. Pooniya *et al.* (2015) have also registered a positive nutrient balance, SOC enhancement and improved soil physico-chemical and biological properties after *in situ* SMB residue-recycling in the soil.

### *Yield attributes and productivity of basmati-rice*

The tillers/hill, grains/panicle, harvest-index (HI) and 1000 grain weight in *Basmati*-rice were found higher following the summer-mungbean residue-recycling (SMB-RR) in different rice genotypes over summer fallow (SF), but all genotypes behaved statistically similar with respect to above parameters (Table 2). A non-significant variation was observed in Zn-fertilized plots *w.r.t.* all above mentioned parameters except 1,000 grains weight. The maximum

Table 2 Summer mungbean residue-recycling (SMB-RR) and Zn-fertilization on yield attributes and productivity of *Basmati*-rice cultivars (2 years' av.)

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	Tillers/hill at 60 days	Grains/panicle	Harvest index	1000-grain weight (g)
<i>Residue-recycling (I)</i>						
SMB-RR	4.35 <sup>A</sup>	8.21 <sup>A</sup>	15.8	136.8	0.35	23.32
Summer Fallow	3.89 <sup>B</sup>	7.50 <sup>B</sup>	14.3	131.8	0.34	23.37
Tukey's HSD at 5%	0.18	0.59	ns	ns	ns	ns
<i>Cultivars (H)</i>						
Pusa Basmati-1	3.81 <sup>B</sup>	7.45 <sup>B</sup>	16.6 <sup>A</sup>	149.9 <sup>A</sup>	0.34 <sup>B</sup>	19.79 <sup>C</sup>
Pusa-1121	3.94 <sup>B</sup>	8.64 <sup>A</sup>	17.0 <sup>A</sup>	93.3 <sup>B</sup>	0.31 <sup>C</sup>	26.24 <sup>A</sup>
Pusa-1401	3.65 <sup>B</sup>	7.93 <sup>B</sup>	15.9 <sup>A</sup>	146.3 <sup>A</sup>	0.32 <sup>C</sup>	20.72 <sup>B</sup>
Pusa-2511	5.07 <sup>A</sup>	7.42 <sup>B</sup>	10.5 <sup>B</sup>	147.2 <sup>A</sup>	0.40 <sup>A</sup>	26.64 <sup>A</sup>
Tukey's HSD at 5%	0.35	0.53	2.56	13.0	0.02	0.68
<i>Zinc fertilization (F)</i>						
Control (only N)	3.95 <sup>B</sup>	7.71 <sup>B</sup>	14.7	135.6	0.34	23.07 <sup>B</sup>
ZSHH	4.28 <sup>A</sup>	8.00 <sup>A</sup>	15.4	132.9	0.35	23.63 <sup>A</sup>
Tukey's HSD at 5%	0.25	0.38	ns	ns	ns	0.48

Bars followed by a similar letter within a column are not significantly different at  $P \leq 0.05$  level of significance according to Tukey's HSD mean separation test.

tillers hill<sup>-1</sup> (15.8), grains/panicle (136.8), and HI (0.35) were recorded when basmati-rice was grown in SMB-RR plots. The tillers/hill and grains/panicle with SMB-RR were enhanced by 9.49 and 3.65% over SF. Among genotypes, highest tillers/hill and grains/panicle were observed in Pusa 1121 and Pusa Basmati-1; while highest HI and 1000 grains weight (26.6 g) were recorded in Pusa 2511. Application of ZSHH exhibited higher tillers/hill, HI and 1000 grains weight over control. SMB-RR offers viable alternative to achieve higher profitability and sustainability (Pooniya *et al.* 2015, 2018). Thus, among *Basmati*-rice genotypes (Table 2), significantly highest yield was registered in Pusa 2511 (5.07 t/ha) and significantly superior to Pusa Basmati 1 (3.81 t/ha), Pusa 1401 (3.65 t/ha) and Pusa 1121 (3.94 t/ha), respectively. Among genotypes, Pusa 1121 registered significantly highest straw yield (8.64 t/ha) over other genotypes. Grain and straw yield in *Basmati*-rice were consistently and significantly higher with SMB-RR over the SF. Rice grain and straw yields were significantly higher using ZSHH over control. Since, SMB-RR registered higher values of yield attributes in *Basmati*-rice over summer-fallow (SF). In this study, mungbean accumulated NPK nutrients ranging between 83.6–88.4 kg N, 8.62–9.28 kg P<sub>2</sub>O<sub>5</sub> and 97.3–103.2 kg K<sub>2</sub>O/ha; and ultimately these nutrients got recycled into soil and led to higher nutrient availability to rice crop. Residual effect of biological fixed-N in SMB root nodules and its recycling through residue incorporation led to improved yield attributes (Table 2). Among four basmati genotypes, Pusa 1121 registered highest tillers/hill with least number of grains/panicle due to shortest panicles, finally, led to poor yield ability of this genotype. Likewise, comparatively lower tillers/hill and 1000 grains weight are responsible characteristics for lowest grain yield

in Pusa 1401 and Pusa Basmati 1 genotypes too. Pusa 2511 registered lowest tillers/hill but due to its higher 1000 grains-weight and grains/panicle, it produced significantly higher grain yield than rest of genotypes (Table 2). Higher yield under SMB-RR could be attributed to higher N availability and other micronutrient cations into the soil (Kumar *et al.* 2016, Pooniya *et al.* 2018). Pusa 2511 exhibited highest HI which is directly linked with efficient partitioning of photosynthates between harvesting and non-harvesting parts, besides, the economic produce has close association with plant development (Choudhary and Suri 2014, 2018a). Consequently, the differences in photosynthates' partitioning besides varying sink and source relationships of different genotypes perhaps led to a significant variation in HI (Choudhary and Suri 2018a, 2018b).

#### *Hulling, head rice recovery and kernel cooking quality parameters*

SMB-RR and ZSHH significantly influenced the hulling (%) and head-rice recovery (Table 3, 4). Greatest hulling and head-rice recovery (HRR) were achieved by SMB-RR and ZSHH fertilization. Among genotypes, Pusa 2511 registered highest hulling (70.9%) closely followed by Pusa-1121 (70.2%) while Pusa 1401 registered highest HRR (55.5%). Significantly longest kernel length before and after cooking was recorded with SMB-RR with an enhanced magnitude of 3.79 and 5.03%, respectively over SF. Among the genotypes, Pusa 1121 exhibited highest kernel length before and after cooking followed by Pusa 2511. A non-significant variation was observed with Zn-fertilization *w.r.t.* kernel length before cooking, however, it differed significantly after cooking. Kernel breadth did not influence significantly due to SMB-RR, though after cooking SMB-RR led to 4.76% enhanced

Table 3 SMB-RR and Zn fertilization on hulling % and kernel quality parameters of *Basmati*-rice cultivars (2 years' av.)

Treatment	Hulling (%)	Kernel length before cooking (cm)	Kernel breadth before cooking (cm)	Kernel L:B before cooking	Kernel length after cooking (cm)	Kernel breadth after cooking (cm)	Kernel L: B ratio after cooking
<i>Residue-recycling (I)</i>							
SMB-RR	69.7 <sup>A</sup>	0.82 <sup>A</sup>	0.16	5.24	1.46	0.22	6.52
Summer Fallow	68.5 <sup>B</sup>	0.79 <sup>B</sup>	0.15	5.20	1.39	0.21	6.56
Tukey's HSD at 5%	0.59	0.017	ns	ns	ns	ns	ns
<i>Cultivars (H)</i>							
Pusa Basmati -1	67.0 <sup>B</sup>	0.79 <sup>B</sup>	0.15 <sup>C</sup>	5.45	1.33 <sup>B</sup>	0.22 <sup>B</sup>	6.17 <sup>B</sup>
Pusa-1121	70.2 <sup>A</sup>	0.84 <sup>A</sup>	0.16 <sup>AB</sup>	5.32	1.60 <sup>A</sup>	0.20 <sup>B</sup>	7.85 <sup>A</sup>
Pusa-1401	68.3 <sup>B</sup>	0.78 <sup>B</sup>	0.15 <sup>BC</sup>	5.30	1.35 <sup>B</sup>	0.21 <sup>B</sup>	6.28 <sup>B</sup>
Pusa-2511	70.9 <sup>A</sup>	0.81 <sup>B</sup>	0.17 <sup>A</sup>	4.90	1.41 <sup>B</sup>	0.24 <sup>A</sup>	5.87 <sup>B</sup>
Tukey's HSD at 5%	1.60	0.036	0.017	ns	0.11	0.015	0.45
<i>Zinc fertilization (F)</i>							
Control (only N)	68.1 <sup>B</sup>	0.80	0.15 <sup>B</sup>	5.35	1.37 <sup>B</sup>	0.21 <sup>B</sup>	6.49
ZSHH	70.0 <sup>A</sup>	0.81	0.16 <sup>A</sup>	5.08	1.47 <sup>A</sup>	0.23 <sup>A</sup>	6.59
Tukey's HSD at 5%	1.13	ns	0.012	ns	0.073	0.011	ns

Bars followed by a similar letter within a column are not significantly different at  $P \leq 0.05$  level of significance according to Tukey's HSD mean separation test. Interaction effects were not significant for all the quality parameters of basmati rice.

Table 4 SMB-RR and Zn fertilization on N/Zn use-efficiencies and head rice recovery in *Basmati*-rice cultivars (2 years' av.)

Treatment	ZHI	Agronomic efficiency (kg grain increase/kg Zn applied)	Partial factor productivity (kg grain/kg Zn applied)	Partial factor productivity (kg grain/kg N applied)	NHI	Head-rice recovery (%)
<i>Residue-recycling (I)</i>						
SMB-RR	0.14	37.5	828.4 <sup>B</sup>	39.5	0.54	51.9 <sup>A</sup>
Summer Fallow	0.13	25.7	741.4 <sup>A</sup>	35.4	0.54	49.8 <sup>B</sup>
Tukey's HSD at 5%	ns	ns	38.1	1.63	ns	0.18
<i>Cultivars (H)</i>						
Pusa Basmati -1	0.14 <sup>B</sup>	38.6	726.2 <sup>B</sup>	34.7	0.52	50.9 <sup>B</sup>
Pusa-1121	0.12 <sup>C</sup>	37.1	751.7 <sup>B</sup>	35.9	0.53	48.2 <sup>D</sup>
Pusa-1401	0.12 <sup>C</sup>	28.0	695.2 <sup>BC</sup>	33.2	0.52	55.5 <sup>A</sup>
Pusa-2511	0.16 <sup>A</sup>	22.8	966.6 <sup>A</sup>	46.1	0.59	48.8 <sup>C</sup>
Tukey's HSD at 5%	0.013	ns	50.2	2.30	0.042	0.16
<i>Zinc fertilization (F)</i>						
Control (only N)	0.13 <sup>B</sup>	—	—	36.0	0.53	50.3 <sup>B</sup>
ZSHH	0.14 <sup>A</sup>	63.2 <sup>A</sup>	816.5 <sup>A</sup>	39.0	0.55	51.4 <sup>A</sup>
Tukey's HSD at 5%	0.009	—	—	1.63	ns	0.11

Bars followed by a similar letter within a column are not significantly different at  $P \leq 0.05$  level of significance according to Tukey's HSD mean separation test.

kernel breadth over SF, reflecting importance of SMB-RR in enhancing cooking quality. P 2511 recorded highest kernel breadth before (0.17 cm) and after cooking (0.24 cm). Zn application also improved kernel breadth before (6.25%) and after cooking (8.69%) over control. Kernel length: breadth ratio (L: B ratio) before and after cooking was not influenced significantly by the SMB-RR, genotypes and ZSHH. The genotypes showed a significant influence on kernel L: B ratio after cooking. Among genotypes, kernel L:

B ratio after cooking was significantly greater in Pusa-1121 remaining significantly superior over other genotypes. A significant interaction effect was observed among SMB-RR  $\times$  genotypes  $\times$  Zn with respect to HRR (Table 5). Both under SF and SMB-RR, application of ZSHH led to higher HRR under all the genotypes over control. On an average, highest HRR (58.1%) was estimated under P-1401 genotype by using ZSHH followed by Pusa Basmati 1, Pusa 2511 and Pusa 1121, respectively. Under SF plots, all the genotypes

Table 5 Interaction effect between SMB-RR (I) × cultivars (H) × Zn-fertilization (F) with respect to head-rice recovery (HRR)

I × H × F	SMB-RR				Mean	Summer-Fallow				Mean
	PB 1	P 1121	P 1401	P 2511		PB 1	P 1121	P 1401	P 2511	
Control	53.4	48.9	57.7	46.3	51.6	47.3	48.1	50.5	49.7	48.9
ZSHH	53.7	48.3	58.1	48.3	52.1	48.9	47.5	55.7	50.7	50.7
Mean	53.6	48.6	57.9	47.3	51.9	48.1	47.8	53.1	50.2	49.8

Tukey's HSD at Interaction (H × F means) = 0.23; I means at same or different levels of H × F = 0.34; F means at same or different level of I × H = 0.32; H means at same or different level of I × F = 0.32; I means at same or different levels of H = 0.26; I means at same or different levels of F = 0.21; H means at same or different levels of I = 0.23; F means at same or different levels of I = 0.16

Note: Bars followed by a similar letter within a column are not significantly different at P ≤ 0.05 level of significance according to Tukey's HSD mean separation test.

showed lower HRR values under control but the application of ZSHH again improved the HRR in all the genotypes with Pusa-1401 being best performer and Pusa Basmati-1 being poor one in HRR both with and without ZSHH application (Table 5). The SMB-RR and Zn-fertilization significantly influenced the hulling and HRR in *Basmati*-rice genotypes (Pooniya and Shivay 2015). The enhancement in hulling and head rice recovery of different genotypes with Zn fertilization can be ascribed to increased nutrient uptake and mobilization, especially N concentration in grains. This led to an increase in protein content and decreased the breakage loss (Pooniya and Shivay 2015). The greater protein content imparts strength to the grains which results in substantial HRR. From the kernel quality point of view, Pusa 1121 was proved as eminent *Basmati*-rice and it produced longest kernels both before and after cooking as well as L: B ratio after cooking (Table 3). In general, Zn requisition through different sources had considerably influenced the hulling and head rice recovery as well as cooking quality of *Basmati*-rice (Pooniya and Shivay 2015). The current study reflects that Pusa 2511 is significantly better than other genotypes *w.r.t.* yield, ZHI and PFP; but from cooking quality point of view, the Pusa 1121 is superior-most, thus, both these genotypes are better alternatives for the replacement of traditional/low-yielding genotypes in *Basmati*-rice growing areas of north-western IGPR.

#### Zn concentrations and uptake

Zn concentration in grain and straw did not increase significantly by SMB-RR and ZSHH (Fig 1). Among genotypes, Pusa 2511 recorded highest Zn in grain and straw. On an average, Pusa 2511 reported 2.76; 3.96; 7.31% and 2.22; 7.55; 8.53% higher Zn concentration in grains and straw, respectively over Pusa 1121, Pusa Basmati 1 and Pusa 1401 genotypes. Regarding Zn uptake, SMB-RR significantly improved the Zn uptake in grains and straw by 11.9 and 9.59% over SF. Likewise, Zn uptake in straw of Pusa 1121 was significantly higher than Pusa 2511, Pusa 1401 and Pusa Basmati 1, and is directly associated with higher biomass productivity of this genotype. Total Zn uptake by *Basmati*-rice (grain + straw) was significantly highest in P followed by Pusa 2511, Pusa 1401 and Pusa Basmati 1. Application of ZSHH registered highest Zn

uptake to the tune of +13.2 and +40.9 g/ha in grains and straw over control. Total Zn uptake in rice (grain + straw) was significantly improved by Zn fertilization compared to control. In case of Zn content, significantly lowest Zn concentration was recorded in Pusa 1401 and Pusa Basmati 1 both in grains and straw than Pusa 1121 and Pusa 2511 (Fig 1). Pusa 2511 registered highest Zn concentrations, while Zn uptake was highest in Pusa 1121. It indicates that higher biomass production by respective genotypes led to higher Zn uptake both in grains and straw (Pooniya *et al.* 2018). Various studies have suggested that legume residue-recycling significantly increases the micronutrient concentrations and their uptake (Pooniya *et al.* 2015, 2018, Kumar *et al.* 2016b). Zn concentration was not influenced significantly by Zn fertilization, as the Zn availability in experimental soil is nearing upper limit of critical values (0.38–0.90 mg/kg), however the higher values of Zn concentration were revealed in Zn fertilized plots. Zn uptake in *basmati*-rices significantly increased by Zn fertilization and SMB-RR (Fig 1), which can be explained on the basis of improved Zn solubility due to SMB-RR, and thus, enhanced Zn absorption in these genotypes. Under waterlogged situations, Zn deficiency is more acute due to reduced Zn availability and its uptake, besides suppression caused by high levels of Fe<sup>2+</sup> and Mn<sup>2+</sup> concentrations (Shivay *et al.* 2010). Many researchers have reported positive interaction of Zn × N in cereals and this positive interaction lead to improvement in Zn uptake through roots and its translocation to the sink (Kutman *et al.* 2010, Kumar *et al.* 2017).

#### N concentrations and uptake

On an average, SMB-RR recorded 2.54 and 3.77% higher N concentrations in grains and straw but statistically differences were non-significant (Fig 2). Among genotypes, Pusa Basmati-1 was superior-most *w.r.t.* N concentrations in grains and straw. This genotype reported 0.83; 4.16; 5.83% and 10.5; 19.3; 5.3% more N concentration in grains and straw, respectively over Pusa 1401, Pusa 1121 and Pusa 2511. Zn application increased the N concentration compared to the control. The N uptake was significantly influenced by SMB-RR and it increased by 12.7, 13.5 and 12.6% compared to SF. Among genotypes, Pusa-2511 exhibited significantly highest N uptake in rice grains and total N

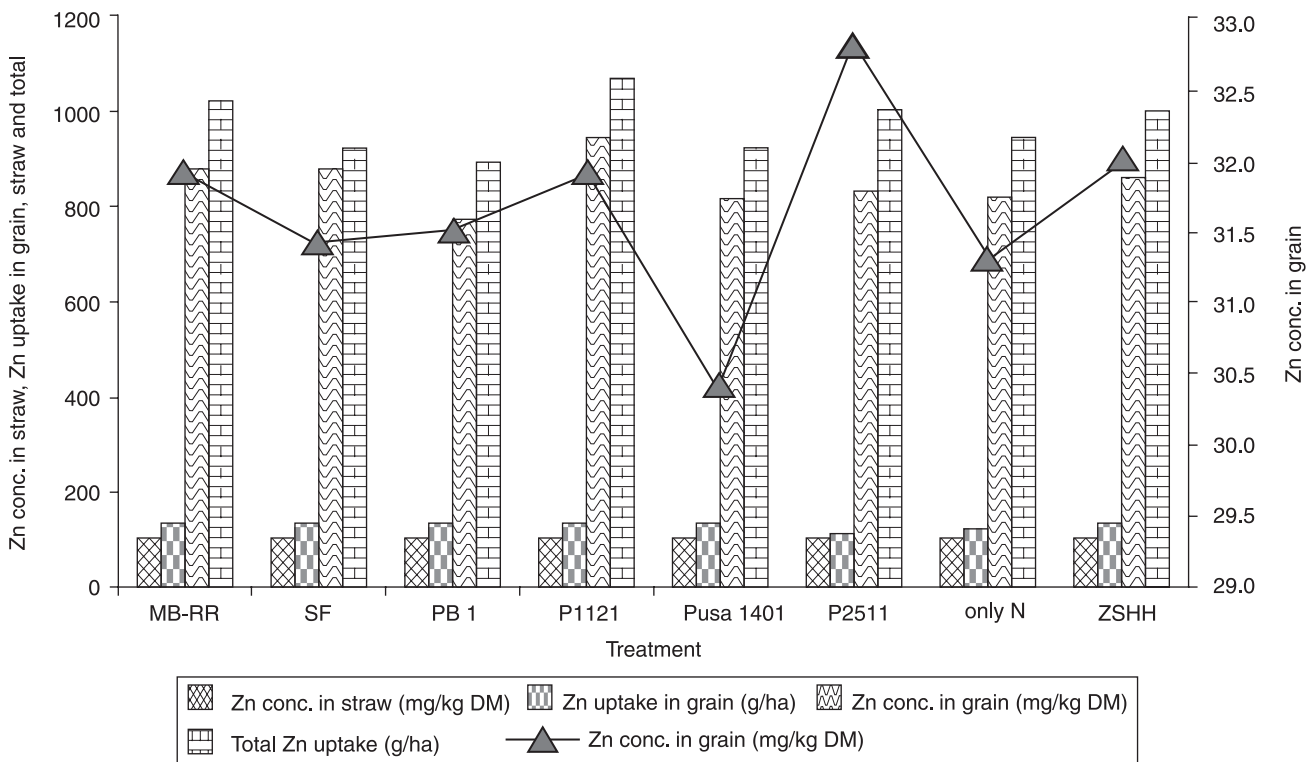


Fig 1 Effect of SMB-RR and ZSHH on Zn concentrations and uptake in grain, straw and total in *Basmati*-rice cultivars.

uptake. Zn fertilization registered highest N uptake to the tune of +6.1, +2.6 and +8.7 kg/ha in grains, straw as well as total uptake over control. Higher N concentrations in SMB-RR plots might be due to an increase in N availability through synchronized N released from legume-residue and applied fertilizers (Pooniya *et al.* 2018), which might have

increased the N concentration proportionately in grains and straw and ultimately led to higher N uptake (Kumar *et al.* 2017, Pooniya *et al.* 2018).

*Zn/N use-efficiencies of basmati rice*

SMB-RR exhibited non-significant effect on Zn/N

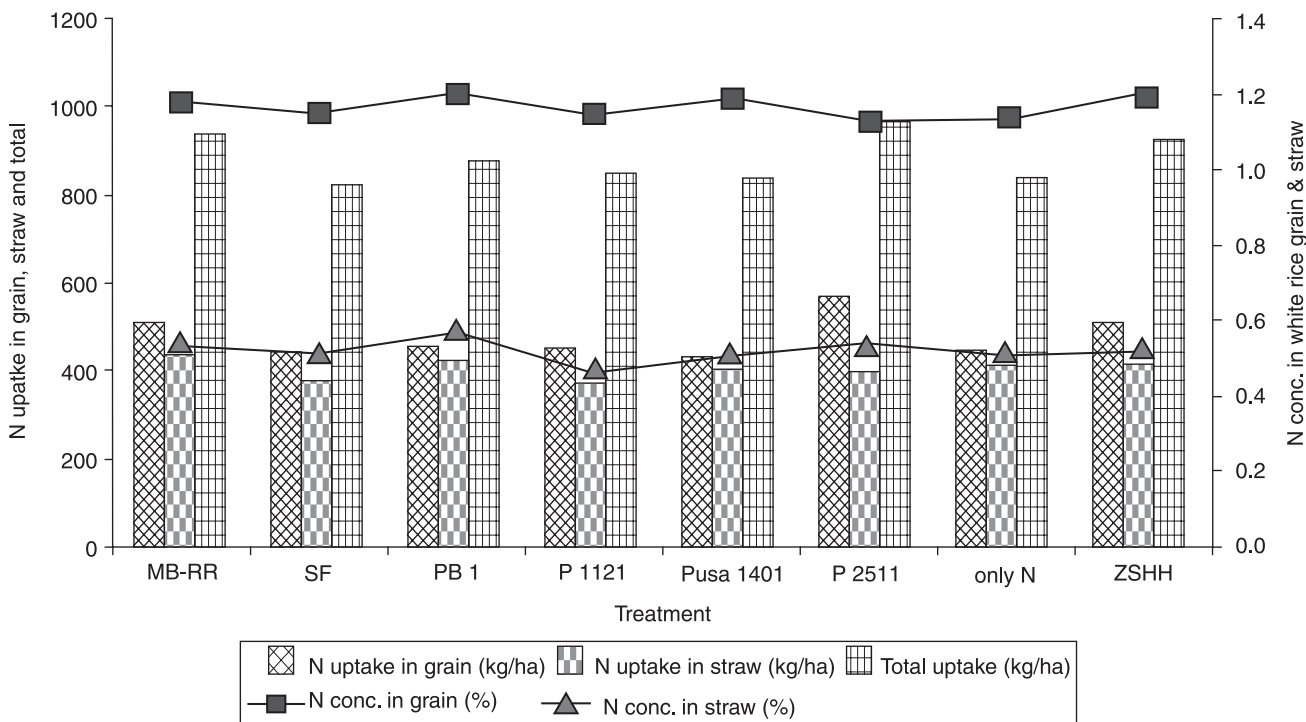


Fig 2 Effect of SMB-RR and ZSHH on N concentrations and uptake in grain, straw and total in *Basmati*-rice cultivars.

harvest index (Z/NHI), and agronomic efficiency (AE) to applied Zn in *Basmati*-rice (Table 4) except partial factor productivity (FPF). Obviously, higher ZHI and AE were recorded with SMB-RR over SF, but NHI exhibited similar values both in SMB-RR and SF plots. Likewise, highest PFP (828.4; 39.5 kg grains/kg of Zn/N applied) was recorded in SMB-RR and least in SF (741.4; 35.4 kg grains/kg of Zn/N applied). Pusa 2511 recorded significantly highest ZHI/NHI over Pusa Basmati 1, Pusa 1121 and Pusa 1401. AE did not differ significantly in all the genotypes though highest AE was recorded with Pusa Basmati 1 followed by Pusa 1121. The PFP of applied Zn/N was significantly highest in Pusa 2511 over Pusa 1121, Pusa Basmati 1 and Pusa 1401. A significant difference between Zn fertilization treatments was recorded *w.r.t.* ZHI, PFP and AE. The Zn fertilization led to significant enhancement in PFP and ZHI of applied Zn/N collectively over control plots. The AE in Zn fertilized plots was computed as 63.2 kg grains/kg Zn applied. In current study, ZUEs' are higher at lower Zn application rates because of its rapid adsorption over clay minerals and soil organic matter (Hazra and Mandal 1995, Kumar *et al.* 2016a, 2017), besides following slow desorption (Mandal *et al.* 2000). High PFP, AE and ZHI were due to the reason that a very small amount of Zn is needed for rice growth and development compared to N (Cassman *et al.* 1998). Soil application of Zn improves ZHI by 2% (Prasad *et al.* 2014). Available reports suggested that soil applied-Zn has greater significance in brown rice compared to foliar applied Zn; as a sizeable portion of foliar-applied Zn remains in husk (Prasad *et al.* 2014). In rice, Zn absorbed through roots plays a significant role in Zn bio-fortification while the mobilization through leaves play a little role (Jiang *et al.* 2007). Overall, Zn fertilization to soil has greater significance towards improving productivity, nutritional quality and Zn bio-availability in grains and straw which has great potential in curtailing Zn malnutrition both in humans and animals (Kumar *et al.* 2017).

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#### REFERENCE

- Alloway B J. 2008. *Zinc in Soils and Crop Nutrition*. A publication of International Zinc Association and International Fertiliser Industry Association, Brussels.
- APEDA. 2006. Guidelines for use of the geographical indication *Basmati* in India. Agricultural and Processed Food Products Export Development Authority (APEDA), Ministry of Commerce and Industry, Govt. of India. [http://apeda.gov.in/apedawebbsite/Archive/labeling\\_guidelines\\_Basmati.doc](http://apeda.gov.in/apedawebbsite/Archive/labeling_guidelines_Basmati.doc) [Accessed on 22 Dec., 2017].
- Cassman K G, Penj S, Olk D C, Ladha J K, Reichardt W, Dobermann A and Singh U. 1998. Opportunities for increased N efficiency from improved resource management in irrigated rice system. *Field Crops Research* **56**: 7-39.
- Choudhary A K and Suri V K. 2013. *On-farm* participatory technology development effects on resource conservation technologies in rainfed upland paddy in Himachal Pradesh, India. *Communications in Soil Science and Plant Analysis* **44** (17): 2605-17.
- Choudhary A K and Suri V K. 2014. Integrated nutrient management technology for direct-seeded upland rice in northwestern Himalayas. *Communications in Soil Science and Plant Analysis* **45** (6): 777-84.
- Choudhary A K and Suri V K. 2018a. System of rice intensification in promising rice hybrids in north-western Himalayas: Crop and water productivity, quality and economic profitability. *Journal of Plant Nutrition* **41** (8): 1020-34.
- Choudhary A K and Suri V K. 2018b. System of rice intensification in short duration rice hybrids under varying bio-physical regimes: New opportunities to enhance rice productivity and rural livelihoods in north-western Himalayas under a participatory-mode technology transfer program. *Journal of Plant Nutrition*, DOI: 10.1080/01904167.2018.1510515.
- Fageria N K and Baligar V C. 2003. Methodology for evaluation of lowland rice genotype for nitrogen use efficiency. *Journal of Plant Nutrition* **26**: 1315-33.
- Hanway J J and Heidel H. 1952. *Soil analysis methods as used in Iowa State College Soil Testing Laboratory*. Bulletin 57, Iowa State College of Agriculture, USA, 131 p.
- Hazra G C and Mandal B. 1995. Zn absorption in soils in relation to soil properties. *Indian Journal of Agricultural Sciences* **65**: 659-64.
- IRRI. 1997. *Rice Almanac*, 2<sup>nd</sup> Edition, p 181 International Rice Research Institute, Los Banos, Philippines.
- Jiang W, Strik P C, Lingna J, van Keulen H, Ming Z and Stomph T J. 2007. Uptake and distribution of root-applied or foliar applied <sup>65</sup>Zn after flowering in aerobic rice. *Annals of Applied Biology* **150**: 383-91.
- Kumar A, Choudhary A K and Suri V K. 2016b. Influence of AM fungi, inorganic phosphorus and irrigation regimes on plant water relations and soil physical properties in okra (*Abelmoschus esculentus* L.)-pea (*Pisum sativum* L.) cropping system in Himalayan acid Alfisol. *Journal of Plant Nutrition* **39**(5): 666-82.
- Kumar A, Choudhary A K and Suri V K. 2017. Agronomic bio-fortification and quality enhancement in okra-pea cropping system through arbuscular mycorrhizal fungi at varying phosphorus and irrigation regimes in Himalayan acid Alfisol. *Journal of Plant Nutrition* **40** (8): 1213-29.
- Kumar A, Choudhary A K, Pooniya V, Suri V K and Singh U. 2016a. Soil factors associated with micronutrient acquisition in crops-Biofortification perspective. *Biofortification of Food Crops* pp 159-76. (Singh *et al.* (Eds), Springer Publishers.
- Kumar S, Choudhary A K, Rana K S and Sarkar A and Singh M. 2018. Bio-fortification potential of global wild annual lentil core collection. *PLoS One* **13** (1): e0191122.
- Kutman UB, Yildiz B, Oztruk L and Cakmal I. 2010. Biofortification of durum wheat with zinc through soil and foliar application of nitrogen. *Cereal Chemistry* **87**: 1-9.
- Lindsay W I and Norvell W A. 1978. Development of DTPA soil test for zinc, iron, manganese and copper. *Soil Science Society of America Journal* **42**: 421-48.
- Mandal B, Hazra G C and Mandal L N. 2000. Soil management

- influences on zinc desorption for rice and maize nutrition. *Soil Science Society of America Journal* **64**: 1699–705.
- Mishra B N and Prasad R. 2000. Integrated nutrient management for sustained production in a rice–wheat cropping system. *Acta Agronomica Hungarica* **48**: 257–62.
- Olsen S R, Cole C V, Watanabe F S and Dean L. 1954. Estimation of available phosphorus in soil by extraction with sodium carbonate. Circular 933, USDA, Washington.
- Paul J, Choudhary A K, Suri V K, Sharma A K, Kumar V and Shobhna. 2014. Bio-resource nutrient recycling and its relationship with bio-fertility indicators of soil health and nutrient dynamics in rice–wheat cropping system. *Communications in Soil Science and Plant Analysis* **45** (7): 912–24.
- Pooniya V and Shivay Y S. 2015. Influence of green manuring and Zn fertilization on quality parameters of *Basmati* rice. *Communications in Soil Science and Plant Analysis* **46**: 382–92.
- Pooniya V, Choudhary A K, Bana R S, Swarnalaxami K, Pankaj, Rana D S and Puniya M M. 2018. Influence of summer legume residue-recycling and varietal diversification on productivity, energetics and nutrient dynamics in basmati rice–wheat cropping system of western Indo-Gangetic Plains. *Journal of Plant Nutrition* **41** (12): 1491–1506.
- Pooniya V, Choudhary A K, Dass A, Bana R S, Rana K S, Rana D S, Tyagi V K and Puniya M M. 2015. Improved crop management practices for sustainable pulse production: An Indian perspective. *Indian Journal of Agricultural Sciences* **85** (6): 747–58.
- Pooniya V, Shivay Y S, Rana A, Nain L and Prasanna R. 2012. Enhancing soil nutrient dynamics and productivity of *Basmati* rice through residue incorporation and zinc fertilization. *European Journal of Agronomy* **41**: 28–37.
- Prasad R, Shivay Y S and Kumar D. 2014. Agronomic biofortification of cereal grains with iron and zinc. *Advances in Agronomy* **125**: 55–91.
- Rana K S, Choudhary A K, Sepat S, Bana R S and Dass A. 2014. *Methodological and Analytical Agronomy*, p 276. Post Graduate School, Indian Agricultural Research Institute, New Delhi, India.
- Shivay Y S, Prasad R and Rahal A. 2010. Genotypic variation for productivity, Zn utilization efficiencies, and kernel quality in aromatic rices under low available Zn conditions. *Journal of Plant Nutrition* **33**: 1835–48.
- Stein A J, Nestel P, Meenakshi J V, Qaim M, Sachdev H P S and Bhutta Z A. 2007. Plant breeding to control Zn deficiency in India: How cost-effective is biofortification? *Public Health Nutrition* **10**: 492–501.
- Subbiah B V and Asija G L. 1956. A rapid procedure for assessment of available-N in rice soils. *Current Science* **25**: 259–60.
- Walkley A J and Black I A. 1934. An examination of the Degtjareff method for determination of soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* **37**: 29–38.
- WHO. 2002. *The zinking feeling zinc in human nutrition health-letter*. World Health Report 2002, World Health Organization (WHO), Geneva.