



Evaluation of Wheat Cultivars for Zinc Efficiency and Bio-fortification

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

The present study was conducted to identify Zn efficient/inefficient wheat genotypes through application of Zn. A field experiment was conducted during 2009-10 and 2010-11 under AICRP on micro-secondary nutrients and pollutant element in soils and plants at Department of Soil Science and Agricultural Chemistry, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur. The sixteen varieties of wheat crop and three levels of Zn (0, 20 kg Zn ha⁻¹ as basal application and 20 kg Zn ha⁻¹ as soil application in combination of 0.5% foliar spray of ZnSO₄) were tested in a split plot design. The pooled data showed that variety GW-366 and GW-273 were found significantly superior to all other varieties for grain yield, uptake by grain and total Zn uptake. The Zn content in grain and straw of Sujata, C-306 and WH-147 were observed significantly superior to other wheat varieties. The Zn concentration in grain and straw and their Zn uptake successively and significantly increased with the application of 20 kg Zn ha⁻¹ and 20 kg Zn + 0.5% foliar spray of ZnSO₄. The most effective Zn fertilization could be via soil+foliar for enhancement of grain Zn concentrations of Zn-inefficient genotype GW-273.

Keywords: Uptake efficiency index; yield; zinc uptake; Zn- efficient and inefficient wheat genotypes.

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1. INTRODUCTION

In India, the intensification of agriculture to meet the increasing food demand of burgeoning population had accentuated soil hunger for Zinc. On an average about 44% soil of India are deficient in Zn [1]. Zinc deficiencies in field crops have been reported worldwide [2] and resulted decrease in growth and grain yield of wheat [3]. It is estimated that about 50% of soils used for cereal production in the world have low levels of plant-available Zn [4] particularly in soils with high pH, soil applied Zn will become less available for plant uptake due to soil fixation [5].

There are different approaches to alleviate Zn deficiency including application of fertilizers containing Zn [6] and the use of plant breeding techniques and genetic engineering [7]. Soil application of fertilizers seems to be a useful approach for increasing grain yield of cereals under Zn-deficient conditions [8]. Adding more fertilizer to maintain a sufficient level of available Zn will increase total Zn content in soil. Other options are available such as banding Zn in combination with acid-forming fertilizers (DAP) and the use of Zn chelates and/or complexes, which have relatively high availability in high-pH soils [9] but the ability to absorb sufficient Zn from soil is a concern, particularly in calcareous soils [10]. Thus, Zn deficiency is generally due to a shortage in the readily plant available Zn pool [10]. High costs of Zn fertilizers and relatively less efficiency may be sufficient justification for selection of efficient wheat genotypes that can grow well on soils with low amounts of available Zn [11]. Large differences in Zn efficiency (ZE) have been reported among wheat genotypes [2,3].

Plant nutrient efficiency defined as the ability of a genotype to produce a high yield under conditions in which a soil nutrient is growth limiting [12]. Micronutrient efficiency has been calculated as the ratio of yield (shoot dry matter or grain yield) produced under micronutrient deficiency (-M) to yield produced with micronutrient fertilization (+M) [12]. The nutrient efficiency index is used for the selection of micronutrient efficient genotypes in a breeding program or to provide information on qualities of commercial genotypes for growers. However, zinc efficiency (ZE) indicator failed to distinguish genotypes with high yield under stress and non-stress conditions from genotypes with low grain yield potential [2,3]. Stress tolerance index (STI), which can be used to identify genotypes that

produce high yields under both non-stress and stress environments [13]. According to the Soil Science Society of America (1997), nutrient efficiency is the ability of a plant to absorb, translocation, or utilize more of a specific nutrient than other plants under conditions of relatively low nutrient availability in the soil. Nutrient efficient genotype defined as a genotype that produces higher economic yield with a determined quantity of applied or absorbed nutrient than other genotypes under similar growing conditions [14]. The essentiality and importance of Zn in plant, animals and human has long been recognized. About 3 billion people in the world area affected by Zn and Fe deficiency [15].

In recent years, increased emphasis is being given to on Zn malnutrition due to consumption of agricultural produced from Zn deficient soils. There are three ways to address the Zn malnutrition, one dietary supplementation with Zn, second, improving the diet composition by including more pulses, fruits and animal protein and third, fortification/enrichment of cereal grains with Zn. The present study was conducted to identify Zn efficient/inefficient wheat genotypes through application of Zn.

2. MATERIALS AND METHODS

An experiment was conducted in *rabi* during 2009-10 and 2010-11 at Research Farm of College of Agriculture under AICRP on micro-secondary nutrients and pollutant element in soils and plants in Department of Soil Science & Agricultural Chemistry, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur. The soil of the experimental site was Typic Haplustert, clayey in texture, having pH 7.45, EC 0.15 dSm⁻¹, available nitrogen 230 kg ha⁻¹ as low, phosphorus 32.60 kg ha⁻¹ as high and potassium 270 kg ha⁻¹ as medium and DTPA extractable Zn 0.46 mgkg⁻¹ as low. The sixteen varieties of wheat (LOK-1, HD-2864, GW-273, GW-322, GW-3020, GW-366, MP-3173, DL-803-3, HD-2932, Sujata, JW-17, C-306, HW-2004, HI-1454, JW-3173, and WH-147) and three levels of Zn (0, 20 and 20 kg ha⁻¹ + 0.5% ZnSO₄ spray) were tested in main and sub plot, respectively in a split plot design with three replications. The varieties were sown in experiment on 05-12-2010 and 08-12-2011 at 22.5 cm apart during 2009-10 and 2010-11, respectively. The recommended dose of 120 kg ha⁻¹ N, 60 kg ha⁻¹ P₂O₅ and 40 kg ha⁻¹ K₂O were applied for rice crop. A basal dose of 60 kg ha⁻¹ N, 60 kg ha⁻¹ P₂O₅ and 40 kg ha⁻¹ K₂O were applied at the time of sowing. The

remaining 60 kg ha⁻¹ N was applied at crown root initiation stage (CRI) stage. The three irrigations were applied during both years. The spray of ZnSO₄ was performed at dough stage pre and after flowering. The crop was harvested at maturity and left for few days for sun drying. After drying, the crop was threshed and the grain and straw yield was recorded. The grain and straw samples were washed with 0.1 N HCl and then with double distilled water and dried in oven at 60-70°C for 6 hours. The concentration of zinc in grain and straw was analyzed with Atomic Absorption Spectrophotometer (AAS) as suggested by [16] after digestion of the sample in diacid mixture of nitric and perchloric acid (10:4 ratio). Zinc uptake was estimated by multiplying yield and concentration of Zn. Further, yield efficiency index and uptake efficiency index were determined using the standard formula [12].

Yield efficiency index = Total yield in control plots/Total yield in treated plots) X 100

Uptake efficiency index = (Total uptake in control plots/ Total uptake in treated plots) X 100

Yield efficiency index and uptake efficiency index values of each cultivar were plotted in scattered diagram to find out the efficient as well as inefficient varieties. The genotypes having high yield as well as uptake efficiency index were fall in quadrant A as depicted in scattered diagram and defined genetically efficient genotypes, while reverse of this fall in quadrant C and defined as genetically inefficient genotypes. Interestingly, the genetically inefficient genotypes were agronomically highly efficient. Thus, the efficient genotypes may be utilized by breeder for quantitative trait locus (QTL) identification and developing high yielding Zn enriched genotypes (genetic bio-fortification) while the inefficient genotypes may be used for agronomic bio-fortification to dense the grains of highly responsive genotypes to Zn.

3. RESULTS AND DISCUSSION

3.1 Grain and Straw Yield

The pooled data of grain yield varied from 3.70 t ha⁻¹ (C-306) to 6.01 t ha⁻¹ (GW-366) and straw yield from 5.96 t ha⁻¹ (HI -1454) to 8.13 t ha⁻¹ (GW-273). The wheat varieties LOK-1, HD -2864, GW-273, GW-322, GW -3020, GW-366, MP- 3173, DL 803-3, HD- 2932, JW 17, HI-1454, JW-3173 and WH-147 were found

significantly superior to C-306, Sujata and HW-2004. Similarly, the varieties LOK-1, GW 273, GW-322, GW-366 and HD-2932 produced significantly higher grain yield than that of DL-803-3. However, the variety GW-366 was found significantly superior to all the varieties except GW-322 and GW- 273, which showed parity for grain yield. The varieties LOK-1, HD 2864, GW-273, GW-3020, GW-366, HD-2932, JW-17 and C-306 produced significantly higher straw yield than HW-2004. However, GW- 273 was also found significantly superior to GW-322, DL 803-3 and Sujata but the varieties i.e. MP -3173, HI-1454, JW-3173 and WH-147 showed parity amongst themselves. The higher grain yield of high yielding varieties might be due to genetic potential.

The grain and straw yield of wheat varieties successively and significantly increased with the application of 20 and 20 kg Zn ha⁻¹ +0.5% Zn SO₄ spray. The increase of grain and straw yield with Zn application might be due to beneficial effect of Zn in increasing the Zn availability in soil, which increased the yield. The increase of wheat yield with Zn application was reported by [17-19].

3.2 Zn Content in Grain and Straw

Table 1 indicated the pooled data of Zn content in grain varied from 26.45 mgkg⁻¹ (GW-322) to 35.11 mgkg⁻¹ (Sujata) and in straw from 10.58 mgkg⁻¹ (HW-2004) to 14.27 mgkg⁻¹ (Sujata). All the wheat varieties showed significantly higher Zn content in grain than GW-322 (26.45 mgkg⁻¹) and HD-2932 (26.92 mgkg⁻¹) but the varieties LOK-1, HD-2864, GW-273, GW-3020, GW-366, DL 803-3 and JW-17 showed parity amongst themselves. The maximum Zn content in grain of 35.11 mgkg⁻¹ was observed in Sujata followed by 34.8 mg kg⁻¹ in C-306 and 33.76 mg kg⁻¹ in WH-147. Thus the varieties Sujata, C-306 and WH-147 were found significantly superior to all the remaining varieties but these varieties were found on par amongst themselves. The Zn content in straw was found significantly higher in varieties DL-803-3, GW-322, Sujata, JW-17, C-306, HI-1454, JW-3173, and WH-147 than HW-2004 but the varieties HD-2864, MP-3173 and HD-2932 were found on par. The lower Zn content in high yielding varieties (GW-322) than lower yielding varieties (Sujata) might be due to dilution effect. As the low yielder varieties require less number of irrigation while the higher yielding varieties are more responsive to higher irrigation. The Zn content in grain and straw successively and significantly increased with the application of

20 kg Zn ha⁻¹ and 20 kg Zn+0.5% spray of ZnSO₄. It might be due to beneficial effect of Zn in increasing the Zn availability in soil and resulted in higher Zn content in grain and straw of wheat. The significant increase of Zn content in grain and straw with Zn application was reported by [17-19].

3.3 Zn Uptake

The pooled data presented in Table 2 indicated that the Zn uptake by grain varied from 129.89 g ha⁻¹ (C-306) to 182.41 g ha⁻¹ (GW-366) and in straw 71.64 g ha⁻¹ (HI-1454) to 106.70 g ha⁻¹ (C-306) and total Zn uptake 203.83 g ha⁻¹ (HW-2004) to 272.11 g ha⁻¹ (GW-366). The varieties Lok-1, HD-2864, GW-273, GW-322, GW-3020, GW-366, MP-3173, DL- 803-3, HD-2932, JW-17, HI-1454, JW-3173 and WH-147 were found significantly superior to C- 306 and HW-2004 for Zn uptake by grain but the varieties Sujata, C-306 and HW-2004 were found on par.

However, the varieties LOK-1, HD-2864 and WH-147, GW-273, GW-366 were found significantly superior to GW-322, GW-3020, and JW -17 and HD-2932 for Zn uptake by grain. The Zn uptake by straw were found significantly higher with the varieties LOK-1, HD-2864, GW-273, GW-322, GW-3020, GW-366, DL 803-3, HD-2932, Sujata, JW-17 and C-306 than HI-1454 but the varieties MP- 3173, HW-2004, HI-1454, JW-3173 and WH-147 showed parity. However, the Zn uptake by straw by variety Sujata and C-306 were found significantly higher than the all these varieties except JW-17 but the difference between the two varieties was found non-significant. For the total Zn uptake by wheat all the varieties were found significantly superior to HW-2004 except HI-1454 but the varieties GW-3020, MP-3173, HD-2932 were found on par. However, the variety GW-273 and GW-366 were found significantly superior to other varieties for total Zn uptake by wheat.

The interaction effect of wheat genotypes and zinc levels was found significant for zinc uptake by wheat grain and total zinc uptake by wheat (Table 3). The Zn uptake by grain and total Zn uptake by all the wheat genotypes successively and significantly increased with the application of 20 kg Zn and 20 kg Zn +0.5% spray of ZnSO₄ except total Zn uptake by C-306 with 20 kg Zn +0.5% spray of ZnSO₄. The Zn uptake by grain by variety GW-366 was found significantly superior to HD-2864, MP-3173, DL-803-3, HD-

2932, Sujata, JW-17, C-306, WH-2004, HI-1454 and JW-3173 at 0, 20 kg Zn and 20 kg Zn +0.5% spray of ZnSO₄. The GW-366 was also found significantly superior to GW-322, GW-3020, WH 147 and LOK-1 with 20 kg Zn and 20 kg Zn +0.5% ZnSO₄ spray except variety WH-147 at 20 kg Zn +0.5% ZnSO₄ spray for Zn uptake by grain.

The total Zn uptake by variety GW-366 was found significantly higher than GW-3020, MP-3173, HD-2932, HW-2004, HI-1454 and JW-3173 at 20 kg Zn ha⁻¹. However, the GW-366 was also found significantly superior to all the varieties at 20 kg Zn +0.5% ZnSO₄ spray except GW-273 and WH-147. The significant increase of Zn uptake by wheat with Zn application was reported by [17-19].

3.4 Efficiencies of Wheat Genotypes

The genotypes were significantly different in Zn concentrations of grain and also responded to the external Zn application. The Zn concentrations of wheat grain ranged from 26.45 to 35.11 mg kg⁻¹. The mean Zn concentration in grain due to external Zn supply was from 21.72 in no Zn to 37.77 mgkg⁻¹ in high Zn treatments. The genotypes were also significantly different for variation in grain yield. External Zn supply significantly increased mean grain yield from 4600 kg ha⁻¹ in control to 5220 kg ha⁻¹ in high Zn application.

The wheat genotypes were screened based on yield and uptake indices to identify the Zn efficient and Zn-inefficient groups. Among the genotypes studied, GW-3020 and C-306 were grouped under Zn most efficient genotypes; whereas, HW-2004 and GW- 273, MP-3173, JW-3173 were considered as Zn least efficient genotypes.

Zn enrichment study in wheat revealed that foliar feeding of Zn along with soil application has resulted significant increase up to 73.90% in Zn concentration in wheat grains. Whereas, little effect in increasing the grain yield of efficient variety of wheat as compared to inefficient varieties. Among the efficient cultivar, the maximum increase (15%) in yield was recorded. The maximum yield enhancement in inefficient cultivar of wheat was registered (23%). The degree of increase in yield varied with type of genotypes and soil are also influenced the extent of increase of Zn in grains.

Table 1. Variation in grain yield and Zn content of wheat due to different genotypes and Zn levels (pooled data of 2009-10 and 2010-11)

Wheat genotype	Grain yield (t ha ⁻¹)			Straw yield(t ha ⁻¹)			Zn content in grain (mgkg ⁻¹)			Zn content in straw (mgkg ⁻¹)		
	2010	2011	pooled	2010	2011	pooled	2010	2011	pooled	2010	2011	pooled
LOK-1	4.87	5.93	5.40	6.79	8.31	7.55	32.99	25.28	29.14	12.16	11.00	11.58
HD-2864	4.88	5.82	5.35	6.80	8.46	7.63	32.45	26.30	29.38	9.84	11.97	10.91
GW-273	5.34	6.43	5.88	7.45	8.81	8.13	29.48	29.83	29.66	11.81	11.00	11.41
GW-322	4.75	6.44	5.59	6.67	8.11	7.39	31.06	21.85	26.45	13.13	10.75	11.94
GW-3020	4.44	5.72	5.08	6.24	8.77	7.50	33.67	24.18	28.93	10.73	12.05	11.39
GW-366	5.54	6.48	6.01	7.73	8.04	7.89	32.15	27.96	30.05	11.60	10.67	11.13
MP-3173	4.41	5.08	4.74	6.14	7.07	6.60	34.48	27.58	31.03	11.61	10.13	10.87
DL-803-3	4.59	5.55	5.07	6.47	7.55	7.01	32.49	26.21	29.35	11.27	12.38	11.82
HD-2932	4.92	5.95	5.44	6.89	8.62	7.76	31.41	22.43	26.92	10.08	12.14	11.11
Sujata	3.71	4.00	3.85	6.19	8.46	7.33	39.88	30.34	35.11	13.26	15.28	14.27
JW-17	4.74	5.04	4.89	6.62	8.41	7.51	33.24	25.42	29.33	10.75	14.56	12.66
C-306	3.63	3.76	3.70	6.20	8.97	7.58	40.12	29.48	34.80	13.72	14.09	13.90
HW-2004	4.54	3.56	4.05	6.39	7.12	6.76	33.56	28.83	31.19	10.82	10.34	10.58
HI-1454	3.93	5.62	4.78	5.57	6.34	5.96	35.03	27.07	31.05	12.87	10.93	11.90
JW-3173	4.50	5.15	4.82	6.33	5.96	6.15	34.50	25.49	29.99	12.27	14.14	13.20
WH-147	4.79	4.89	4.84	6.53	5.67	6.10	37.16	30.35	33.76	11.75	13.00	12.37
Comparisons of two genotypes SEM±	0.143	0.173	0.112	0.199	0.437	0.240	0.759	0.962	0.613	0.583	0.458	0.371
CD P=0.05	0.41	0.49	0.31	0.57	1.20	0.66	2.19	2.77	1.69	1.68	1.32	1.02
Zn levels (kg ha⁻¹)												
0	4.30	4.90	4.60	6.18	6.80	6.49	24.28	19.16	21.72	9.51	8.09	8.80
20	4.74	5.42	5.08	6.76	7.77	7.27	35.22	28.10	31.66	11.89	12.64	12.27
20 + 0.5%ZnSO ₄ Spray	4.75	5.70	5.22	6.75	8.81	7.78	42.44	33.10	37.77	13.79	15.72	14.76
Comparisons of two Zn levels SEM±	0.056	0.143	0.05	0.078	0.088	0.094	0.350	0.417	0.334	0.240	0.165	0.186
CD P=0.05	0.15	0.40	0.13	0.22	0.24	0.26	0.99	1.17	0.92	0.68	0.46	0.51
Comparisons of two Zn levels at the same genotypes SEM±	0.224	0.171	0.197	0.313	0.254	0.375	1.401	1.668	1.337	0.962	0.662	0.745
CD P=0.05	NS	NS	NS	NS	NS	NS	3.96	4.71	NS	NS	1.87	NS
Comparisons of two genotypes at the same or different levels of Zn SEM±	0.272	0.410	0.196	0.380	1.070	0.389	1.569	2.886	1.970	1.139	1.265	0.713
CD P=0.05	NS	NS	NS	NS	NS	NS	4.43	8.16	NS	NS	3.57	NS

CD-Critical difference, SEM± Standard Error of Mean, NS-Non significant

Table 2. Variation in Zn uptake by wheat due to different genotypes and zinc levels (pooled data of 2009-10 and 2010-11)

Wheat genotype	Zn uptake by grain (g ha ⁻¹)			Zn uptake by straw (g ha ⁻¹)			Total Zn uptake(g ha ⁻¹)		
	2010	2011	pooled	2010	2011	pooled	2010	2011	pooled
LOK-1	161.83	151.55	156.69	83.00	92.70	87.85	244.83	244.25	244.54
HD-2864	159.07	155.92	157.49	67.31	103.28	85.30	226.38	259.20	242.79
GW-273	160.36	193.62	176.99	89.24	98.24	93.74	249.60	291.85	270.73
GW-322	148.04	142.26	145.15	88.07	91.41	89.74	236.11	233.68	234.89
GW-3020	151.39	138.39	144.89	67.17	107.76	87.47	218.55	246.15	232.35
GW-366	180.74	184.08	182.41	89.98	89.41	89.70	270.72	273.49	272.11
MP-3173	154.43	141.93	148.18	72.10	73.89	73.00	226.54	215.82	221.18
DL-803-3	150.28	149.00	149.64	72.63	96.67	84.65	222.91	245.67	234.29
HD-2932	151.69	136.93	144.31	68.70	104.69	86.69	220.39	241.62	231.01
Sujata	148.73	122.25	135.49	82.32	130.71	106.51	231.05	252.96	242.00
JW-17	159.14	128.79	143.97	71.35	126.80	99.08	230.49	255.60	243.04
C-306	147.23	112.55	129.89	85.10	128.29	106.70	232.32	240.85	236.59
HW-2004	155.71	104.87	130.29	70.00	77.09	73.54	225.71	181.95	203.83
HI-1454	138.91	154.50	146.71	71.95	71.33	71.64	210.87	225.82	218.35
JW-3173	157.32	132.30	144.81	78.24	87.31	82.77	235.56	219.62	227.59
WH-147	179.79	150.28	165.03	77.45	76.04	76.74	257.24	226.32	241.78
Comparisons of two genotypes SEm±	5.714	7.720	3.65	4.709	7.182	4.314	8.535	12.281	5.3
CD P=0.05	16.48	22.26	10.33	13.58	20.71	12.20	24.62	35.42	14.98
Zn levels(kg ha⁻¹)									
0	104.03	93.00	98.52	58.36	54.86	56.61	162.39	147.87	155.13
20	165.07	151.20	158.13	79.97	98.60	89.28	245.04	249.79	247.42
20+ 0.5% ZnSO ₄ Spray	200.53	186.91	193.72	93.16	138.22	115.69	293.68	325.13	309.41
Comparisons of two Zn levels SEm±	2.633	2.373	1.838	1.811	1.929	2.075	3.648	3.013	2.90
CD P=0.05	7.44	6.72	5.14	5.12	5.45	5.81	10.31	8.52	8.12
Comparisons of two Zn levels at the same genotypes SEm±	10.534	9.494	7.356	7.242	7.715	8.304	14.591	12.050	11.604
CD P=0.05	NS	26.84	20.38	NS	21.81	NS	NS	34.07	32.49
Comparisons of two genotypes at the same or different levels of Zn SEm±	11.801	13.389	7.923	8.906	11.951	9.121	16.960	19.961	12.081
CD P=0.05	NS	37.86	22.18	NS	33.79	NS	NS	56.45	33.82

CD-Critical difference, SEm± Standard Error of Mean, NS-Non significant

Table 3. Interaction effects of wheat genotypes and zinc levels on zinc uptake (pooled data of 2009-10 and 2010-11)

Wheat genotype	Zn uptake by grain (g ha ⁻¹)			Total Zn uptake(g ha ⁻¹)			Uptake efficiency
	Zn levels(kg ha ⁻¹)			Zn levels(kg ha ⁻¹)			
	0	20	20+0.5%ZnSO ₄ Spray	0	20	20+0.5%ZnSO ₄ Spray	
LOK-1	100.83	169.50	199.83	163.50	260.17	309.83	52.77
HD-2864	99.17	167.17	206.17	147.33	257.5	323.50	45.54
GW-273	111.83	197.00	222.17	172.00	297.67	342.50	50.22
GW-322	101.00	151.50	182.83	153.5	244.33	306.83	50.03
GW-3020	112.33	150.83	171.50	170.33	238.00	288.67	59.01
GW-366	123.00	190.00	234.33	180.83	275.5	360.00	50.23
MP-3173	95.83	160.17	188.5	143.17	232.83	287.33	49.83
DL-803-3	84.83	156.17	207.83	141.17	242.83	319.00	44.25
HD-2932	100.67	142.33	190.00	161.17	237.33	294.33	54.76
Sujata	92.50	149.33	164.67	163.67	260.17	302.17	54.42
JW-17	99.00	146.83	186.00	160.67	244.17	324.33	49.54
C-306	80.00	148.50	161.00	159.33	262.50	288.00	55.32
HW-2004	73.67	139.50	177.67	120.33	210.33	280.67	42.87
HI-1454	97.67	143.33	199.17	145.80	214.00	295.33	49.37
JW-3173	100.33	152.17	182.00	151.50	238.67	292.50	51.79
WH-147	103.83	165.50	225.67	147.33	242.67	335.33	43.94
Comparisons of two Zn levels at the same genotypes SEM±	7.356			11.604			
CD <i>P</i> =0.05	20.39			32.49			
Comparisons of two genotypes at the same or different levels of Zn SEM±	7.923			12.081			
CD at <i>P</i> =0.05	22.18			33.82			

CD-Critical difference, SEM± Standard Error of Mean, NS-Non significant

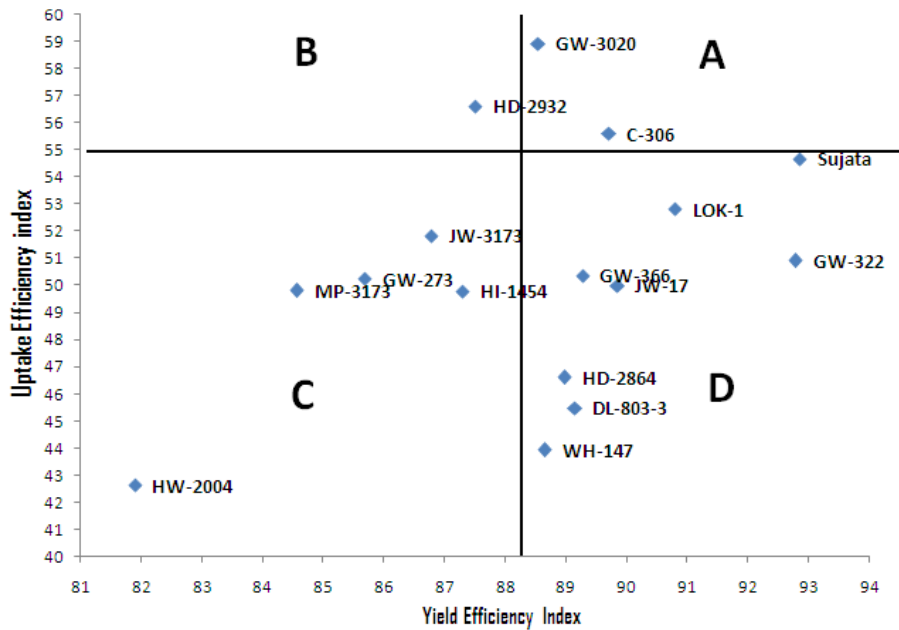


Fig. 1. Effect of 20 kg Zn ha⁻¹ + 0.5% spray of ZnSO₄ application on uptake and yield efficiency index

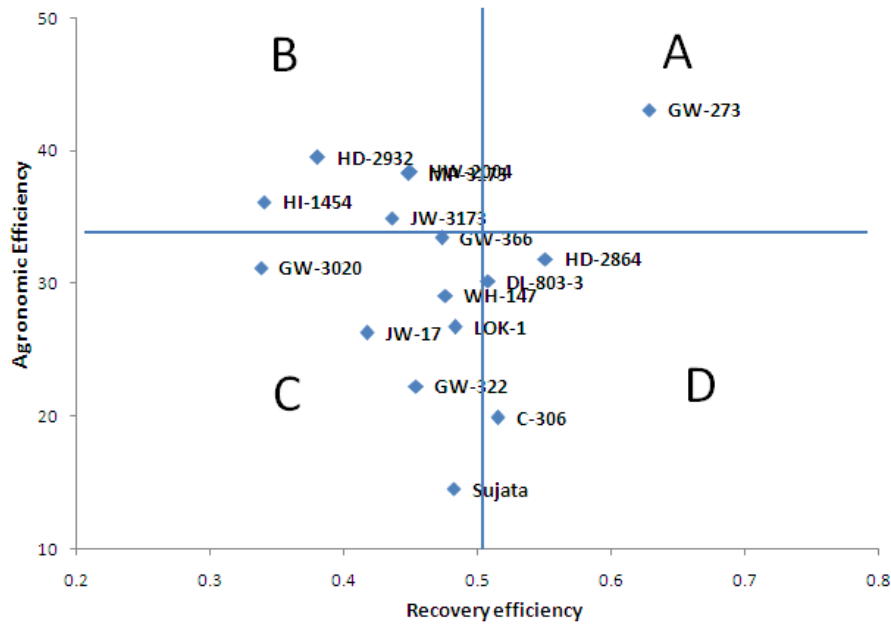


Fig. 2. Effect of 20 kg Zn + 0.5% spray of ZnSO₄ application on agronomic and recovery efficiency of genotypes

Yield efficiency index and Uptake efficiency index values of each cultivar were plotted in scattered diagram depicted Fig. 1 above to find out the efficient as well as inefficient varieties under 20 kg Zn SO₄ treatment in combination with foliar spray. The genotypes having high yield as well as uptake efficiency index were fall in quadrant A

as depicted in scattered diagram and defined genetically efficient genotypes, while reverse of this fall in quadrant C and defined as genetically-inefficient genotypes. Interestingly, the genetically inefficient genotypes were agronomically highly efficient Fig. 2 above. Thus, the efficient genotypes may be utilized by

breeder for QTL identification and developing high yielding Zn enriched genotypes (genetic biofortification) while the inefficient genotypes may be used for agronomic biofortification to dense the grains of highly responsive genotypes with Zn. Categorization of wheat genotypes under Zn-efficient and Zn inefficient groups using Zn efficiency index- yield base and Zn efficiency index uptake base.

4. CONCLUSION

Results concluded that the variety GW-366 and GW-273 were found significantly superior to all other varieties for grain yield, uptake by grain and total Zn uptake. The most effective Zn fertilization could be via soil+foliar for enhancement of grain Zn concentrations of Zn-inefficient genotype GW-273 and foliar spray can enhance Zn density in edible plant parts, which can lead to better human health.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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