Evaluation of Bio-fortified Wheat Genotypes for Grain Yield, Zinc and Iron Content

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Abstract

A field experiment was conducted at Bhairahawa, Rupandehi, Nepal during November to April, 2015/2016 with the objective of identifying high yielding, zinc and iron rich bio-fortified spring wheat genotypes. A total of 27 wheat genotypes selected from 5th Harvest Plus Yield Trial (HPYT), were evaluated along with three check genotypes (Tilottama, BAJ#1 and KACHU#1) using Alpha Lattice design with three replications. Analysis of variance showed significant ($P \leq 0.05$) differences among the genotypes for days to maturity, plant height, spike length, number of grains/spike, 1000-kernels weight, grain yield and grain zinc and iron content. The wheat genotype namely Neloki/3/ IWA8600211//2*PBW343*2/Kukuna produced the highest grain yield (3.953 kg/ha) followed by Francolin#1/3/ Croc_1/*Ae. squarrosa* (210)//2*PBW343*2/Kukuna (3.870 kg/ha) and C80.1/3*Batavia//2*WBLL1/3/Attila/3*BCN*2//Bav92/4/WBLL1*2/Kuruku/5/IWA8600211//2*PBW343*2/Kukuna (3.839 kg/ha). The grain Fe content ranged from 35.33 to 49.03 ppm whereas grain Zn ranged from 22.76 to 34.03 ppm among the evaluated genotypes. The highest grain Zn content was found in Croc_1/Ae.squarrosa(210)//Inqalab91*2/Kukuna/3/PBW343*2/Kukuna (34.03 ppm), whereas the highest grain Fe content was recorded in TRCH/Srtu//Kachu/5/Toba97/Pastor/3/T.dicocconPI94624/Ae.squarrosa(409)// BCN/4/BL1496/Milan//PI610750 (49.03 ppm). Based on the high grain yield and the grain Zn and Fe content, the wheat genotype namely Neloki/3/ IWA8600211//2*PBW343*2/Kukuna was identified a promising genotype and can be further evaluated and promoted as a candidate variety. A positive correlation ($r=0.237$) was observed between grain Fe and Zn content. The studied wheat genotypes could be valuable resources for the development of Zn and Fe enriched wheat varieties to address the malnutrition problem in Nepal.

Keywords: Bio-fortified wheat, Grain yield, Iron content, Zinc content.

Introduction:

Wheat (*Triticum aestivum* L.) is the third important cereal crop of Nepal after rice and maize both in area and production. At present, wheat-sown area is about 735,850 ha, with a total production of 1,879,191 million ton (MOALD, 2017; Pandey *et al.*, 2019). It is a major winter cereal crop in Nepal and more than 80% of wheat is grown in rice-wheat cropping pattern. It is nutritious, easy to store and transport and can be processed into various types of food (Kandel *et al*., 2018). It is the third most important staple crop after rice and maize and shares about 27% of the total cereal production in Nepal. Wheat grain contains about 75-78% carbohydrate, 12-14% protein, and up to 2% fat and minerals. It is a good source of vitamins B and E. Wheat grain contains zinc (Zn) and iron (Fe) at the range of 20-115 and 23-88 (ppm), respectively (Velu *et al*., 2015).

Micronutrient malnutrition has been widely recognized as a major health problem affecting almost three billion people worldwide, especially in countries with a high consumption of cereals. Nearly 17% of the world's population suffers from micronutrient deficiency mainly due to inadequate Zn intake and annually more than 100,000 deaths of children below five attributed to Zn deficiency (Black *et al*., 2013). Similarly, it is estimated that approximately 25% of the global population suffers from anemia and the Fe deficiency anemia is responsible for the loss of about 46,000 disability adjusted life years around the world (Murray and Lopez, 2013). The most effective and economic approach for reducing micronutrient deficiency such as Zn and Fe at mass level worldwide is by genetic bio-fortification of food crops through breeding efforts (Garg *et al*., 2018). Plant breeding methods have been successfully applied to enhance micronutrients content of food crops and are the powerful dietary enhancement tools to address the malnourishment issues of most vulnerable people, i.e., resource poor woman, infants, and children (Pfeiffer and McClafferty, 2007). Correlation analysis helps to identify effective traits in order to make indirect selection for selecting superior genotypes.

The mainstream wheat breeding programs in Nepal are mainly focused on increasing grain yield and little attention is paid on nutritional quality of wheat. It is assumed that Nepalese wheat varieties are not rich in Zn and Fe concentrations. In recent times, International Maize and Wheat Improvement Center (CIMMYT) has emphasized on the development of micronutrients enriched wheat variety in South Asia including Nepal, through the Harvest Plus project. This study was carried out to evaluate the performance of CIMMYT developed Zn and Fe bio-fortified advanced wheat lines/genotypes under Nepalese production environment.

Materials and Methods:

Plant materials:

A total of 30 spring wheat genotypes were evaluated in this study. Among them, 27 were advanced lines selected from 5th Harvest Plus Yield Trial (HPYT) set obtained from CIMMYT, evaluated in the previous years at Agriculture Botany Division, Nepal Agricultural Research Council (NARC), Khumaltar. One local check- Nepalese variety Tilottama and two CIMMYT checks, BAJ#1 and KACHU#1 were included (Table 1).

Table 1. The list of entries and their pedigree information included in the study

S.N.	**Genotypes**	Pedigree/cross
1	**Tilottama**	NL 1073 (local check)
2	**Baj#1**	Baj#1 (CIMMYT check)
3	**Kachu#1**	Kachu #1 (CIMMYT check)
4	**HPYT404**	Croc_1/Ae.squarrosa(210)//Inqalab91*2/Kukuna/3/PBW343*2/Kukuna
5	**HPYT407**	Pauraq/Solala//Pauraque #1
6	**HPYT405**	T.dicocconCI9309/Ae.squarrosa(409)//Mutus/3/2*Mutus
7	**HPYT410**	TRCH/Srtu//Kachu/8/REH/Hare//2*BCN/3/Croc_1/Ae.squarrosa(213)//PGO/4/Huites/5/T.dicocconPI94624/Ae.squarrosa(409)//BCN/6/REH/Hare//2*BCN/3/Croc_1/Ae.squarrosa(213)//PGO/4/Huites/7/Mutus
8	**HPYT412**	Kachu/3/IWA8600211//2*PBW343*2/Kukuna
9	**HPYT413**	Francolin#1/7/REH/Hare//2*BCN/3/Croc_1/Ae.squarrosa(213)//PGO/4/Huites/5/T.speltaPI348599/6/REH/Hare//2*BCN/3/Croc_1/Ae.squarrosa (213)//PGO/4/Huites
10	**HPYT414**	Francolin#1/7/REH/Hare//2*BCN/3/Croc_1/Ae.squarrosa(213)//PGO/4/Huites/5/T.speltaPI348599/6/REH/Hare//2*BCN/3/Croc_1/Ae.squarrosa (213)//PGO/4/Huites
11	**HPYT415**	Francolin#1/3/Croc_1/Ae.squarrosa(210)//2*PBW343*2/Kukuna
12	**HPYT419**	SUP152/3/IWA 8600211//2*PBW343*2/Kukuna
13	**HPYT420**	Neloki/3/IWA 8600211//2*PBW343*2/Kukuna
14	**HPYT422**	Melon//Filin/Milan/3/Filin/8/NAC/TH.AC//3*PVN/3/Mirlo/BUC/4/2*Pastor/5/T.speltaPI348774/6/Baceu#1/7/WBLL1*2/4/Yaco/PBW65/3/Kauz*2/Trap//Kauz
15	**HPYT423**	Melon//Filin/Milan/3/Filin/5/Croc_1/Ae.squarrosa(444)/3/T.dicocconPI94625/Ae.squarrosa(372)//3*Pastor/4/T.dicocconPI94625/Ae. squarrosa(372)//3*Pastor
16	**HPYT424**	Melon//Filin/Milan/3/Filin/5/Croc_1/Ae.squarrosa(444)/3/T.dicocconPI94625/Ae.squarrosa(372)//3*Pastor/4/T.dicocconPI94625/Ae.squarrosa(372)//3*Pastor
17	**HPYT426**	NG8201/Kauz/4/Sha7//PRL/Vee#6/3/Fasan/5/Milan/Kauz/6/Achyut/7/PBW343*2/Kukuna/8/IWA8600211//2*PBW343*2/Kukuna
18	**HPYT429**	Inqalab91*2/Tukuru//wheat/3/IWA8600211//2*PBW343*2/Kukuna
19	**HPYT432**	THB/Kea//PF85487/3/Ducula/4/WBLL1*2/Tukuru/5/IWA8600211//2*PBW343*2/Kukuna
20	**HPYT435**	C80.1/3*Batavia//2*WBLL1/3/Attila/3*BCN*2//Bav92/4/WBLL1*2/Kuruku/5/IWA8600211//2*PBW343*2/Kukuna
21	**HPYT437**	WBLL1/Kukuna//Tacupetof2001/3/Baj#1/4/IWA8600211//2*PBW343*2/Kukuna
22	**HPYT438**	Trap#1/Bow/3/Vee/PJN//2*Tui/4/Bav92/Rayon/5/Kachu#1/6/Toba97/Pastor/3/T.dicocconPI94624/Ae.squarrosa(409)//BCN/4/BL1496/Milan//PI610750
23	**HPYT439**	Trap#1/Bow/3/Vee/PJN//2*Tui/4/Bav92/Rayon/5/Kachu#1/6/Toba97/Pastor/3/T.dicocconPI94624/Ae.squarrosa(409)//BCN/4/BL1496/Milan//PI610750
24	**HPYT440**	Rolf07*2/Kiritati/3/IWA8600211//2*PBW343*2/Kukuna
25	**HPYT441**	Fret2*2/4/SNI/Trap#1/3/Kauz*2/Trap//Kauz*2/5/Tukuru/6/IWA8600211//2*PBW343*2/Kukuna
26	**HPYT442**	TRCH/Srtu//Kachu/8/REH/Hare//2*BCN/3/Croc_1/Ae.squarrosa(213)//PGO/4/Huites/5/T.dicocconPI94624/Ae.squarrosa(409)//BCN/6/REH/Hare//2*BCN/3/Croc_1/Ae.squarrosa(213)//PGO/4/Huites/7/Muts
27	**HPYT443**	TRCH/Srtu//Kachu/3/IWA8600211//2*PBW343*2/Kukuna
28	**HPYT448**	TRCH/Srtu//Kachu/5/Toba97/Pastor/3/T.dicocconPI94624/Ae.squarrosa(409)//BCN/4/BL1496/Milan//PI610750
29	**HPYT449**	Picaflor#1/8/REH/Hare//2*BCN/3/Croc_1/Ae.squarrosa(213)//PGO/4/Huites/5/T.dicocconPI94624/Ae.squarrosa(409)//BCN/6/REH/Hare//2*BCN/3/Croc_1/Ae.squarrosa(213)//PGO/4/Huites/7/Mutus
30	**HPYT450**	Picaflor#1/8/REH/Hare//2*BCN/3/Croc_1/Ae.squarrosa(213)//PGO/4/Huites/5/T.dicocconPI94624/Ae.squarrosa(409)//BCN/6/REH/Hare//2*BCN/3/Croc_1/Ae.squarrosa (213)//PGO/4/Huites/7/Mutus

Field Experiment:

The field experiment was conducted at National Wheat Research Program (NWRP), Bhairahawa (27^{o}32' N, 83^{o}25 E', 104m msl), Nepal. Chemical and physical properties of the soils of field experiment were analyzed at the Soil Science Division, NARC, Khumaltar (Table 2). The experiment was conducted using Alpha lattice design with three replications. The experiment unit plot consisted of 8 rows of 3 m length (6 m^2) with a row spacing of 25 cm and continuous plant spacing within rows. Seeding was done on 29th November, 2015 with seed rate of 120 kg/ha. Fertilizer was applied at the rate of 120:60:40 (kg/ha) $N:P_2O_5:K_2O$; half of N (60 kg) and full doses of P_2O_5 and K_2O were applied at sowing and remaining half of the N applied at two splits, i.e., 25 and 50 days after the sowing.

Table 2. Physical-chemical properties of soil of the field experiment

Depth (cm)	Block 1		Block 2		Block 3		Rating
	0-30	30-60	0-30	30-60	0-30	30-60	
pH	7.31	7.43	7.42	7.51	7.45	7.39	**Slightly alkaline**
OM (%)	2.1	1.5	1.4	1.01	1.6	1.1	**Low**
N (%)	0.09	0.06	0.08	0.05	0.08	0.06	**Low**
P_2O_5 (kg/ha)	30	25	40	21	43	32	**Medium**
K_2O (kg/ha)	170	151	184	163	195	184	**Medium**
Fe (ppm)	45	52	60	58	53	41	**High**
Zn (ppm)	1.3	1.1	1.7	1.4	1.8	1.2	**Medium**

Data recording

Observations were recorded for agronomic traits and grain yield. Plant height (cm), spike length (cm), grains/spike and 1000-kernel weight (g) were recorded from 10 random plants, whereas days to maturity and grain yield (kg/ha) were recorded on plot basis. The grain yield was adjusted in 12% moisture. Hectoliter weight (test weight) was determined by measuring the weight of unit volume (1 liter) wheat sample and converted to kg/hectoliter.

Grain analysis

Grain sample (20 g) of each genotype was sent to Wheat Quality Lab, Banaras Hindu University, Varanasi, India for micronutrient analysis. The samples were analyzed with a bench-top, non-destructive, energy-dispersive X-ray fluorescence spectrometry (EDXRF) instrument (Model X-supreme800, Oxford Instruments plc, Abingdon, UK) that was standardized for high-throughput screening of grain Zn and grain Fe concentrations (unit: mg/kg) in wheat grain (Paltridge *et al*., 2012).

Statistical analysis

Data entry and processing was carried out using Microsoft Office Excel 2016. Analysis of variance (ANOVA) and mean estimations were done with R 3.6.1. Correlation analysis was done with SPSS Statistics V26. Correlation coefficient was calculated as followed by Ojha et al. (2018) and Adhikari et al. (2018). The treatment means were compared by the Least Significant Difference (LSD) test at 5% level (Gomez and Gomez, 1984; Devkota *et al*., 2019; Shrestha, 2019; Kandel and Shrestha, 2019).

Results and Discussion:

The analysis of variance showed highly significant differences among the genotypes and checks for all the studied traits (Table 3). Days to maturity ranged from 109 to 123 days. Genotype Croc_1/*Ae.squarrosa*(210)…*2/Kukuna was the earliest (109 days), which was 5 to 14 days earlier than the checks. Similar maturity range was reported by Joshi et al. (2010) on Zn and Fe fortified wheat evaluated in the eastern Gangetic plains of India. Early maturity is a desirable trait in heat stressed areas, e.g., south Asia where shorter crop cycle can escape terminal heat stress. The plant height ranged from

86 to 101 cm; WBLL1/…*2/Kukuna was shortest among all and this genotype can be of interest to the breeding programs targeted for high input production environment where lodging is a prominent problem. Spike length ranged from 9 to13 cm and number of grains/spike ranged from 28 to 47. The grains/spike range observed in this study was comparable to the result obtained by Kumar (2014). Thousand kernels weight (TKW) ranged from 31.6 to 43.4 g. A similar range of TKW of the Zn and Fe bio-fortified spring wheat genotypes was reported by Velu *et al.*, (2012). The TKW of the local check Tilottama (36.6 g) and CIMMYT check Baj#1 (36.1 g) did not differ significantly. On the other hand, the TKW of another CIMMYT check Kuchu#1 (43.4 g) was highest of all, and significantly higher than the other two checks.

Grain yield ranged from 2.030 to 3.953 kg/ha, which was higher than the grain yield obtained by Joshi *et al*., (2010), however, lower than the yield reported by Velu et al. (2012) and Mishra et al. (2015). The grain yield of check varieties Baj#1, Tilottama and Kachu#1 were 3.795; 3.702 and 2.030 kg/ha, respectively. The highest grain yield was recorded for genotype Neloki/3/IWA…*2/Kukuna (3953 kg/ha). This genotype had a yield advantage of about 4% to 95%, relative to the highest (Baj#1) and lowest (Kachu#1) performing checks, respectively. The grain yields of the 17 highest yielding genotypes from HPYT were at par with the local check, a recently released Nepalese variety, Tilottama (3.703 t/ha). The yields of these genotypes were 1.4% to 16.7% higher than the overall mean of the 30 studied genotypes and checks (i.e., 3.387 kg/ha). The higher grain yield of Zn and Fe enriched genotypes as compared to the recently released Nepalese standard variety 'Tilottama' indicated that there is a possibility to enhance grain Zn and Fe concentrations of wheat without compromising the grain yield. The work of Velu *et al*., (2012) also indicated such possibility. The test weight (hectoliter weight) of the evaluated genotypes ranged from 74.6 to 81.5 (kg/hectoliter). Highest test weight was recorded for C80.1/3*Batavia//…/ Kukuna (81.47 kg/hL) followed by Kachu/3/IWA8600211/.../Kukuna (80.21 kg/hL). The hectoliter weight range reported here was slightly lower than that reported by Guzman *et al*., (2014) indicating the presence of plump grains.

Grain Zn concentration varied from 22.76 to 34.03 ppm with the highest Zn concentration observed in Croc_1/*Ae.squarrosa* (210)//…*2/Kukuna. In this study, six genotypes had Zn concentration more than 30 ppm. The grain Zn concentration range reported here was narrower than the previous reports of 15-51 ppm (Velu *et al*., 2011a) and 17-61 ppm (Velu *et al*., 2011b). The average grain Zn concentration of wheat in various countries has been reported between 20 and 35 ppm (Cakmak *et al*., 2004). The soil Zn concentration in the experiment plots ranged from 1.3 to 1.8 ppm (0-30 cm depth) and 1.1 to 1.4 ppm (30-60 cm depth) indicating a medium level of soil Zn content (Table 2). Large variation in soil Zn content can confound the genetic differences among genotypes thereby preventing the identification of lines with genetically superior concentrations of grain Zn (Velu *et al*., 2012). Grain Fe concentration ranged from 35.33 to 49.03 ppm; highest Fe was found in TRCH/Srtu//…PI610750 followed by Pauraq/Solala//Pauraque#1 (46.96 ppm). In total 17 genotypes had Fe concentration more than 40 ppm. Similar ranges of grain Fe concentrations were reported in previous studies (Velu *et al*., 2011a; Velu *et al*., 2011b; Velu *et al*., 2012). It is imperative to mention that the high soil Fe content of the experiment plots in this study might have contributed to higher grain Fe concentrations, in contrary to the grain Zn concentrations, for which the soil was medium and the grain Zn concentration range was lower than that reported by Velu *et al*., (2011a) and Velu *et al*., (2011b).

Table 3. Agronomic performance, grain yield, Zn and Fe concentrations of studied wheat genotypes at Bhairahawa

Entry (5th HPYT)	DM (d)	PHT (cm)	SPL (cm)	GPS (n)	Grain yield (kg)	TKW (g)	Zinc (ppm)	Iron (ppm)	Kg/Hectolitre
BAJ#1	114^{gh}	92.76^{e-j}	9.16^{m}	37^{b-h}	3795.99^{ab}	36.10^{h-l}	22.76^{f}	35.33^{o}	76.04^{l-o}
HPYT404	109^{i}	89.53^{j-m}	9.50^{lm}	37^{c-h}	3005.75^{e-g}	38.10^{e-i}	34.03^{a}	44.23^{bc}	74.64^{o}
HPYT405	115^{fg}	101.13^{a}	11.20^{b-d}	40^{b-f}	3619.31^{a-d}	39.26^{c-f}	23.30^{f}	42.00^{c-i}	77.80^{e-j}
HPYT407	115^{e-g}	90.33^{i-l}	10.76^{d-h}	44^{ab}	3354.42^{b-f}	37.70^{f-j}	28.96^{b-e}	46.23^{ab}	78.140^{c-i}
HPYT410	117^{cd}	95.43^{b-e}	10.60^{d-i}	41^{a-f}	3402.41^{b-f}	41.16^{a-d}	29.83^{a-e}	39.70^{g-n}	79.00^{b-f}
HPYT412	119^{b}	91.33^{f-l}	11.63^{bc}	44^{a-c}	3463.02^{a-f}	37.80^{f-j}	26.93^{d-f}	36.50^{m-o}	80.21^{ab}
HPYT413	116^{d-f}	90.83^{h-l}	10.26^{f-k}	39^{b-g}	3642.90^{a-d}	31.63^{op}	28.30^{c-e}	36.76^{l-o}	76.71^{i-n}
HPYT414	116^{d-f}	91.30f^{-l}	10.06^{h-l}	37^{c-h}	3596.51^{a-d}	35.76^{i-l}	25.46^{ef}	39.53^{h-n}	77.60^{f-k}
HPYT415	116^{d-f}	90.30^{i-l}	10.00^{i-l}	38^{b-g}	3870.06^{ab}	30.98^{p}	28.20^{c-e}	36.26^{no}	75.26^{no}
HPYT419	114^{gh}	91.13^{g-l}	9.80^{jklm}	38^{b-h}	3203.70^{c-g}	33.93^{l-o}	28.80^{c-e}	39.10^{i-n}	76.13^{k-o}
HPYT420	121^{a}	91.10^{g-l}	11.06^{c-e}	42^{ac}	3953.45^{a}	32.94^{m-p}	28.56^{c-e}	39.76^{g-m}	77.53^{f-l}
HPYT422	119^{b}	93.60^{d-i}	10.83^{d-g}	32^{g-i}	2747.74^{g}	39.61^{c-f}	30.30^{a-d}	37.10^{j-o}	76.57^{j-n}
HPYT423	116^{d-f}	91.73^{e-k}	9.76^{k-m}	37^{c-h}	3785.24^{ab}	40.03^{b-f}	25.43^{ef}	40.03^{f-l}	77.22^{h-m}
HPYT424	119^{b}	94.43^{b-h}	10.13^{g-l}	35^{d-i}	3358.13^{b-f}	39.52^{c-f}	25.20^{ef}	41.63^{c-i}	77.96^{d-j}
HPYT426	115^{e-g}	92.46^{e-j}	12.53^{a}	41^{a-e}	3343.97^{b-f}	34.85^{k-n}	29.60^{a-e}	36.96^{k-o}	77.57^{f-k}
HPYT429	115^{e-g}	94.76^{b-g}	10.53^{d-j}	29^{i}	2981.84^{fg}	41.54^{a-c}	27.10^{d-f}	40.30^{e-k}	79.29^{b-e}
HPYT432	115^{fg}	96.80^{b-d}	10.36^{e-k}	35^{d-i}	3584.20^{a-d}	42.58^{ab}	27.06^{d-f}	42.70^{c-h}	79.51^{bc}
HPYT435	118^{bc}	95.10^{b-f}	11.90^{ab}	48^{a}	3839.88^{ab}	39.16^{c-f}	29.03^{b-e}	40.63^{d-i}	81.47^{a}
HPYT437	115^{e-g}	85.56^{n}	10.56^{d-i}	34^{e-i}	2659.17^{g}	35.84^{i-l}	32.70^{a-c}	44.26^{bc}	78.36^{c-h}
HPYT438	117^{c-e}	90.66^{h-l}	10.93^{c-f}	38^{b-h}	3414.49^{a-f}	38.68^{d-h}	28.66^{c-e}	43.90^{b-d}	78.85^{b-g}
HPYT439	117^{cd}	91.96^{e-j}	10.96^{c-f}	39^{b-g}	3620.28^{a-d}	43.40^{a}	30.36^{a-d}	42.36^{c-i}	79.25^{b-e}
HPYT440	113^{h}	94.20^{c-h}	9.66^{k-m}	43^{a-c}	3616.83^{a-d}	35.40^{j-m}	26.10^{d-f}	43.40^{b-f}	75.78^{m-o}
HPYT441	116^{d-f}	98.16^{ab}	10.93^{c-f}	39^{b-g}	3338.83^{b-f}	42.47^{ab}	26.00^{d-f}	41.96^{c-i}	76.70^{i-n}
HPYT442	117^{c-e}	88.00^{k-n}	10.86^{d-g}	33^{f-i}	2938.09^{fg}	32.65^{n-p}	30.26^{a-d}	43.66^{b-e}	78.48^{c-h}
HPYT443	115^{e-g}	96.83^{b-d}	10.93^{c-f}	38^{b-h}	3416.51^{a-f}	38.92^{d-g}	25.73^{d-f}	37.13^{j-o}	76.75^{i-n}
HPYT448	115^{fg}	87.53^{l-n}	10.80^{d-h}	31^{hi}	3151.29^{d-g}	40.65^{b-e}	28.53^{c-e}	49.03^{a}	76.64^{i-n}
HPYT449	115^{fg}	98.26^{ab}	10.90^{c-f}	38^{b-h}	3628.48^{a-d}	39.01^{c-g}	27.03^{d-f}	40.50^{d-j}	80.12^{ab}
HPYT450	115^{fg}	97.93^{a-c}	10.60^{d-i}	42^{a-d}	3529.79^{a-e}	37.66^{f-j}	26.70^{d-f}	43.13^{b-g}	79.44^{b-d}
KACHU	123^{a}	86.00^{mn}	10.86^{d-g}	28^{i}	2030.43^{h}	43.37^{a}	33.66^{ab}	39.46^{h-n}	78.310^{c-h}
Tilottama	119^{b}	90.26^{i-l}	10.96^{c-f}	44^{a-c}	3702.86^{a-c}	36.55^{g-k}	27.40^{d-f}	39.46^{h-n}	77.45^{g-l}
Grand Mean	116	92.65	10.63	38	3386.52	37.91	28.06	40.77	77.82
F-test	21.76**	7.63**	7.38**	3.14**	4.67**	13.99**	2.54**	6.96**	8.78**

CV %	0.85	2.53	4.23	11.59	9.78	4.15	10.28	5.87	1.18
LSD $_{0.05}$	1.63	3.86	0.74	7.24	545.71	2.59	4.75	3.47	1.51

DM=days to maturity, PHT=plant height, SPL=spike length, GPS=grains/spike, TKW=1000-kernels weight, GY=grain yield, HW=hectoliter weight. Means within a column followed by the same letter (s) were not significantly different (LSD $_{0.05}$). '*'; '**' F- test significant at 0.05 and 0.01 probability levels, respectively.

The correlation analyses revealed days to maturity significantly and positively correlated with spike length and test weight (Table 4). The positive influence of longer maturity period on spike length and test weight might be due to longer growing degree days which overall facilitated higher carbon assimilation. This was further supported by the fact that spike length and test weight were positively correlated in this study. Plant height showed significant positive correlation with grain yield, while it was negatively correlated with zinc concentration (Table 4). Grains/spike was positively correlated with grain yield hence, genotypes with higher number of grains/spike could be selected for improved grain yield. The correlation between grain yield and grain Zn concentration was negative, which was in agreement with the findings of Gomez-Becerra *et al.*, (2010), Morgounov *et al*., (2007), Peleg *et al.*, (2009), Velu *et al*., (2012) and Zhao *et al*., (2009). Grain Fe concentration was not correlated with any of the studied traits (Table 4). The absence of correlation of 1000-kernels weight with Zn and Fe concentration in this study comply with the findings by Velu *et al*., 2012. In contrast, Pfeiffer and McClafferty, (2007) reported that Zn and Fe enriched genotypes had higher 1000-kernels weights.

Table 4. Pearson's correlation coefficient between studied traits of the 30 wheat genotypes and checks at Bhairahawa

	PHT	SPL	GPS	TKW	GY	Fe	Zn	HW
DM	-0.187	0.443^{*}	-0.033	0.126	-0.137	-0.305	0.101	0.385^{*}
PHT		0.125	0.292	0.312	0.437^{*}	-0.146	-0.624^{**}	0.237
SPL			0.271	0.151	-0.053	-0.031	0.174	0.570^{**}
GPS				-0.300	0.688^{**}	-0.110	-0.237	0.168
TKW					-0.292	0.288	0.026	0.386^{*}
GY						-0.209	-0.637^{**}	0.038
Fe							0.237	0.111
Zn								0.015

****, **; Significant at 5% and 1% level of probability, respectively. DM=days to maturity, PHT=plant height (cm), SPL=spike length (cm), GPS=grains/spike, TKW=1000-kernel weight (g), GY=grain yield (kg/ha), Fe=grain Iron concentration, Zn=grain Zinc concentration, HW=hectoliter weight (kg/hL)***

Conclusion:

The high grain yield of Neloki/3/IWA8600211//2*PBW343*2/Kukuna and its grain Zn and Fe concentration comparable with the local check variety Tilottama, suggest it as a promising genotype that can be further evaluated and promoted as a candidate variety. In terms of grain Zn concentration, Croc_1/*Ae.squarrosa*…*2/Kukuna and Fe concentration, TRCH/Srtu//…/Milan//PI610750 were the top performing genotype. Moreover, the Fe concentration of Croc_1/*Ae.squarrosa*…*2/Kukuna and Zn concentration of TRCH/Srtu//…/Milan//PI610750 were higher than the overall means, respectively. Although these two genotypes were superior in agronomic performance, they had below average grain yield. These genotypes can be utilized as parents to develop grain Zn and Fe enriched populations. The high grain Zn containing genotype, Croc_1/*Ae.squarrosa*…*2/Kukuna was earliest maturing and therefore can better adapt to drought and heat stressed environments as well as rice-wheat cropping system of Nepal. The studied materials can be valuable resources for the development of Zn and Fe enriched wheat varieties in Nepal.

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Conflict of interest:

The authors declare no conflicts of interest regarding publication of this manuscript.

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تقويم الغلة والمحتوى من الزنك والحديد لأصناف القمح المحصّنة حيوياً

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الملخص

نفذت تجربة حقلية في بهيراهاوا، رباندهي، نيبال، خلال الفترة من تشرين الثاني وحتى نيسان من الموسم 2016/2015، بهدف التعرف على أصناف القمح الربيعية مرتفعة الغلة والمحصنة حيوياً بعنصري الحديد والزنك. تم انتخاب 27 صنف من القمح من تجارب غلة الحصاد الخامس (HPYT)، وتم تقويمها بالمقارنة مع ثلاثة أصناف كشاهد (Tilottama، و BAJ#1 ، وKACHU#1) وفق تصميم المربع اللاتيني ألفا بثلاثة مكررات. أظهر تحليل التباين فروقاً معنويةً ($P\leq0.05$) ما بين الأصناف بالنسبة لعدد الأيام حتى النضج، وارتفاع النبات، وطول السنبلة، وعدد الحبوب في السنبلة، ووزن الألف حبة، وغلة الحبوب، والمحتوى من الحديد والزنك. أعطى الصنف Neloki/3/ IWA8600211//2*PBW343*2/Kukuna أعلى غلة حبية بلغت (3.953 طن/هكتار)، تلاه الصنف Francolin#1/3/ Croc_1/*Ae. squarrosa* (210)//2*PBW343*2/Kukuna بغلة حبية (3.877 طن/هكتار) ثم الصنف C80.1/3*Batavia//2*WBLL1/3/Attila/3*BCN*2//Bav92/4/WBLL1*2/Kuruku/5/IWA8600211//2*PBW343*2/Kukuna بغلة حبية بلغت (3.839 طن/هكتار). تراوح محتوى الحبوب للأصناف المختبرة من الحديد من 35.33 وحتى 49.03 جزء بالمليون، في حين محتوى الحبوب من الزنك من 22.76 وحتى 34.03 جزء بالمليون. بلغت أعلى قيمة لمحتوى الحبوب من الزنك (34.03 جزء بالمليون) في الصنف Croc_1/Ae.squarrosa(210)//Inqalab91*2/Kukuna/3/PBW343*2/Kukuna، ووصلت أعلى قيمة من محتوى الحبوب من الحديد (49.03 جزء بالمليون) لدى الصنف TRCH/Srtu//Kachu/5/Toba97/Pastor/3/T.dicocconPI94624/Ae.squarrosa(409)//BCN/4/BL1496/Milan//PI610750. اعتبر الصنف Neloki/3/ IWA8600211//2*PBW343*2/Kukuna هو الصنف المبشر والمرشح للدراسات اللاحقة لارتفاع غلته من الحبوب، وارتفاع محتواه من عنصري الزنك والحديد. وقد وجد ارتباط إيجابي ($r=0.237$) ما بين محتوى الحبوب من الزنك والحديد. ويمكن اعتبار أصناف القمح المختبرة مصدر ذا قيمة لتحسين محتوى الحديد والزنك فيها للتغلب على مشكلة سوء التغذية في نيبال.

الكلمات المفتاحية: القمح الحيوي المحصن، الغلة الحبية، محتوى الحديد، محتوى الزنك.