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Performance of Biofortified Spring Wheat Genotypes for Grain Zinc and Iron Concentrations, Grain Yield and Associated Traits in Terai/plains of Nepal

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Authors' contributions

This work was carried out in collaboration among all authors. Authors KRP and DP conceptualized this study. Authors KRP, DP and RPY performed the Methodology. Author KRP did formal analysis, software analysis, data curation and project administration. Authors KRP, NRG, SRU and DP did data validation. Authors, KRP and NRG investigated the work. Authors SRU, DBT, KRP and DP searched for resources. Authors KRP and AN did data visualization and supervised the study, wrote and reviewed original draft of the manuscript. Authors NRG, DBT and KRP supervised the study. Author NRG did funding acquisition. All authors have read and agreed to the published version of the manuscript.

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ABSTRACT

Breeding for nutrient-rich high yielding wheat varieties is one of the most economical and feasible ways to improve micronutrient deficiency ad hoc building better consumer health among the rural people of South Asia. To identify the Zinc (Zn) and Iron (Fe) enriched high yielding wheat genotypes, 7th Harvest Plus Yield Trial (7th HPYT) and 8th Harvest Plus Yield Trial (8th HPYT) both composed of 50 genotypes (including two CIMMYT checks " Kachu#1" and "Baj#1" and one Local Check "Gautam") were evaluated in alpha lattice design with 2 replications under timely sown irrigated condition at NWRP, Bhairahawa during 2016/17 and 2017/18. The grain Zn concentration and Fe concentration varies among genotypes from 23.8 to 42.4 ppm and 20.6 to 60.6 ppm, respectively. The highly significant positive correlation was found between grain zinc and iron concentration (r = 0.74** in 7th HPYT and r=0.67** in 8th HPYT). This highly positive significant relation between grain Zn and grain Fe indicates that it is feasible to simultaneously improve both micronutrients. In addition, this study reveals that thousand grains weight (TGW) has shown highly significant positive correlation (r = 0.3) with grain zinc and (r=0.4) with grain iron in 7th HPYT to non-significant negative correlation (r = -0.1) with grain zinc and (r=-0.1) with grain iron in 8th HPYT. As Nepali farmers major trait of interest second to grain yield is TGW, this showed that Zn and Fe enriched wheat varieties with higher TGW (bold grain) is feasible. The 9 genotypes in 7th HPYT and 48 genotypes in 8th HPYT showed higher grain yield than local check variety "GAUTAM" which indicates that bio-fortified genotypes are capable of producing higher grain yield with added micronutrient supplements in them. This study recommended 17 genotypes from the 7th HPYT and 38 genotypes from the 8thHPYT based on higher grain yield, grain Zn and Fe concentration and these lines were included in national yield trial for further evaluation in different agro-ecological domain of Nepal. The genotypes with higher grain Zn and Fe concentration viz., 7HPYT409, 7HPYT410, 8HPYT417, 8HPYT404 and 7HPYT442 could be used as donor parents in national wheat breeding program and high yielding genotypes 7HPYT448, 7HPYT418, 7HPYT426, 7HPYT413, 8HPYT415, 8HPYT431, 8HPYT429, 8HPYT407 and 8HPYT405 would be further evaluated throughout the Terai region of Nepal, and outstanding genotype could be recommended as variety for Terai/plains of Nepal.

Keywords: Biofortification; grain Zn; Fe concentration; grain yield; wheat.

1. INTRODUCTION

Wheat (*Triticum aestivum* L.) is a globally grown cereal crop with an annual estimated production of around 785 million MT in 2023/2024 and is grown on around 220.7 million hectares worldwide" (FAOSTAT, 2023). Wheat is consumed by 35% of the world's population and contributes 20% of human calories and protein across the world" [1]. In the context of Nepal, wheat ranks third after rice (*Oryza sativa L.)* and Maize (*Zea mays L.*) in production but ranks second in consumption after rice. During 2021/2022, the area under cultivation, production and productivity were 716978 ha, 2144568 metric tons and 2991 tons/ha respectively [2]. More than half (55%) of the wheat area is in Terai which contributes 62% of total production [2].

According to USAID, around 1 million (36%) of children below 5 years of age are suffering from chronic malnutrition (stunting or low height-for-age) while around 10% suffer from acute malnutrition (low weight-for-height) creating an alarming situation for Government of Nepal [3]. To reduce malnutrition Calderini & Ortiz Monasterio (2003) identified that developing more nutrient-dense staple food crops could be a possible option [4]. The Harvest Plus initiative, a program launched by CGIAR (Consultative Group on International Agricultural Research) focusing on breeding and dissemination of food crops with high micronutrient contents [5]. The Harvest Plus project works with different national and international partners to eliminate micronutrient deficiencies like Zn and Fe through the fortification of staple food crops. The deficiency of Fe and Zn in dietary content affects more than two billion people globally [6]. The global average prevalence of Zn deficiency has been estimated to be 31% with the most severe expression in Africa and South Asia. It's deficiency is known to significantly increase the risk of many diseases viz., diarrhea, pneumonia and malaria, therefore Zn deficiency has been linked to the morbidity and mortality of children. The resulting deficiency of Fe and Zn in developing countries is primarily associated with consumption of cereal-based foods with low concentration and reduced bioavailability of Zn and Fe [7]. CIMMYT, Mexico and Harvest plus project improves the nutrient content by supplementing essential minerals and vitamins and this process is considered as one of the most economical and effective solution to human micronutrient deficiency issues” [8].

The biofortified wheat varieties developed in Harvest Plus project are 20-30% better in Zn & Fe concentration (grain) than the best local checks of Nepal. They are also agronomically superior (around 5%) and capable of escaping (due to earliness) or tolerating the terminal heat stress. The Zn and Fe concentration in biofortified wheat genotypes range from 19-52 mg kg^{-1} and 23-52 mg kg^{-1}, respectively [9]. In South Asia, nutritionists target to increase Fe and Zn levels of wheat genotypes currently grown in the region by 25 and 10 mg/kg, respectively. On average, this translates into Zn and Fe levels in the grain of 35 and 50 mg/kg, respectively [10]. Biofortified high-Zn wheat could benefit 120 million resource poor people in South Asia, thus, providing sustainable solution to malnutrition problems by exploring natural genetic variation” [11]. Therefore, improvement in the breeding techniques to increase the nutrient content of the staple cereal crops with micronutrient like Zn and Fe is a priority issue.

In Nepal, 54 wheat varieties developed by NARC were released for different ecology. Among them 6 are biofortified (zinc and iron-enriched), 3 wheat varieties (Zinc Gahun 1, Zinc Gahun 2 and Borlaug 2020) for Terai/Plains and 3 varieties (Himganga, Bheri-Ganga and Khumal-Shakti) for hills were released in 2021 [12,13]. This has provided base for the assumption that high percentage of Nepalese people are in the risk of Zn and Fe deficiency. Therefore, National Wheat Research Program, Bhairahawa in collaboration with International Maize and Wheat Improvement Center (CIMMYT), Mexico is testing and releasing zinc and iron enriched wheat varieties in Nepal. Biofortified wheat has several potential advantages as a delivery vehicle of zinc and iron through wheat in diets of Nepalese where most of the wheat produced is milled locally and use of whole grain wheat (*atta*) for making chapati allows retaining most of the zinc and iron in human body. The nutrient rich high yielding wheat cultivars offer the most economical and feasible means for improving micronutrient nutrition in rural areas. The main objective of this research was to evaluate advanced zinc and iron enriched material to identify high-yielding biofortified lines for terai/plains of Nepal.

2. MATERIALS AND METHODS

2.1 Experimental Design and Procedure

During 2016/17 and 2017/18 wheat seasons 7th Harvest Plus Yield Trial (7HPYT) and 8th Harvest Plus Yield Trial (8HPYT), respectively were carried out at National Wheat Research Program, Bhairahawa. This research farm is geographically situated within latitude 27º31’49” N and longitude 83º27’36” E at altitude 105 m above sea level. The research was laid out in a α-Lattice design with two replications. Each replication had 5 blocks i.e., 10 experimental units (plots). Each plot had 6 rows of 3-meter length. The planting material of 7HPYT and 8HPYT consisted of 50 genotypes, 47 of them were advanced lines obtained from CIMMYT with significantly improved Zn and Fe concentrations and desirable agronomic traits, two commercial checks [BAJ#1, KACHU#1] and one local check (Gautam). The genotypic detail is given in Annexes 1 and 2. The genotypes which are used in this study were having *T. dicoccum* and *Aegilopes squarrosa* in their pedigree which are identified donors of high Fe and Zinc. The standard protocol recommended by National Wheat Research Program, Bhairahawa, Nepal was followed for all cultivation practices throughout the cropping season. Fertilizers application rate was 100:50:50 N: P_2O_5: K_2O kg ha-1. Data recording were carried on quantitative characteristics like days to heading, days to maturity, plant height, thousand grains weights, grain yield and biomass yield.

2.2 Grain Sampling and Micronutrient Determination

During harvesting, 20 spikes from each plot were hand plucked using gloves at physiological maturity. Afterwards, they were threshed carefully and were sorted for Zn and Fe analysis. Samples were monitored making sure to avoid metal contamination. About 20g grain samples were taken and examined to remove broken grains and foreign materials. After sorting, the samples were used for micronutrient analysis. Grain samples were analyzed using a non-destructive, bench-top, energy-dispersive X-ray fluorescence (EDXRF) machine (model X-supreme 800, Oxford Instruments plc, Abingdon, UK) standardized for high throughput screening of GZnC and GFeC (unit: mg kg-1 or ppm) concentration in whole grain wheat (Paltridge et al., 2012). Micronutrient Analysis (Zn and Fe) was done at Banaras Hindu University (BHU), Varanasi, India.

2.3 Statistical Analysis

Microsoft Office Excel 2007 was used for data entry and processing. Analysis of variance (ANOVA), correlation analysis, cluster analysis, principal component analysis (PCA), and calculation of means were conducted using R Studio software version 4.3.1. Statistical significance was determined at a 5% level of probability.

3. RESULTS AND DISCUSSION

3.1 7th Harvest Plus Yield Trial (7thHPYT)

Days to heading, days to maturity, grain zinc and iron concentration, thousand grains weight and grain yield were highly significant ($p \leq 0.01$) among the genotypes when compared with checks (Table 2). Additionally, plant height and biomass yield were also found significantly higher ($p \leq 0.05$) among genotypes than the checks in 7th HPYT (Table 1).

3.1.1 Days to heading, days to maturity and plant height

The days to heading among genotypes varied between 75 to 88 days with an average value of 83 days. The earliest heading was found in genotype 7HPYT404 followed by 7HPYT413, BAJ#1, 7HPYT416 and 7HPYT450. The Check Variety Gautam headed in 82 days. Similarly, the days to maturity varied among genotypes from 115 to 123 days with a mean value of 118 days. Genotype 7HPYT404, 7HPYT413, 7HPYT416, BAJ#1 and 7HPYT409 were found early maturing genotype with 115 days to maturity. The late maturing genotype was 7HPYT431 (123 days). The plant height varied from 78 to 91 cm. The shortest plant height was found in genotype 7HPYT409 (78 cm) followed by 7HPYT410, 7HPYT416 and 7HPYT420 with 80 cm. The check variety Gautam has plant height 88 cm (Table 1).

3.1.2 Grain zinc and iron concentration

Among the genotypes, the grain Zn concentration differed from 25.8 to 42.4 ppm with the mean of 32.07 ppm. The highest grain Zn concentration was found in genotype 7HPYT409 (42.4 ppm) followed by genotype 7HPYT410 (39.6 ppm). The lowest grain Zn concentration was found in 7HPYT412 (25.8 ppm). The grain Zn concentration of check variety Gautam was found 39.1 ppm (Table 1 and Fig. 1).

The grain Fe concentration was found between 20.6 to 57.9 ppm with a mean of 37.5 ppm. The highest grain Fe concentration was found in genotype 7HPYT442 (57.9 ppm) followed by 7HPYT410 (57.2 ppm), 7HPYT409 (54.7 ppm) and7HPYT406(49.6 ppm). The lowest grain Fe concentration was found in 7HPYT421 (20.6 ppm). The grain iron concentration of check variety Gautam was found 40.5 ppm (Table 1 and Fig. 1).

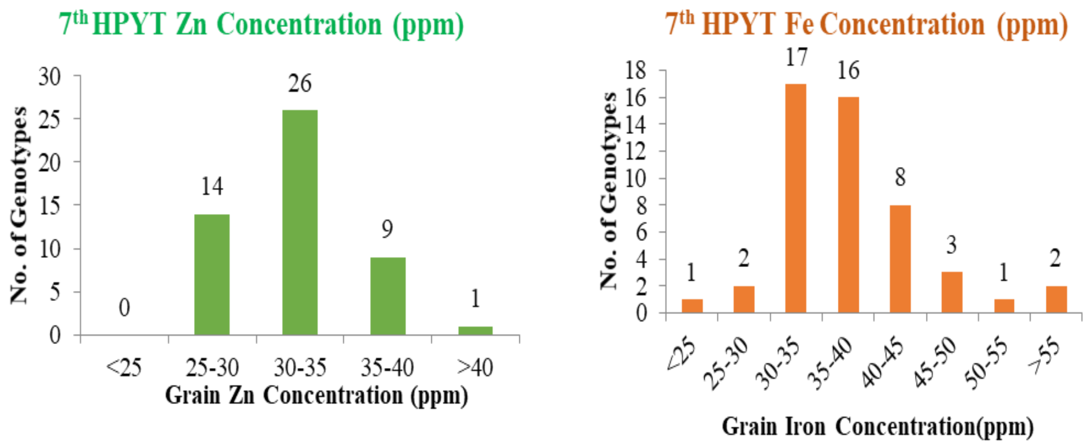


Fig. 1. Frequency distribution for grain Zn and Fe concentrations of 7th HPYT entries

Table 1. Mean value of 7th HPYT entries for days to heading, days to maturity, plant height, 1000-grain weight, grain Zn and Fe concentrations, grain yield and Biomass Yield

E. N	Genotypes	DTH (days)	DTM (days)	PH (cm)	TGW (g)	GZnC (ppm)	GFeC (ppm)	GY (kg/ha)	BY (kg/ha)
1	GAUTAM	82	120	88	46	39.1	40.5	3403	7142
2	BAJ #1	78	115	81	38	30.1	33.0	3102	7232
3	KACHU #1	83	119	83	40	31.6	34.1	3401	7968
4	7HPYT404	75	115	85	44	34.9	43.6	2689	6277
5	7HPYT405	81	116	88	44	32.4	39.5	3136	7267
6	7HPYT406	86	119	88	47	37.3	49.6	2935	6840
7	7HPYT407	80	118	85	49	34.6	46.8	2610	5801
8	7HPYT408	85	118	83	48	37.2	40.4	2589	5877
9	7HPYT409	80	115	78	42	42.4	54.7	2572	6028
10	7HPYT410	86	119	80	48	39.6	57.2	2205	5845
11	7HPYT411	86	119	82	45	32.4	40.1	3205	7843
12	7HPYT412	85	120	83	36	25.8	30.7	2994	7095
13	7HPYT413	77	115	85	44	27.0	27.5	3592	7404
14	7HPYT414	82	118	88	43	28.5	33.4	3446	7848
15	7HPYT415	84	118	87	50	31.4	38.5	2842	6988
16	7HPYT416	78	115	80	45	27.7	33.8	3230	6581
17	7HPYT417	84	119	83	43	32.2	34.4	3244	7212
18	7HPYT418	85	119	81	50	29.1	33.0	3760	7868
19	7HPYT419	81	117	83	49	33.3	35.3	3430	7030
20	7HPYT420	83	119	80	44	30.2	32.9	2743	6535
21	7HPYT421	80	118	87	44	28.6	20.6	3487	8510
22	7HPYT422	86	118	88	43	31.7	40.3	3267	8055
23	7HPYT423	81	117	86	49	28.9	34.4	3271	6742
24	7HPYT424	87	117	85	46	26.1	31.6	3416	7150
25	7HPYT425	85	120	83	43	28.7	29.0	2885	6257
26	7HPYT426	86	120	89	47	37.2	43.0	3688	8176
27	7HPYT427	83	118	84	50	32.5	46.2	3266	7325
28	7HPYT428	82	119	82	39	35.1	31.2	3085	6890
29	7HPYT429	86	119	89	41	35.9	33.0	3354	7877
30	7HPYT430	84	119	86	40	27.7	35.1	3051	6764
31	7HPYT431	88	123	84	36	27.1	36.8	2243	6139

E. N	**Genotypes**	**DTH (days)**	**DTM (days)**	**PH (cm)**	**TGW (g)**	**GZnC (ppm)**	**GFeC (ppm)**	**GY (kg/ha)**	**BY (kg/ha)**
32	7HPYT432	79	116	82	43	30.3	36.2	2872	6906
33	7HPYT433	81	118	87	45	30.8	33.6	3311	7188
34	7HPYT434	87	119	89	44	31.5	38.3	3244	7094
35	7HPYT435	83	119	88	42	30.7	35.3	3047	6724
36	7HPYT436	85	119	87	40	38.7	40.4	3081	6856
37	7HPYT437	84	119	87	39	34.0	39.9	2928	6554
38	7HPYT438	82	119	87	41	32.1	34.5	2894	6544
39	7HPYT439	87	116	86	36	31.4	31.2	3310	7735
40	7HPYT440	83	118	88	51	32.7	39.1	2797	7166
41	7HPYT441	83	118	91	47	28.9	32.1	3158	7217
42	7HPYT442	88	120	90	55	38.6	57.9	2536	7357
43	7HPYT443	87	119	88	41	28.7	38.5	2940	6899
44	7HPYT444	88	119	87	41	32.8	36.3	3007	6616
45	7HPYT445	87	118	87	42	28.8	35.4	3473	7492
46	7HPYT446	88	119	85	42	31.0	37.6	2987	6504
47	7HPYT447	88	119	85	39	30.9	35.6	3086	6824
48	7HPYT448	82	116	85	43	30.6	34.5	3821	8197
49	7HPYT449	83	119	88	46	32.1	41.7	3054	6947
50	7HPYT450	78	117	82	43	33.3	39.0	3337	7379
	Grand Mean	83.42	118.03	85.31	43.91	32.07	37.55	3100.5	7055
	CV (%)	2.47	1.11	3.39	3.7	9.42	16.77	10.73	9.1
	LSD value (0.05)	4.66	4.76	5.03	5.23	5.4	11.87	1086.8	1814.9
	P value	<0.01	<0.01	0.015	<0.01	<0.01	0.005	0.007	0.023

Where, DTH=days to heading, DTM=days to maturity, PH=plant height, TGW=Thousand grain weight, GFeC(ppm)=Grain Iron concentration, GZnC(ppm)=Grain Zinc concentration, GY=Grain yield, BY=Biomass Yield, CV=Coefficient of variation and LSD=least significant difference

Table 2. Mean value of 8th HPYT entries for days to heading, days to maturity, plant height, 1000-grain weight, grain Zn and Fe concentrations, grain yield and Biomass Yield

E. N	Genotypes	DTH (days)	DTM (days)	PH (cm)	TGW (g)	GZnC (ppm)	GFeC (ppm)	GY (kg/ha)	BY (kg/ha)
1	GAUTAM	85	118	83.5	40.3	30.7	36.3	2648	6516
2	BAJ #1	84	117	80.0	34.3	25.6	31.0	3296	7355
3	KACHU #1	87	119	86.5	36.8	24.2	29.5	3409	8770
4	8HPYT404	77	116	76.0	38.0	34.4	35.9	2937	7000
5	8HPYT405	87	119	84.0	37.0	27.6	31.4	3848	7683
6	8HPYT406	86	119	83.5	47.8	32.0	34.5	2713	6755
7	8HPYT407	91	121	85.5	39.0	30.5	33.0	3959	8936
8	8HPYT408	90	121	93.5	40.5	28.2	32.9	3837	9000
9	8HPYT409	89	119	90.5	39.5	29.9	29.3	3328	7711
10	8HPYT410	91	121	88.0	37.8	28.4	30.7	2828	6378
11	8HPYT411	90	120	81.0	35.5	27.6	30.5	3168	6812
12	8HPYT412	88	120	85.0	35.8	29.4	31.5	3295	7328
13	8HPYT413	87	119	85.0	42.8	28.7	33.5	3156	6915
14	8HPYT414	89	119	82.5	42.3	29.5	32.4	3192	7190
15	8HPYT415	89	120	84.0	40.0	27.1	31.6	4456	9582
16	8HPYT416	87	120	89.5	41.3	26.7	30.4	3492	7857
17	8HPYT417	92	122	86.0	34.3	37.5	60.6	2245	5661
18	8HPYT418	89	121	89.5	40.3	27.7	31.8	3161	6833
19	8HPYT419	87	119	94.5	41.8	26.3	30.8	3835	7979
20	8HPYT420	88	119	85.5	37.0	29.3	33.0	3394	7000
21	8HPYT421	84	117	87.0	49.5	23.8	29.1	3831	8695
22	8HPYT422	86	119	84.5	39.3	28.9	29.9	3000	6839
23	8HPYT423	88	119	85.0	42.3	30.6	30.1	3574	7817
24	8HPYT424	89	120	85.0	44.8	27.9	32.9	3078	6587
25	8HPYT425	93	122	82.0	44.5	32.1	33.3	2667	5833
26	8HPYT426	91	121	86.0	38.3	29.4	33.2	3007	6984
27	8HPYT427	93	121	88.0	40.5	31.3	34.0	3578	8254
28	8HPYT428	88	120	79.0	38.5	29.7	34.0	3084	6667
29	8HPYT429	83	117	88.0	44.5	25.8	33.3	3964	8529
30	8HPYT430	86	118	86.0	36.3	27.4	31.9	3333	7505
31	8HPYT431	90	120	88.0	48.8	29.4	34.9	4079	9172

E. N	**Genotypes**	**DTH (days)**	**DTM (days)**	**PH (cm)**	**TGW (g)**	**GZnC (ppm)**	**GFeC (ppm)**	**GY (kg/ha)**	**BY (kg/ha)**
32	8HPYT432	88	120	84.0	35.8	28.8	34.1	2908	7569
33	8HPYT433	87	120	83.5	37.8	32.7	33.6	3085	7418
34	8HPYT434	88	120	81.0	38.8	28.2	32.7	3667	8090
35	8HPYT435	84	117	82.5	42.5	31.3	37.8	3832	8447
36	8HPYT436	88	119	83.5	38.8	31.7	30.1	3075	6736
37	8HPYT437	91	120	82.5	38.5	27.2	29.9	2969	6918
38	8HPYT438	91	120	84.5	37.5	27.8	30.9	2667	5924
39	8HPYT439	88	119	92.0	34.3	27.6	32.1	3163	7839
40	8HPYT440	91	120	73.5	35.8	28.6	30.4	3498	8447
41	8HPYT441	91	121	84.0	36.3	28.6	31.3	3255	7661
42	8HPYT442	90	119	85.5	36.5	30.9	32.5	3003	6553
43	8HPYT443	89	119	89.5	42.3	33.5	38.1	2932	6284
44	8HPYT444	89	120	92.0	33.3	28.0	30.3	2765	6784
45	8HPYT445	91	120	88.0	34.8	29.4	32.6	3005	7328
46	8HPYT446	92	122	92.0	36.8	30.1	30.2	3474	8138
47	8HPYT447	92	121	87.0	36.0	27.8	30.1	3670	8720
48	8HPYT448	88	121	81.5	41.0	27.8	31.3	3075	6800
49	8HPYT449	90	122	91.5	40.3	29.2	28.9	3009	7133
50	8HPYT450	88	120	80.5	36.8	31.2	33.0	3708	8805
	Grand Mean	88.4	119.6	85.4	39.2	29.2	32.7	3283.0	7474.6
	CV (%)	1.58	0.93	4.64	4.2	8.86	8.88	8.68	9.48
	LSD value (0.05)	4.13	2.13	8.49	3.43	6.33	4.77	780.72	2296.11
	P value	<0.01	<0.01	0.004	<0.01	0.03	<0.01	<0.01	<0.01

Where, DTH=days to heading, DTM=days to maturity, PH=plant height, TGW=Thousand grain weight, GFeC(ppm)=Grain Iron concentration, GZnC(ppm)=Grain Zinc concentration, GY=Grain yield, BY=Biomass Yield, CV=Coefficient of variation and LSD=least significant difference

3.1.3 Thousand grain weights, grain yield and biomass yield

The value of thousand grains weights ranged between 36 and 55 g with a mean of 43.9g. The highest thousand grains weight was found in genotype 7HPYT422 (55g) followed by genotypes 7HPYT440 (51g), 7HPYT415 (50g) while the lowest one was found in 7HPYT439 (36g). The check variety Gautam has thousand grain weight 46g. The grain yield varied among genotypes from 2205 - 3821 kg/ha with a mean value of 3100 kg/ha (Table 1). Highest grain yield was found in genotype 7HPYT448 (3821 kg/ha) followed by 7HPYT418 (3760 kg/ha), 7HPYT426 (3688 kg/ha), 7HPYT413 (3592 kg/ha), 7HPYT421 (3487 kg/ha), 7HPYT414 (3446 kg/ha), 7HPYT419 (3430 kg/ha) and 7HPYT424 (3416 kg/ha) while the lowest grain yield was found in 7HPYT410 (2205 kg/ha). The check variety Gautam produced grain yield of 3403 kg/ha. Similarly, the biomass yield varied among genotypes from 5801 to 8510 kg/ha with a mean value of 7055 kg/ha (Table 1). Genotype 7HPYT421 (8510 kg/ha) had the highest biomass yield followed by 7HPYT448 (8197 kg/ha), 7HPYT426 (8176 kg/ha), 7HPYT422 (8055 kg/ha) and kachu#1 (7968 kg/ha) while the lowest biomass yield was of genotype 7HPYT407 (5801 kg/ha). The check variety Gautam produced biomass yield of 7142 kg/ha.

In 7th HPYT, out of all 50 biofortified wheat genotypes, 8 genotypes (i.e., 16% of genotypes) yielded more than local check (Gautam). 17 genotypes were selected and promoted to NAL (Nepal Advance line) and CB (Crossing Block). The grain yield percentage of all genotypes over local check is given in Fig. 3.

3.2 8th Harvest Plus Yield Trial (8th HPYT)

High significant differences ($p \leq 0.01$) were found among the genotypes for days to heading, days to maturity, plant height, grain iron concentration, thousand grain weight and grain yield whereas significant difference ($p \leq 0.05$) was noticed among the genotypes for grain zinc concentration when compared with the checks (Table 2).

3.2.1 Days to heading, days to maturity and plant height

The days to heading among genotypes varied between 77 to 93 days with an average of 88 days. The earliest heading was found in genotype 8HPYT404 followed by 8HPYT429, 8HPYT421 and BAJ#1. The check variety Gautam headed in 85 days. Similarly, the days to maturity varied among genotypes from 116 to 122 days with a mean value of 120 days. Genotype 8HPYT404 (116 days), 8HPYT429 and 8HPYT435 were found early maturing genotype with 117 days to maturity. The plant height varied from 74 to 95 cm. Genotype 8HPYT440 (74 cm) had the shortest plant height followed by 8HPYT404 and 8HPYT428. The check variety Gautam had plant height of 84 cm (Table 2).

3.2.2 Grain zinc and iron concentration

Grain Zn concentration was found varied from 23.8 to 37.5 ppm among the genotypes with the mean of 29.2 ppm. Highest Zn concentration was found in genotype 8HPYT417 (37.5 ppm) followed by genotype 8HPYT404 (34.4 ppm), 8HPYT443 (33.5 ppm) and 8HPYT433 (32.7 ppm). The lowest grain Zn concentration was found in 8HPYT421 (23.8 ppm). The grain zinc concentration of check variety "Gautam" was found 30.7 ppm (Table 2 and Fig. 2).

Similarly, the value of grain iron concentration varied between 28.9 to 60.6 ppm with a mean value of 32.7 ppm. The grain Fe concentration was found highest in genotype 8HPYT417 (60.6 ppm) followed by 8HPYT443 (38.1 ppm) and 8HPYT435 (37.8 ppm). The lowest grain Fe concentration was found in 8HPYT449 (28.9 ppm). The grain Fe concentration of check variety Gautam was found 36.3 ppm (Table 2 and Fig. 2).

3.2.3 Thousand grain weights, grain yield and biomass yield

In the study, the weight of thousand grains varied from 34 and 50 g with a mean of 39.2g. Genotype 8HPYT421 (49.5g) had the highest thousand grains weight followed by genotypes 8HPYT431 (49g), 8HPYT406 (48g) and 8HPYT424 (45g). The check variety Gautam had thousand grains weight of 40g. The grain yield varied among genotypes from 2245 to 4456 kg/ha with a mean value of 3283 kg/ha (Table 2). The grain yield was found highest in genotype 8HPYT415 (4456 kg/ha) followed by 8HPYT431 (4079 kg/ha), 8HPYT429 (3964 kg/ha), 8HPYT407 (3959 kg/ha), and 8HPYT405 (3848 kg/ha) while the lowest grain yield was found in 8HPYT417 (2245 kg/ha). The check variety (Gautam) produced grain yield of 2648 kg/ha.

Similarly, the biomass yield varied among genotypes from 5661to 9582 kg/ha with a mean value of 7475 kg/ha (Table 2). The biomass yield was found highest in 8HPYT415 (9582 kg/ha) followed by 8HPYT431 (9172 kg/ha), 8HPYT408 (9000 kg/ha), 8HPYT407 (8936 kg/ha), 8HPYT450 (8805 kg/ha) and Kachu#1(8770 kg/ha) while the lowest biomass yield was found in 8HPYT417 (5661 kg/ha). The check variety (Gautam) produced biomass yield of 6516 kg/ha. In 8th HPYT, out of all 50 biofortified wheat genotypes, 48 genotypes (i.e., 96% of genotypes) yielded more than local check (Gautam). 38 genotypes were selected and promoted to Nepal Advance line (NAL), Nepal Rainfed Nursery (NRN), Initial Evaluation Trial-Biofortified (IET-B) and IET-TTL (Initial Evaluation Trial -Terai, Tar and Lower valley). The grain yield percentage of all genotypes over local check is given in Fig. 3.

Micronutrient deficiency is alarming situation in Nepal. One of the reasons for growing Zn and Fe deficiencies in developing countries like Nepal is because of the food habit. Monotonous consumption of cereal-based foods which are low in micronutrient and have reduced bioavailability of Zn and Fe adds to the micronutrient deficiency in South Asia [7]. In this study, an approach to evaluate different biofortified wheat lines for grain Zn and Fe concentration, grain yield and associated component traits have been carried out.

The study has showed that the concentration of grain Zn varied from 25.8 to 42.4 ppm in 7th HPYT and 23.8 to 37.5 ppm in 8th HPYT among genotypes. The range of 29-39.5 ppm and 17-61 ppm was also reported by Velu et al.[10] and Velu et al.[9]. Also, the concentration of grain Fe ranged from 20.6 to 57.9 ppm in 7th HPYT and 28.9 to 60.6 ppm in 8th HPYT among genotypes (Figs. 1 and 2). Similar results were reported in previous studies by Velu et al.[10] and Pant et al.[14]

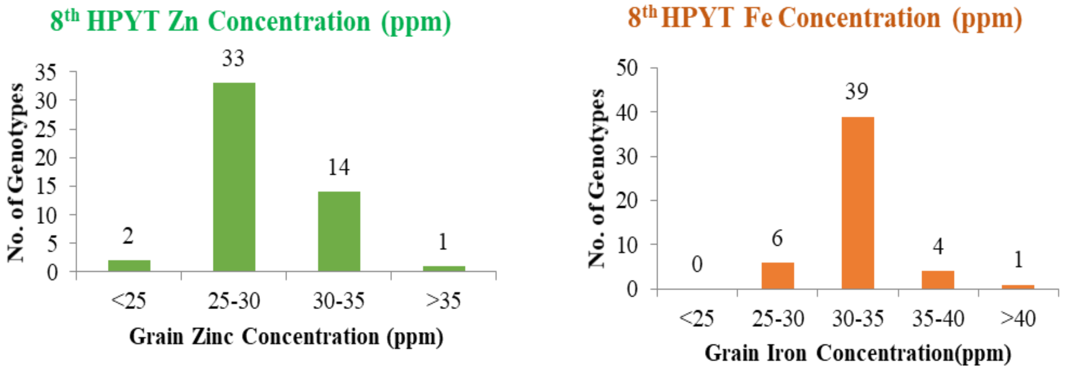


Fig. 2. Frequency distribution for grain Zn and Fe concentrations of 8th HPYT entries

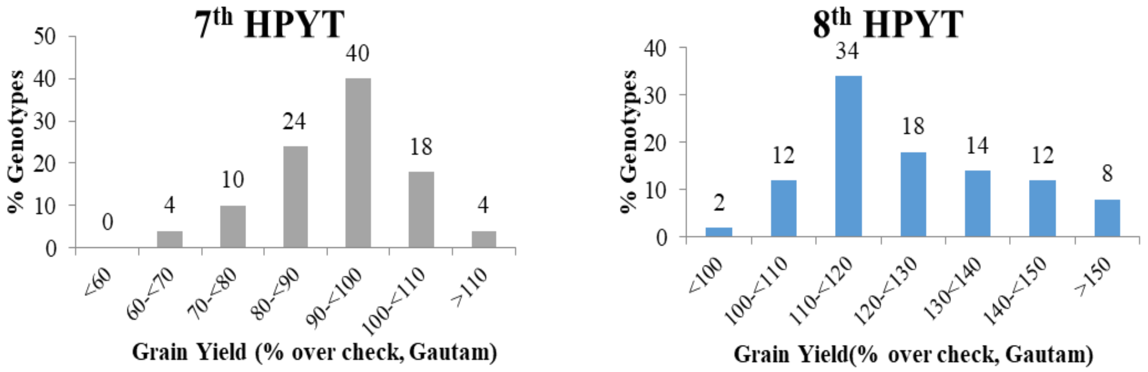


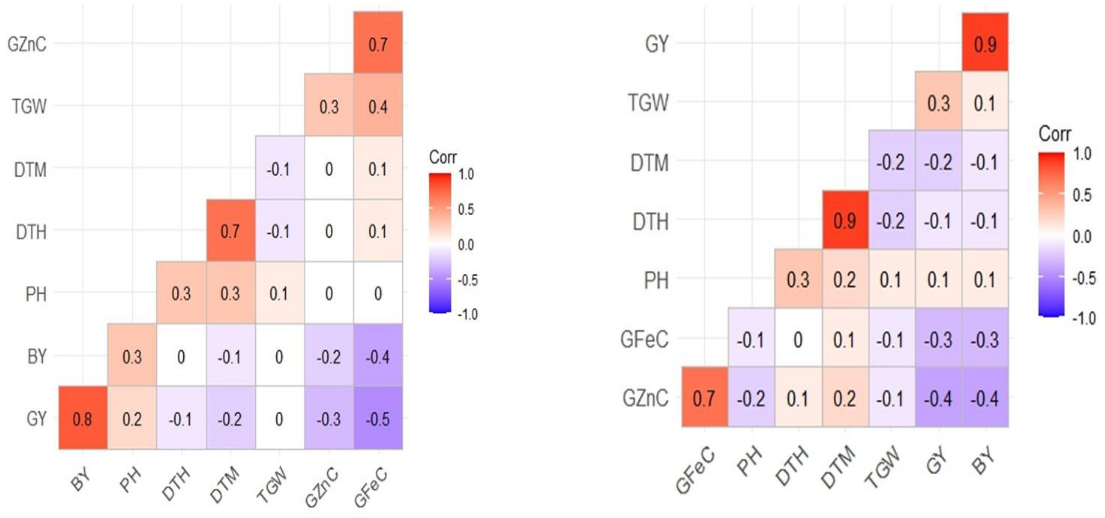
Fig. 3. Increased grain yield of 7th HPYT and 8th HPYT entries over local check (Gautam)

Correlation between grain yield and Zn concentration was observed negative (r= −0.32* in 7th HPYT and −0.43** in 8th HPYT), which was also reported by Gomez-Becerra et al. [15] and Velu et al. [10]. The correlation between grain Fe with grain yield was significantly negative (−0.54** in 7th HPYT and −0.33* in 8th HPYT) similar to the results obtained by various authors in their studies [10], [15]. The correlation of plant height with grain yield was observed non-significant positive whereas it was non-significant negative with grain Zn and grain Fe concentration (Fig. 4a and 4b). This result was consistent with the study conducted by Srinivasa et al. [16]. The result illustrates that intake of Zn and Fe is higher when the plant height is lower as compared those plants with greater heights.

Genotypes expressed highly significant different for days to maturity with the range of 115-123 days in 7th HPYT and 116-122 days in 8th HPYT. The results are similar to the findings of Pandey et al. [17] & Nainabasti et al. [18]. The correlation between days to maturity and grain yield was found negative but non-significant (r = -0.24 in 7th HPYT and r = -0.17 in 8th HPYT) (Fig. 4a and 4b). This finding is in contrast to finding reported by Asif et al. [19]. Thousand grain weights showed positive correlation with zinc and iron concentrations which comply with the findings McDonald et al [20] and Pfeiffer &McClafferty [11]. They reported zinc and iron-enriched genotypes had higher thousand grains weights.

The highly significant positive correlation was found between grain zinc and iron concentration (r = 0.74** in 7th HPYT and r=0.67** in 8th HPYT) (Fig. 4a and 4b). The observed result of high positive significant relation between grain Zn and grain Fe suggests that it is feasible to simultaneously improve both micronutrients. Similar result also reported by Velu et al. [10] and Pant et al. [21].

Grain yield of biofortified entries ranged between 2205 to 3821 kg/ha in 7th HPYT and 2245 to 4456 kg/ha in 8th HPYT with mean value higher than national average (3088 kg/ha) of Nepal. This shows that the biofortified genotypes are capable of producing higher grain yield with added micronutrient supplements in them as compared to the check "Gautam" variety. Thus, the study prospects the enhancement of Zn and Fe content of wheat without really compromising the grain yield. Similar results were also demonstrated earlier by Velu et al. [10] and McDonald et al. [20].



(a) (b)

Fig. 4. (a) Distribution and correlation of morphological and yield related traits of 7th HPYT. (b) Distribution and correlation of morphological and yield related traits of 8th HPYT

*Where, DTH=Days to heading, DTM=Days to maturity, PH=plant height, TGW=Thousand grain weight, GFeC(ppm)=Grain iron concentration, GZnC (ppm)=Grain Zinc concentration, GY=Grain yield and BY=Biomass yield, *=Significant different at 5 % level of significance, **=Highly Significant different at 1 % level of significance and ***=Highly Significant different at 0.1 % level of significance*

3.3 Principal Component Analysis (PCA)

3.3.1 In 7HPYT

The PCA analysis indicated that the first five components (PC1, PC2, PC3, PC4 and PC5) explained maximum cumulative variances of 0.916% are important (Table 3). Chatrath et al. [22] also evaluated 50 biofortified genotypes and found that first five principal component explained maximum cumulative variance of 0.8747%. Among all PCs, the first PC (0.332) contributed maximum to the total variance. The major traits contributing to the first PC are grain zinc concentration, grain iron concentration, grain yield and biomass yield. Similarly, for second PC, DTH, DTM and PH were the major contributors. TGW and grain zinc concertation were the diversity contributor traits in the third PC. In fourth PC, max variation was explained by TGW followed grain zinc concertation. The PH and TGW are the major contributing traits for PC5 [23].

The biplot explains the relationship of 50 wheat genotypes with component traits (Fig. 5). Across the 50 genotypes, grain yield was positively associated with biomass yield and negatively with grain zinc and iron concentration.

3.3.2 8HPYT

The PCA analysis indicated that the first five components (PC1, PC2, PC3, PC4 and PC5) explained maximum cumulative variances of 0.935% are important (Table 4). Among all PCs, the first PC (0.341) contributed maximum to the total variance. The major traits contributing to the first PC are grain zinc concentration, grain iron

Table 3. Vector loadings and proportion of variance explained by the first five principal components (PC) of 7th HPYT

Traits	PC1	PC2	PC3	PC4	PC5
Days to heading	0.119883	0.622187	0.136391	-0.14067	-0.28514
Days to maturity	0.156621	0.593864	0.223536	0.036227	-0.24276
Plant height	-0.08343	0.465979	-0.33484	0.318972	0.747138
Thousand grains weight	0.18922	-0.03556	-0.5929	0.584139	-0.46786
Grain Zinc Concentration	0.432996	-0.02719	-0.34696	-0.5752	0.163575
Grain Iron Concentration	0.526352	0.000257	-0.29616	-0.18181	-0.01291
Grain Yield	-0.50924	0.045742	-0.32785	-0.24328	-0.17798
Biomass Yield	-0.44099	0.197425	-0.39014	-0.33592	-0.15511
Loadings					
Standard deviation	1.63	1.3738	1.2221	0.83578	0.77167
Eigen value	2.65	1.887	1.493	0.697	0.594
Proportion of Variance	0.332	0.2359	0.1867	0.08732	0.07443
Cumulative Proportion	0.332	0.5679	0.7546	0.84188	0.91632

Table 4. Vector loadings and proportion of variance explained by the first five principal components (PC) of 8th HPYT

Traits	PC1	PC2	PC3	PC4	PC5
Days to heading	0.237536	0.609792	-0.02221	-0.08913	-0.25302
Days to maturity	0.276181	0.58614	-0.06526	-0.08583	-0.24613
Plant height	-0.07398	0.3997	-0.18596	0.568488	0.66698
Thousand grains weight	-0.19959	-0.11401	-0.53465	0.571162	-0.56526
Grain Zinc Concentration	0.437355	-0.16797	-0.44355	-0.19487	-0.00615
Grain Iron Concentration	0.376994	-0.1684	-0.54114	-0.18173	0.315146
Grain Yield	-0.50922	0.149227	-0.31055	-0.31304	-0.00037
Biomass Yield	-0.47883	0.181638	-0.29799	-0.40779	0.107987
Loadings					
Standard deviation	1.6535	1.3951	1.066	0.974	0.84643
Eigen value					
Proportion of Variance	0.3417	0.2433	0.142	0.1186	0.08956
Cumulative Proportion	0.3417	0.585	0.727	0.8456	0.93518

concentration, grain yield and biomass yield. Similarly, for second PC, DTH, DTM and PH were the major contributors. TGW, grain zinc concertation, grain iron concentration and grain yield were the diversity contributor traits in the third PC. In fourth PC, max variation was explained by TGW followed by PH and biomass yield. The PH, TGW and grain iron concentration are the major contributing traits for PC5" [23].

The biplot explains the relationship of 50 wheat genotypes with component traits (Fig. 6). Across the 50 genotypes, grain yield was positively associated with biomass yield and TGW and negatively with grain zinc and iron concentration.

3.4 Cluster Analysis

Cluster analysis helps plant breeders in identifying genetically diverse parents who fall into different clusters. Cluster analysis or clustering is the process of grouping, categorizing or classifying a set of objects into many subsets called clusters in such a way that items within one subset are more "similar" to each other, while items within other subsets are "dissimilar."

In 7th HPYT, genotypes were clustered based on variables: days to heading, days to maturity, plant height, thousand grains weight, grain zinc concentration, grain iron concentration, grain yield and biomass yield by Hierarchical clustering method. The mean values of clusters are presented in Table 5. The dendrogram constructed using R-studio software version 4.3.1 revealed four major clusters (Fig. 2).

Cluster I consisted of 13 genotypes, which represents 26% of total genotypes. it includes 7HPYT403, 7HPYT413, 7HPYT417, 7HPYT419, 7HPYT424, 7HPYT427, 7HPYT433, 7HPYT434, 7HPYT441, 7HPYT445, 7HPYT450, Baj#1 and Gautam. This cluster represents genotypes with highest TGW (44.7 g) and earliest in heading and maturity. The genotypes under this cluster are moderate in grain zinc and iron concentration and second in grain yield and biomass yield. Similarly, Cluster II consisted of 10 genotypes, which represents 20% of total genotypes. It includes 7HPYT411, 7HPYT414, 7HPYT418, 7HPYT421, 7HPYT422, 7HPYT426, 7HPYT429, 7HPYT439, 7HPYT448 and Kachu#1. This cluster represents genotypes with highest in grain and biomass yield.

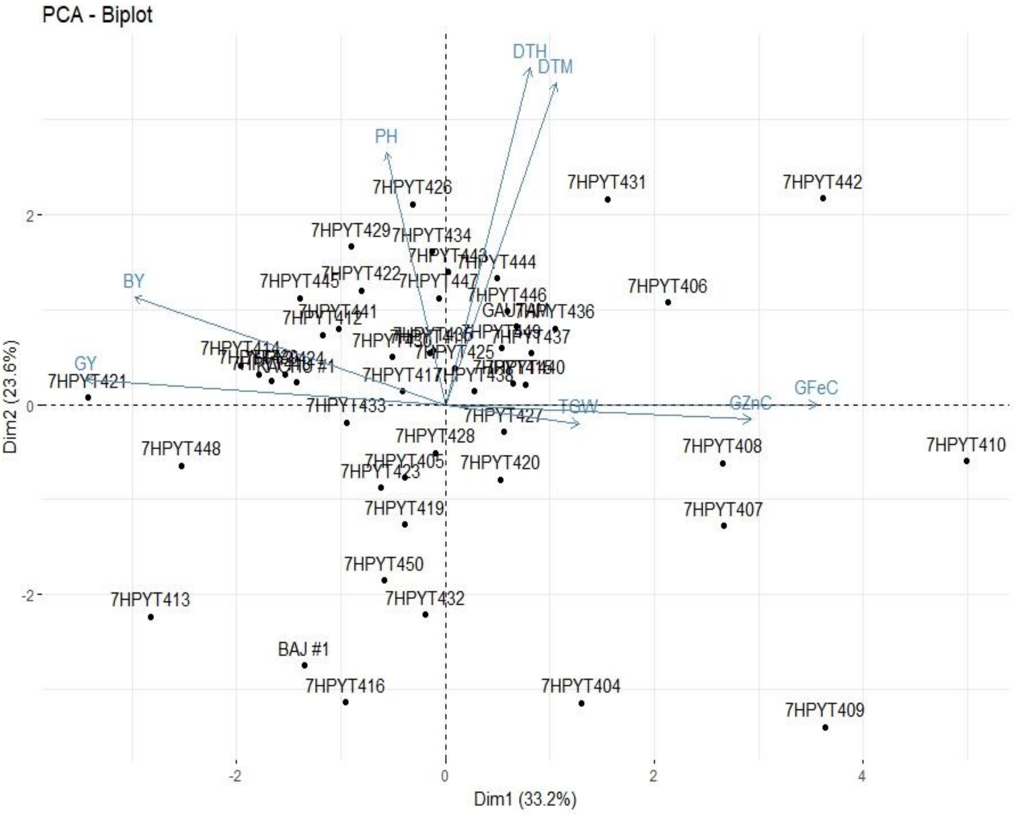


Fig. 5. Principal Component analysis (PCA) between first and second principal components

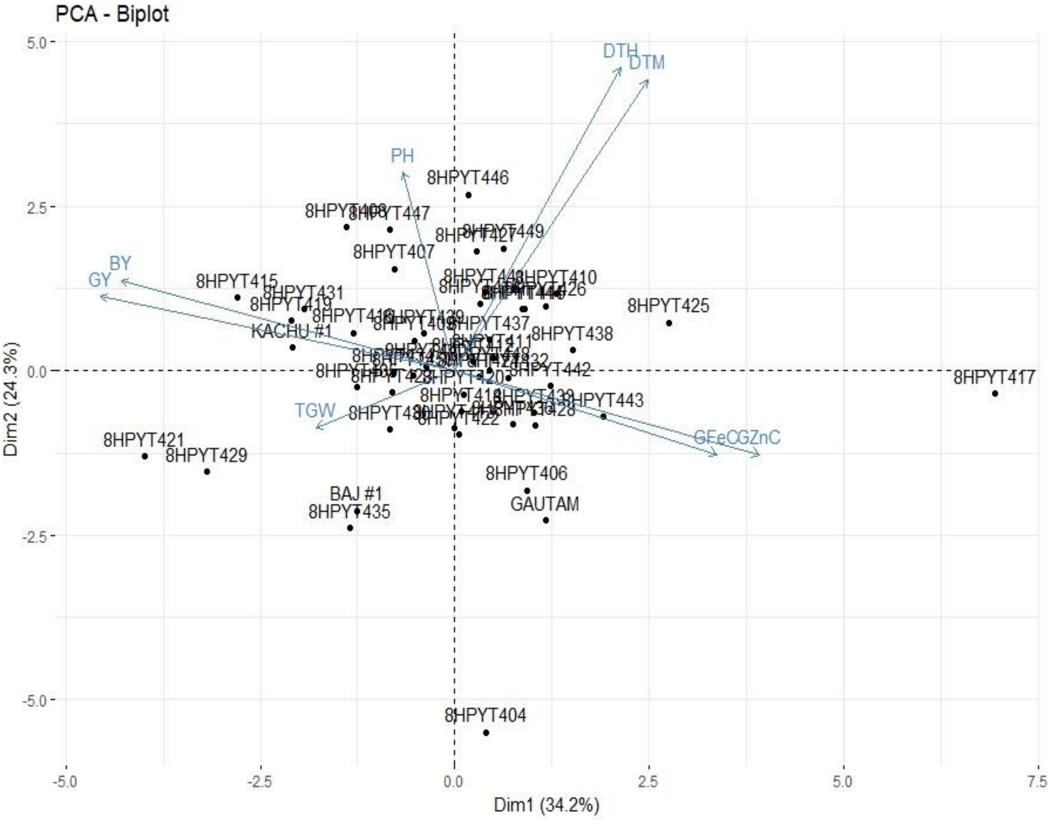


Fig. 6. Principal Component analysis (PCA) between first and second principal components

Table 5. Mean value of traits for 4 clusters obtained from Hierarchical cluster analysis (7th HPYT)

Traits	Cluster I	Cluster II	Cluster III	Cluster IV	Grand Centroid
DTH	82	84	84	84	84
DTM	118	118	119	119	118
PH	85.6	85.8	85.5	82.0	84.7
TGW	44.7	43.2	43.5	44.6	44.0
GZnC	31.2	31.7	31.8	36.2	32.7
GFeC	35.9	34.3	37.8	47.2	38.8
GY	3316.3	3473.9	2952.5	2443.8	3046.6
BY	7240.9	8007.7	6766.6	5938.0	6988.3

Cluster III consisted of 22 genotypes, which represents 44% of total genotypes. It includes 7HPYT404, 7HPYT406, 7HPYT412, 7HPYT415, 7HPYT416, 7HPYT420, 7HPYT423, 7HPYT425, 7HPYT428, 7HPYT430, 7HPYT432, 7HPYT435, 7HPYT436, 7HPYT437, 7HPYT438, 7HPYT440, 7HPYT442, 7HPYT443, 7HPYT444, 7HPYT446, 7HPYT447 and 7HPYT449. This cluster represents genotypes with average value for all traits under study.

Cluster IV consisted of 5 genotypes, which represents 10 % of total genotypes. It includes 7HPYT407, 7HPYT408, 7HPYT409, 7HPYT410 and 7HPYT431.This cluster is characterized with genotypes having lowest grain and biomass yield and highest grain zinc and iron concentration. The mean value of each trait for each cluster was presented in Table 5.

In 8th HPYT, genotypes were clustered based on variables: days to heading, days to maturity, plant height, thousand grains weight, grain zinc concentration, grain iron concentration, grain yield and biomass yield by Hierarchical clustering method. The mean values of clusters are presented in Table 5.

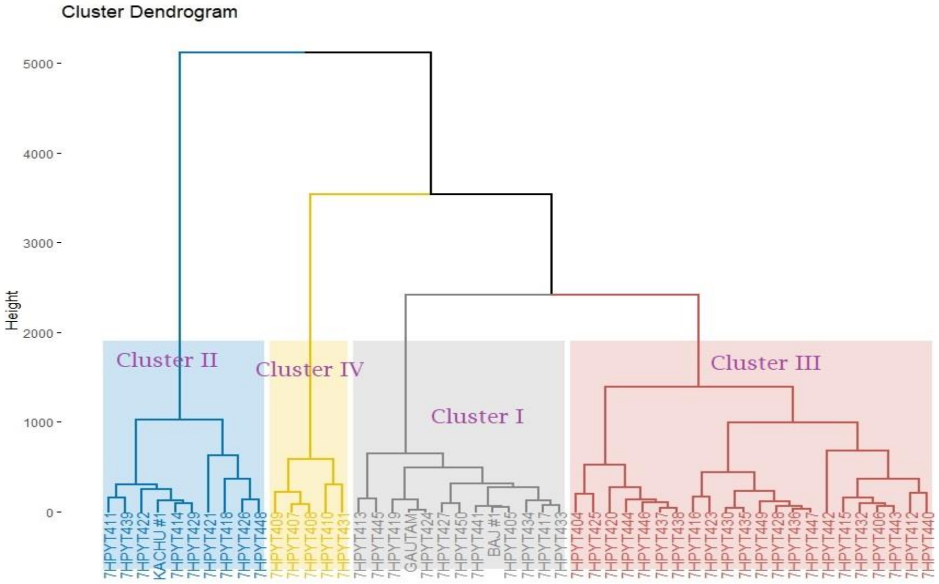


Fig. 7. Clustering of genotypes based on hierarchical clustering method (7th HPYT)

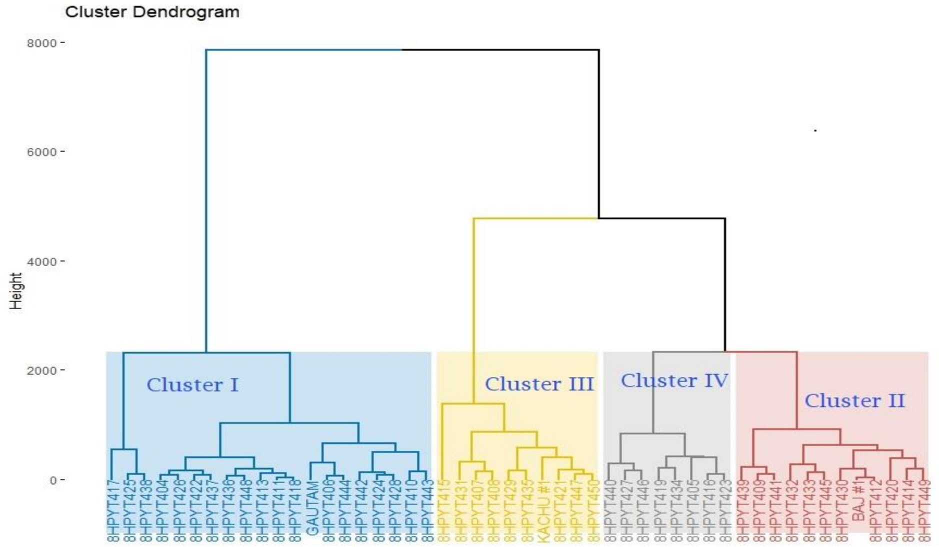


Fig. 8. Clustering of genotypes based on hierarchical clustering method (8th HPYT)

Table 6. Mean value of traits for 4 clusters obtained from Hierarchical cluster analysis (8th HPYT)

Traits	Cluster I	Cluster II	Cluster III	Cluster IV	Grand Centroid
DTH	89	88	88	89	88
DTM	120	120	119	120	120
PH	84.4	86.0	86.3	85.9	85.7
TGW	39.5	37.0	41.4	39.3	39.3
GZnC	30.1	29.0	27.9	28.7	28.9
GFeC	34.0	31.8	32.5	31.3	32.4
GY	2908.9	3188.6	3874.5	3620.8	3398.2
BY	6589.0	7419.8	8865.6	8033.1	7726.9

Cluster I consisted of 20 genotypes, which represents 40% of total genotypes. it includes 8HPYT404, 8HPYT406, 8HPYT410, 8HPYT411, 8HPYT413, 8HPYT417, 8HPYT418, 8HPYT422, 8HPYT424, 8HPYT425, 8HPYT426, 8HPYT428, 8HPYT436, 8HPYT437, 8HPYT438, 8HPYT442, 8HPYT443, 8HPYT444, 8HPYT448 and Gautam. This cluster represents genotypes with highest grain zinc and iron concentration and lowest grain yield and biomass yield. Similarly, Cluster II consisted of 12 genotypes, which represents 24% of total genotypes. It includes 8HPYT409, 8HPYT412, 8HPYT414, 8HPYT420, 8HPYT430, 8HPYT432, 8HPYT433, 8HPYT439, 8HPYT441, 8HPYT445, 8HPYT449 and Baj#1. This cluster represents genotypes with average value for all traits under study.

Cluster III consisted of 10 genotypes, which represents 20% of total genotypes. It includes 8HPYT407, 8HPYT408, 8HPYT415, 8HPYT421, 8HPYT429, 8HPYT431, 8HPYT435, 8HPYT447 and 8HPYT450. This cluster represents genotypes with highest in TGW, grain yield and biomass yield while lowest in grain zinc concentration.

Cluster IV consisted of 8 genotypes, which represents 16% of total genotypes. It includes 8HPYT405, 8HPYT416, 8HPYT419, 8HPYT423, 8HPYT427, 8HPYT434, 8HPYT440 and 8HPYT446. This cluster is characterized with genotypes second in grain yield and biomass yield and moderate in grain zinc and iron concentration. The mean value of each trait for each cluster was presented in Table 6.

4. CONCLUSION

This research showed the existence of large variability for grain zinc and iron concentration and grain yield among the tested biofortified genotypes. The appreciable number of entries exceeded the intermediate to full target level of grain Zn and Fe and grain yield in both 7th HPYT and 8th HPYT trials. Thus, competitive biofortified wheat varieties can be developed with competitive yields and other farmer-preferred agronomic traits. The genotypes with higher grain Zn and Fe concentration viz., 7HPYT409, 7HPYT410, 8HPYT417, 8HPYT404 and 7HPYT442 could be used as donor parents in national wheat breeding program and high yielding genotypes 7HPYT448, 7HPYT418, 7HPYT426, 7HPYT413, 8HPYT415, 8HPYT431, 8HPYT429, 8HPYT407 and 8HPYT405 would be further evaluated throughout the terai region of Nepal, and outstanding genotype could be released as variety for Terai/plains of Nepal.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Bhattarai P, Pokhrel M, Poudel S, Neupane S, Mainali R, Kharel G. Effect of Drought stress on wheat and drought breeding status for it in Nepal with the way forward: A review. Reviews In Food And Agriculture, 2018. 3(1): 24-28. DOI:http://doi.org/10.26480/rfna.01.2022.24.28
2. MoALD, Statistical Information on Nepalese Agriculture (2021/22); Minitry of Agriculture and Livestock Development. 2022.
3. Ministry of Health & Population, Sustainable Development Goal (SDG) Targets; 2017.
4. Calderini DF, Ortiz-Monasterio I. Grain position affects grain macronutrient and micronutrient concentrations in wheat, Crop Sci. 2003;43(1):141–151.
5. Brief H. Breeding crops for better nutrition, Washington, DC, USA; 2006.

6. White PJ, Broadley MR. Biofortification of crops with seven mineral elements often lacking in human diets-iron, zinc, copper, calcium, magnesium, selenium and iodine, New Phytol. 2009;182:49–84.
7. Graham RD, Welch RM, Bouis HE. Addressing micronutrient malnutrition through enhancing the nutritional quality of staple foods: principles, perspectives and knowledge gaps; 2001;77-142.
8. Bouis HE. The potential of genetically modified food crops to improve human nutrition in developing countries 1. In Transgenics and the Poor, Routledge. 2013:79–96.
9. Velu G, Ortiz-Monasterio I, Singh RP, Payne T. Collection accessions of diverse origin. Asian J. Crop Sci. 2011; 3(1):43–48.
10. Velu G, Singh RP, Huerta-Espino J, Peña RJ, Arun B, Mahendru-Singh A, Mujahid MY, Sohu VS, Mavi GS, Crossa J, Alvarado G. Performance of biofortified spring wheat genotypes in target environments for grain zinc and iron concentrations, F. Crop. Res. 2012;137:261–267.
11. Pfeiffer WH, McClafferty B. HarvestPlus: breeding crops for better nutrition,. Crop Sci. 2007;47:S-88.
12. NWRP. Annual Report 2076/77, Bhairahawa, Rupendehi, Nepal; 2020.
13. Thapa DB, Subedi M, Yadav RP, Joshi BP, Adhikari BN, Shrestha KP, Magar PB, Pant KR, Gurung SB, Ghimire S, Gautam NR. Variation in grain zinc and iron concentrations, grain yield and associated traits of biofortified bread wheat genotypes in Nepal. Front. Plant Sci. 2022;13: 881965, 2022,
    DOI: 10.3389/fpls.2022.881965
14. Pant K, Pandey D, Bastola BR, Subedi M, Acharya R, Gautam NR, Dhami NB, Gupt SR, Pandey BP, Thapa DB, Basnet R. Wheat varietal development for the mid and high hill region of Nepal, Proc. 32nd Natl. Winter crop workshop; 2023.
15. Gomez-Becerra HF, Erdem HA, Yazici A, Tutus Y, Torun B, Ozturk L, Cakmak I. Grain concentrations of protein and mineral nutrients in a large collection of spelt wheat grown under different environments. J. Cereal Sci. 2010;52(3): 342–349.
16. Srinivasa J, Arun B, Mishra VK, Chand R, Sharma D, Bhardwaj SC, Joshi AK. Accessing spelt gene pool to develop well-adapted zinc-and iron-rich bread wheat. Crop Sci. 2014;54(5):2000–2010.
17. Pandey D, Pant KR, Bastola BR, Giri R, Bohara S, Shrestha S, Hamal GB, Shrestha J. Evaluation of bread wheat genotypes under rain-fed conditions in Terai districts of Nepal. J. Agric. Nat. Resour. 2021;4(2):303–315.
18. Nainabasti A, Subedi B, Thapa DS, Bohora KB, Shah MK, Pant KR. Evaluation of elite spring wheat genotypes for grain yield and other agronomic attributes in hills of Sudurpaschim Province, Nepal. Arch. Agric. Environ. Sci. 2024;9(1):85–92.
    DOI: 10.26832/24566632.2024.0901013
19. Asif M, Mujahid MY, Kisana NS, Mustafa SZ, Ahmad I. Heritability, genetic variability and path coefficient of some traits in spring wheat; 2004.
20. McDonald GK, Genc Y, Graham RD. A simple method to evaluate genetic variation in grain zinc concentration by correcting for differences in grain yield," Plant Soil. 2008;306:49–55.
21. Pant KR, Ojha BR, Thapa DB, Gautam NR, Shrestha J. Evaluation of biofortified spring wheat genotypes for yield and micronutrient contents, Fundam. Appl. Agric. 2020;5(1):78–87.
22. Chatrath R, Gupta V, Parkash O, Singh GP. Evaluation of biofortified spring wheat genotypes for yield and micronutrients. Journal of Applied and Natural Science. 2018;10(1):210-215.
23. Ghimire S, Thapa DB, Paudel A, Adhikari NR. Variability study of biofortified bread wheat genotypes for grain zinc and iron concentration, yield and yield associated traits at Khumaltar, Lalitpur, Nepal. International Journal of Applied Sciences and Biotechnology. 2019;7(2):184-94.

ANNEXES

Annex 1. Genotypic details of 7HPYT (2016/17)

E.N.	Name of entries	Cross Name	Selection History	Origin
1	GAUTAM(Local Check)	SIDDHARTH/NING8319/NL297	-	NEPAL
2	BAJ #1	BAJ #1	CGSS01Y00134S-099Y-099M-099M-13Y-0B	MXI15-16\M7THHPYT\32
3	KACHU #1	KACHU #1	CMSS97M03912T-040Y-020Y-030M-020Y-040M-4Y-2M-0Y	MXI15-16\M7THHPYT\31
4	7HPYT404	CROC_1/AE.SQUARROSA (210)//INQALAB 91*2/KUKUNA/3/PBW343*2/KUKUNA	CMSA06M00195T-099Y-099Y-9M-0Y-7B-0Y	MXI15-16\M7THHPYT\1
5	7HPYT405	T.DICOCCON CI9309/AE.SQUARROSA (409)//MUTUS/3/2*MUTUS	CMSS08Y01129T-099M-099Y-3M-0Y-5M-0Y	MXI15-16\M7THHPYT\2
6	7HPYT406	DANPHE #1*2/3/T.DICOCCON PI94625/AE.SQUARROSA (372)//SHA4/CHIL/4/WBLL1*2/KURUKU//HEILO/5/WBLL1*2/KURUKU//HEILO	CMSS11B01191T-099TOPY-099M-099Y-3M-0WGY	MXI15-16\M7THHPYT\5
7	7HPYT407	DANPHE #1*2/3/T.DICOCCON PI94625/AE.SQUARROSA (372)//SHA4/CHIL/4/WBLL1*2/KURUKU//HEILO/5/WBLL1*2/KURUKU//HEILO	CMSS11B01191T-099TOPY-099M-099Y-30M-0WGY	MXI15-16\M7THHPYT\7
8	7HPYT408	DANPHE #1*2/3/T.DICOCCON PI94625/AE.SQUARROSA (372)//SHA4/CHIL/4/WBLL1*2/KURUKU//HEILO/5/WBLL1*2/KURUKU//HEILO	CMSS11B01191T-099TOPY-099M-099Y-31M-0WGY	MXI15-16\M7THHPYT\8
9	7HPYT409	CHONTE*2/SOLALA//2*BAJ #1	CMSS11B01204T-099TOPY-099M-099Y-8M-0WGY	MXI15-16\M7THHPYT\24
10	7HPYT410	FRNCLN*2/7/CMH83.1020/HUITES/6/CMH79A.955/4/AGA/3/4*SN64/CNO67//INIA66/5/NAC/8/WBLL1*2/KURUKU//HEILO/9/WBLL1*2/KURUKU//HEILO	CMSS11B01210T-099TOPY-099M-099Y-9M-0WGY	MXI15-16\M7THHPYT\30
11	7HPYT411	FRNCLN*2/7/CMH83.1020/HUITES/6/CMH79A.955/4/AGA/3/4*SN64/CNO67//INIA66/5/NAC/8/WBLL1*2/KURUKU//HEILO/9/WBLL1*2/KURUKU//HEILO	CMSS11B01210T-099TOPY-099M-099Y-16M-0WGY	MXI15-16\M7THHPYT\33
12	7HPYT412	FRNCLN*2/7/CMH83.1020/HUITES/6/CMH79A.955/4/AGA/3/4*SN64/CNO67//INIA66/5/NAC/8/WBLL1*2/KURUKU//HEILO/9/WBLL1*2/KURUKU//HEILO	CMSS11B01210T-099TOPY-099M-099Y-51M-0WGY	MXI15-16\M7THHPYT\39
13	7HPYT413	FRNCLN*2/7/CMH83.1020/HUITES/6/CMH79A.955/4/AGA/3/4*SN64/CNO67//INIA66/5/NAC/8/KIRITATI/4/2*BAV92//IRENA/KAUZ/3/HUITES/9/FRANCOLIN #1//WBLL1*2/BRAMBLING	CMSS11B01213T-099TOPY-099M-099Y-8M-0WGY	MXI15-16\M7THHPYT\41
14	7HPYT414	VILLA JUAREZ	CMSS11B01216T-099TOPY-	MXI15-16\M7THHPYT\46

E.N.	Name of entries	Cross Name	Selection History	Origin
		F2009/SOLALA//WBLL1*2/BRAMBLING/5/WAXWING/3/BL 1496/MILAN//PI 610750/4/FRNCLN/6/MUNAL/3/HUW234+LR34/PRINIA//PFAU/WEAVER	099M-099Y-19M-0WGY	
15	7HPYT415	KVZ/PPR47.89C//TACUPETO F2001*2/BRAMBLING/3/2*TACUPETO F2001*2/BRAMBLING/4/KACHU/5/KACHU #1/3/C80.1/3*BATAVIA//2*WBLL1/4/KACHU	CMSS11B01218T-099TOPY-099M-099Y-7M-0WGY	MXI15-16\M7THHPYT\47
16	7HPYT416	KVZ/PPR47.89C//FRANCOLIN #1/3/2*PAURAQ/4/PBW343*2/KUKUNA*2//FRTL/PIFED/5/MUNAL #1	CMSS11B01222T-099TOPY-099M-099Y-29M-0WGY	MXI15-16\M7THHPYT\50
17	7HPYT417	HGO94.7.1.12/2*QUAIU #1//QUAIU #2/3/KINGBIRD #1//INQALAB 91*2/TUKURU/4/SUP152/BAJ #1	CMSS11B01227T-099TOPY-099M-099Y-13M-0WGY	MXI15-16\M7THHPYT\51
18	7HPYT418	HGO94.7.1.12/2*QUAIU #1//QUAIU #2/5/KIRITATI/4/2*BAV92//IRENA/KAUZ/3/HUITES/6/MUCUY	CMSS11B01228T-099TOPY-099M-099Y-14M-0WGY	MXI15-16\M7THHPYT\53
19	7HPYT419	HGO94.7.1.12/2*QUAIU #1//QUAIU #2/5/KIRITATI/4/2*BAV92//IRENA/KAUZ/3/HUITES/6/MUCUY	CMSS11B01228T-099TOPY-099M-099Y-20M-0WGY	MXI15-16\M7THHPYT\54
20	7HPYT420	CHIH95.2.6//WBLL1*2/KURUKU/3/WBLL1*2/KKTS/4/ND643/2*WBLL1/5/SAUAL/YANAC//SAUAL/6/WBLL1*2/BRAMBLING//VORB/FISCAL/3/BECARD	CMSS11B01230T-099TOPY-099M-099Y-19M-0WGY	MXI15-16\M7THHPYT\55
21	7HPYT421	CHIH95.2.6//WBLL1*2/KURUKU/3/WBLL1*2/KKTS/4/ND643/2*WBLL1/5/TACUPETO F2001/BRAMBLING*2//KACHU/6/KUTZ	CMSS11B01231T-099TOPY-099M-099Y-12M-0WGY	MXI15-16\M7THHPYT\56
22	7HPYT422	T.DICOCCON CI9309/AE.SQUARROSA (409)//2*PANDORA/3/KINGBIRD #1//INQALAB 91*2/TUKURU/5/MUNAL/3/KIRITATI//PRL/2*PASTOR/4/MUNAL	CMSS11B01236T-099TOPY-099M-099Y-31M-0WGY	MXI15-16\M7THHPYT\60
23	7HPYT423	T.DICOCCON CI9309/AE.SQUARROSA (409)//2*PANDORA/5/WAXWING/3/BL 1496/MILAN//PI 610750/4/FRNCLN/6/KACHU/BECARD//WBLL1*2/BRAMBLING	CMSS11B01237T-099TOPY-099M-099Y-3M-0WGY	MXI15-16\M7THHPYT\63
24	7HPYT424	HGO94.7.1.12/2*QUAIU #1//WAXBI/5/WBLL1*2/4/BABAX/LR42//BABAX/3/BABAX/LR42//BABAX	CMSS11B01246T-099TOPY-099M-099Y-23M-0WGY	MXI15-16\M7THHPYT\74
25	7HPYT425	COAH90.26.31/4/2*BL2064//SW89-5124*2/FASAN/3/TILHI/5/UP2338*2/KKTS*2//YANAC/6/MUTUS/AKURI	CMSS11B01249T-099TOPY-099M-099Y-19M-0WGY	MXI15-16\M7THHPYT\80
26	7HPYT426	COAH90.26.31/4/2*BL2064//SW89-5124*2/FASAN/3/TILHI/5/UP2338*2/KKTS*2//YANAC/6/MUTUS/AKURI	CMSS11B01249T-099TOPY-099M-099Y-32M-0WGY	MXI15-16\M7THHPYT\82
27	7HPYT427	CROC_1/AE.SQUARROSA (210)//INQALAB	CMSS11B01270T-099TOPY-	MXI15-16\M7THHPYT\89

E.N.	Name of entries	Cross Name	Selection History	Origin
		91*2/KUKUNA/3/PBW343*2/KUKUNA/5/SAUAL/3/C80.1/3*BATAVIA//2*WBLL1/4/SITE/MO//PASTOR/3/TILHI/6/SAUAL #1/KACHU	099M-099Y-11M-0WGY	
28	7HPYT428	UC1113-GPCB1/3/TACUPETO F2001/BRAMBLING*2//KACHU/4/TACUPETO F2001/BRAMBLING//KACHU	CMSS11B01295T-099TOPY-099M-099Y-10M-0WGY	MXI15-16\M7THHPYT\101
29	7HPYT429	CHONTE*2/SOLALA/5/GARZA/BOY//AE.SQUARROSA (467)/3/T.DICOCCON PI94625/AE.SQUARROSA (372)//3*PASTOR/4/T.DICOCCON PI94625/AE.SQUARROSA (372)//3*PASTOR/6/ATTILA*2/PBW65//PIHA/3/ATTILA/2*PASTOR	CMSS11B01302T-099TOPY-099M-099Y-8M-0WGY	MXI15-16\M7THHPYT\102
30	7HPYT430	QUAIU #1/3/T.DICOCCON PI94625/AE.SQUARROSA (372)//3*PASTOR/4/QUAIU #2/5/BORL14	CMSS11B01045S-099M-099Y-1M-0WGY	MXI15-16\M7THHPYT\107
31	7HPYT431	DANPHE #1*2/SOLALA/3/ATTILA*2/PBW65//MURGA	CMSS11B01057S-099M-099Y-17M-0WGY	MXI15-16\M7THHPYT\109
32	7HPYT432	VILLA JUAREZ F2009/SOLALA//WBLL1*2/BRAMBLING/4/COAH90.26.31//KIRITATI/WBLL1/3/KIRITATI/2*WBLL1	CMSS11B01079S-099M-099Y-16M-0WGY	MXI15-16\M7THHPYT\115
33	7HPYT433	VILLA JUAREZ F2009/SOLALA//WBLL1*2/BRAMBLING/3/PBW343*2/KUKUNA*2//FRTL/PIFED	CMSS11B01081S-099M-099Y-11M-0WGY	MXI15-16\M7THHPYT\123
34	7HPYT434	VILLA JUAREZ F2009/SOLALA//WBLL1*2/BRAMBLING/3/PBW343*2/KUKUNA*2//FRTL/PIFED	CMSS11B01081S-099M-099Y-15M-0WGY	MXI15-16\M7THHPYT\124
35	7HPYT435	T.DICOCCON CI9309/AE.SQUARROSA (409)//MUTUS/3/2*MUTUS/5/T.DICOCCON PI94624/AE.SQUARROSA (409)//BCN/3/WAXWING/4/2*FRNCLN	CMSS11B01083S-099M-099Y-21M-0WGY	MXI15-16\M7THHPYT\128
36	7HPYT436	T.DICOCCON CI9309/AE.SQUARROSA (409)//MUTUS/3/2*MUTUS/4/FRET2/TUKURU//FRET2*2/3/T.SPELTA PI348530	CMSS11B01084S-099M-099Y-6M-0WGY	MXI15-16\M7THHPYT\130
37	7HPYT437	T.DICOCCON CI9309/AE.SQUARROSA (409)//MUTUS/3/2*MUTUS/4/FRET2/TUKURU//FRET2*2/3/T.SPELTA PI348530	CMSS11B01084S-099M-099Y-42M-0WGY	MXI15-16\M7THHPYT\133
38	7HPYT438	T.DICOCCON CI9309/AE.SQUARROSA (409)//MUTUS/3/2*MUTUS/5/PFAU/WEAVER*2/4/BOW/NKT//CBRD/3/CBRD	CMSS11B01087S-099M-099Y-21M-0WGY	MXI15-16\M7THHPYT\136
39	7HPYT439	T.DICOCCON PI94624/AE.SQUARROSA	CMSS11B01090S-099M-099Y-	MXI15-16\M7THHPYT\139

E.N.	Name of entries	Cross Name	Selection History	Origin
		(409)//BCN/3/WAXWING/4/2*FRNCLN/5/VILLA JUAREZ F2009/3/T.DICOCCON PI94625/AE.SQUARROSA (372)//3*PASTOR/4/WBLL1*2/BRAMBLING	1M-0WGY	
40	7HPYT440	CHIH95.2.6/4/BABAX/LR42//BABAX*2/3/SHAMA/5/2*BABAX/LR 42//BABAX*2/3/TUKURU/6/KFA/2*KACHU	CMSS11B01099S-099M-099Y-5M-0WGY	MXI15-16\M7THHPYT\141
41	7HPYT441	HGO94.7.1.12/2*QUAIU #1/3/VILLA JUAREZ F2009/SOLALA//WBLL1*2/BRAMBLING	CMSS11B01126S-099M-099Y-8M-0WGY	MXI15-16\M7THHPYT\149
42	7HPYT442	HGO94.7.1.12//WBLL1*2/KUKUNA/3/WBLL1*2/KURUKU/4/PBW 343*2/KUKUNA*2//FRTL/PIFED	CMSS11B01134S-099M-099Y-9M-0WGY	MXI15-16\M7THHPYT\154
43	7HPYT443	COAH90.26.31//KIRITATI/WBLL1/3/KIRITATI/2*WBLL1/7/OASIS/SKAUZ//4*BCN/3/2*PASTOR/4/T.SPELTA PI348449/5/BACEU #1/6/WBLL1*2/CHAPIO	CMSS11B01145S-099M-099Y-19M-0WGY	MXI15-16\M7THHPYT\158
44	7HPYT444	VILLA JUAREZ F2009/3/T.DICOCCON PI94625/AE.SQUARROSA (372)//3*PASTOR/4/WBLL1*2/BRAMBLING/5/QUAIU #1/3/T.DICOCCON PI94625/AE.SQUARROSA (372)//3*PASTOR/4/QUAIU #2	CMSS11B01149S-099M-099Y-4M-0WGY	MXI15-16\M7THHPYT\160
45	7HPYT445	VILLA JUAREZ F2009/3/T.DICOCCON PI94625/AE.SQUARROSA (372)//3*PASTOR/4/WBLL1*2/BRAMBLING/5/QUAIU #1/3/T.DICOCCON PI94625/AE.SQUARROSA (372)//3*PASTOR/4/QUAIU #2	CMSS11B01149S-099M-099Y-15M-0WGY	MXI15-16\M7THHPYT\161
46	7HPYT446	VILLA JUAREZ F2009/3/T.DICOCCON PI94625/AE.SQUARROSA (372)//3*PASTOR/4/WBLL1*2/BRAMBLING/5/QUAIU #1/3/T.DICOCCON PI94625/AE.SQUARROSA (372)//3*PASTOR/4/QUAIU #2	CMSS11B01149S-099M-099Y-33M-0WGY	MXI15-16\M7THHPYT\164
47	7HPYT447	VILLA JUAREZ F2009/3/T.DICOCCON PI94625/AE.SQUARROSA (372)//3*PASTOR/4/WBLL1*2/BRAMBLING/7/OASIS/SKAUZ//4*BCN/3/2*PASTOR/4/T.SPELTA PI348449/5/BACEU #1/6/WBLL1*2/CHAPIO	CMSS11B01151S-099M-099Y-21M-0WGY	MXI15-16\M7THHPYT\165
48	7HPYT448	VILLA JUAREZ F2009/3/T.DICOCCON PI94625/AE.SQUARROSA (372)//3*PASTOR/4/WBLL1*2/BRAMBLING/5/BAJ #1/AKURI	CMSS11B01152S-099M-099Y-6M-0WGY	MXI15-16\M7THHPYT\167
49	7HPYT449	VILLA JUAREZ F2009/3/T.DICOCCON PI94625/AE.SQUARROSA (372)//3*PASTOR/4/WBLL1*2/BRAMBLING/5/ATTILA*2/PBW65//	CMSS11B01153S-099M-099Y-14M-0WGY	MXI15-16\M7THHPYT\169

E.N.	Name of entries	Cross Name	Selection History	Origin
		MUU #1/3/FRANCOLIN #1		
50	7HPYT450	68.111/RGB-U//WARD/3/AE.SQUARROSA (321)/4/INQALAB 91*2/KUKUNA/5/PBW343*2/KUKUNA/6/MUCUY	CMSS11B01182S-099M-099Y-8M-0WGY	MXI15-16\M7THHPYT\170

Annex 2. Genotypic details of 8HPYT (2017/18)

E.N.	Name of entries	Cross Name	Selection History	Origin
1	GAUTAM (Local Check)	SIDDHARTH/NING8319/NL297	-	Nepal
2	BAJ #1	BAJ #1	CGSS01Y00134S-099Y-099M-099M-13Y-0B	MXI16-17\M8THHPYT\125
3	KACHU #1	KACHU #1	CMSS97M03912T-040Y-020Y-030M-020Y-040M-4Y-2M-0Y	MXI16-17\M8THHPYT\25
4	8HPYT404	ZINCSHAKTHI	CMSA06M00195T-099Y-099Y-9M-0Y-7B-0Y	MXI16-17\M8THHPYT\75
5	8HPYT405	MAYIL	CMSS08Y01129T-099M-099Y-3M-0Y-5M-0Y	MXI16-17\M8THHPYT\100
6	8HPYT406	DANPHE #1*2/3/T.DICOCCON PI94625/AE.SQUARROSA (372)//SHA4/CHIL/4/BOKOTA	CMSS12B01158S-099M-099Y-8M-0WGY	MXI16-17\M8THHPYT\1
7	8HPYT407	QUAIU #1/3/T.DICOCCON PI94625/AE.SQUARROSA (372)//3*PASTOR/4/QUAIU #2/5/VILLA JUAREZ F2009/3/T.DICOCCON PI94625/AE.SQUARROSA (372)//3*PASTOR/4/WBLL1*2/BRAMBLING	CMSS12B01180S-099M-099Y-2M-0WGY	MXI16-17\M8THHPYT\7
8	8HPYT408	QUAIU #1/3/T.DICOCCON PI94625/AE.SQUARROSA (372)//3*PASTOR/4/QUAIU #2/5/VILLA JUAREZ F2009/3/T.DICOCCON PI94625/AE.SQUARROSA (372)//3*PASTOR/4/WBLL1*2/BRAMBLING	CMSS12B01180S-099M-099Y-32M-0WGY	MXI16-17\M8THHPYT\8
9	8HPYT409	WHEAR/KUKUNA/3/C80.1/3*BATAVIA//2*WBLL1/4/T.DICOCCON PI94625/AE.SQUARROSA (372)//3*PASTOR/5/WHEAR/KUKUNA/3/C80.1/3*BATAVIA//2*WBLL1/6/QUAIU #1/SOLALA//QUAIU #2	CMSS12B01199S-099M-099Y-13M-0WGY	MXI16-17\M8THHPYT\12
10	8HPYT410	MANKU/ZINCOL	CMSS12B01216S-099M-099Y-6M-0WGY	MXI16-17\M8THHPYT\15
11	8HPYT411	MANKU/ZINCOL	CMSS12B01216S-099M-099Y-35M-0WGY	MXI16-17\M8THHPYT\16
12	8HPYT412	KOKILA/BOKOTA	CMSS12B01232S-099M-099Y-12M-0WGY	MXI16-17\M8THHPYT\21
13	8HPYT413	ZINCOL/VALI	CMSS12B01234S-099M-099Y-10M-0WGY	MXI16-17\M8THHPYT\24

E.N.	Name of entries	Cross Name	Selection History	Origin
14	8HPYT414	ZINCOL/VALI	CMSS12B01234S-099M-099Y-29M-0WGY	MXI16-17\M8THHPYT\26
15	8HPYT415	PAURAQ//RL6043/4*NAC/3/QUAIU #1/SOLALA//QUAIU #2	CMSS12B01290S-099M-099Y-10M-0WGY	MXI16-17\M8THHPYT\37
16	8HPYT416	DANPHE #1*2/3/T.DICOCCON PI94625/AE.SQUARROSA (372)//SHA4/CHIL/4/SHAKTI/5/VALI	CMSS12B01359T-099TOPY-099M-099Y-32M-0WGY	MXI16-17\M8THHPYT\45
17	8HPYT417	VALI*2/6/WHEAR/KUKUNA/3/C80.1/3*BATAVIA//2*WBLL1/4/T.DICOCCON PI94625/AE.SQUARROSA (372)//SHA4/CHIL/5/WHEAR/KUKUNA/3/C80.1/3*BATAVIA//2*WBLL1	CMSS12B01362T-099TOPY-099M-099Y-56M-0WGY	MXI16-17\M8THHPYT\46
18	8HPYT418	VALI/6/2*WHEAR/KUKUNA/3/C80.1/3*BATAVIA//2*WBLL1/4/T.DICOCCON PI94625/AE.SQUARROSA (372)//SHA4/CHIL/5/WHEAR/KUKUNA/3/C80.1/3*BATAVIA//2*WBLL1	CMSS12B01363T-099TOPY-099M-099Y-20M-0WGY	MXI16-17\M8THHPYT\47
19	8HPYT419	VALI/MAYIL/6/WHEAR/KUKUNA/3/C80.1/3*BATAVIA//2*WBLL1/4/T.DICOCCON PI94625/AE.SQUARROSA (372)//SHA4/CHIL/5/WHEAR/KUKUNA/3/C80.1/3*BATAVIA//2*WBLL1	CMSS12B01366T-099TOPY-099M-099Y-17M-0WGY	MXI16-17\M8THHPYT\51
20	8HPYT420	VALI/MAYIL/6/WHEAR/KUKUNA/3/C80.1/3*BATAVIA//2*WBLL1/4/T.DICOCCON PI94625/AE.SQUARROSA (372)//SHA4/CHIL/5/WHEAR/KUKUNA/3/C80.1/3*BATAVIA//2*WBLL1	CMSS12B01366T-099TOPY-099M-099Y-40M-0WGY	MXI16-17\M8THHPYT\53
21	8HPYT421	WHEAR/KUKUNA/3/C80.1/3*BATAVIA//2*WBLL1/4/T.DICOCCON PI94625/AE.SQUARROSA (372)//SHA4/CHIL/5/WHEAR/KUKUNA/3/C80.1/3*BATAVIA//2*WBLL1*2/6/ZINCOL	CMSS12B01368T-099TOPY-099M-099Y-22M-0WGY	MXI16-17\M8THHPYT\54
22	8HPYT422	COAH90.26.31//KIRITATI/WBLL1/3/KIRITATI/2*WBLL1/6/2*WHEAR/KUKUNA/3/C80.1/3*BATAVIA//2*WBLL1/4/T.DICOCCON PI94625/AE.SQUARROSA (372)//SHA4/CHIL/5/WHEAR/KUKUNA/3/C80.1/3*BATAVIA//2*WBLL1	CMSS12B01374T-099TOPY-099M-099Y-52M-0WGY	MXI16-17\M8THHPYT\69
23	8HPYT423	QUAIU #1/3/T.DICOCCON PI94625/AE.SQUARROSA (372)//3*PASTOR/4/QUAIU #2/5/VALI/6/BECARD/QUAIU #1	CMSS12B01377T-099TOPY-099M-099Y-8M-0WGY	MXI16-17\M8THHPYT\71
24	8HPYT424	QUAIU #1/3/T.DICOCCON PI94625/AE.SQUARROSA (372)//3*PASTOR/4/QUAIU #2/5/VALI/6/BECARD/QUAIU #1	CMSS12B01377T-099TOPY-099M-099Y-10M-0WGY	MXI16-17\M8THHPYT\72
25	8HPYT425	MAYIL/ZINCOL//ITP40/AKURI	CMSS12B01380T-099TOPY-099M-099Y-40M-0WGY	MXI16-17\M8THHPYT\79
26	8HPYT426	HOLO/BORL14//VALI	CMSS12B01392T-099TOPY-099M-099Y-23M-0WGY	MXI16-17\M8THHPYT\84
27	8HPYT427	REH/HARE//2*BCN/3/CROC_1/AE.SQUARROSA (213)//PGO/4/HUITES/5/T.SPELTA PI348599/6/REH/HARE//2*BCN/3/CROC_1/AE.SQUARROSA (213)//PGO/4/HUITES/7/QUAIU/8/2*QUAIU #1/SOLALA//QUAIU #2	CMSS12B01406T-099TOPY-099M-099Y-22M-0WGY	MXI16-17\M8THHPYT\94

E.N.	Name of entries	Cross Name	Selection History	Origin
28	8HPYT428	FRET2/TUKURU//FRET2*2/3/T.SPELTA PI348530/4/VALI/5/MUCUY	CMSS12B01408T-099TOPY-099M-099Y-39M-0WGY	MXI16-17\M8THHPYT\102
29	8HPYT429	KATERE/3/QUAIU #1/SOLALA//QUAIU #2/4/BECARD/QUAIU #1	CMSS12B01418T-099TOPY-099M-099Y-21M-0WGY	MXI16-17\M8THHPYT\105
30	8HPYT430	KATERE/2*BORL14	CMSS12B01419T-099TOPY-099M-099Y-16M-0WGY	MXI16-17\M8THHPYT\106
31	8HPYT431	KATERE/BORL14/3/WBLL1*2/KURUKU//SUP152	CMSS12B01420T-099TOPY-099M-099Y-18M-0WGY	MXI16-17\M8THHPYT\107
32	8HPYT432	KATERE/BORL14/3/WBLL1*2/KURUKU//SUP152	CMSS12B01420T-099TOPY-099M-099Y-30M-0WGY	MXI16-17\M8THHPYT\110
33	8HPYT433	CROC_1/AE.SQUARROSA (210)//PBW343*2/KUKUNA/3/PBW343*2/KUKUNA/4/VALI/5/MANKU	CMSS12B01424T-099TOPY-099M-099Y-24M-0WGY	MXI16-17\M8THHPYT\118
34	8HPYT434	SHAKTI/2*BORL14	CMSS12B01430T-099TOPY-099M-099Y-27M-0WGY	MXI16-17\M8THHPYT\120
35	8HPYT435	VALI/MAYIL	CMSS12Y01314S-099Y-099M-099Y-6M-0WGY	MXI16-17\M8THHPYT\122
36	8HPYT436	WHEAR/KUKUNA/3/C80.1/3*BATAVIA//2*WBLL1/4/T.DICOCCON PI94625/AE.SQUARROSA (372)//SHA4/CHIL/5/WHEAR/KUKUNA/3/C80.1/3*BATAVIA//2*WBLL1/6/DANPHE #1*2/3/T.DICOCCON PI94625/AE.SQUARROSA (372)//SHA4/CHIL	CMSS12Y01317S-099Y-099M-099Y-12M-0WGY	MXI16-17\M8THHPYT\129
37	8HPYT437	WHEAR/KUKUNA/3/C80.1/3*BATAVIA//2*WBLL1/4/T.DICOCCON PI94625/AE.SQUARROSA (372)//SHA4/CHIL/5/WHEAR/KUKUNA/3/C80.1/3*BATAVIA//2*WBLL1/6/ZINCOL	CMSS12Y01319S-099Y-099M-099Y-24M-0WGY	MXI16-17\M8THHPYT\131
38	8HPYT438	MAYIL/ZINCOL	CMSS12Y01376S-099Y-099M-099Y-12M-0WGY	MXI16-17\M8THHPYT\146
39	8HPYT439	HOLO/VALI	CMSS12Y01405S-099Y-099M-099Y-27M-0WGY	MXI16-17\M8THHPYT\154
40	8HPYT440	VILLA JUAREZ F2009/3/T.DICOCCON PI94625/AE.SQUARROSA (372)//3*PASTOR/4/WBLL1*2/BRAMBLING/5/VALI	CMSS12Y01415S-099Y-099M-099Y-6M-0WGY	MXI16-17\M8THHPYT\155
41	8HPYT441	VILLA JUAREZ F2009/3/T.DICOCCON PI94625/AE.SQUARROSA (372)//3*PASTOR/4/WBLL1*2/BRAMBLING/5/VALI	CMSS12Y01415S-099Y-099M-099Y-12M-0WGY	MXI16-17\M8THHPYT\157
42	8HPYT442	ZINCOL/3/QUAIU #1/SOLALA//QUAIU #2	CMSS12Y01432S-099Y-099M-099Y-15M-0WGY	MXI16-17\M8THHPYT\162
43	8HPYT443	REH/HARE//2*BCN/3/CROC_1/AE.SQUARROSA (213)//PGO/4/HUITES/5/T.SPELTA PI348599/6/REH/HARE//2*BCN/3/CROC_1/AE.SQUARROSA	CMSS12Y01444S-099Y-099M-099Y-33M-0WGY	MXI16-17\M8THHPYT\165

E.N.	Name of entries	Cross Name	Selection History	Origin
		(213)//PGO/4/HUITES/7/QUAIU/8/KFA/2*KACHU		
44	8HPYT444	CROC_1/AE.SQUARROSA (210)//PBW343*2/KHVAKI/3/PBW343*2/KUKUNA/4/VALI	CMSS12Y01479S-099Y-099M-099Y-34M-0WGY	MXI16-17\M8THHPYT\167
45	8HPYT445	QUAIU #1/3/T.DICOCCON PI94625/AE.SQUARROSA (372)//3*PASTOR/4/QUAIU #2/5/CHONTE*2/3/T.DICOCCON PI94625/AE.SQUARROSA (372)//3*PASTOR/6/VALI	CMSS12Y01494T-099TOPM-099Y-099M-099Y-11M-0WGY	MXI16-17\M8THHPYT\168
46	8HPYT446	QUAIU #1/3/T.DICOCCON PI94625/AE.SQUARROSA (372)//3*PASTOR/4/QUAIU #2/5/CHONTE*2/3/T.DICOCCON PI94625/AE.SQUARROSA (372)//3*PASTOR/6/VALI	CMSS12Y01494T-099TOPM-099Y-099M-099Y-14M-0WGY	MXI16-17\M8THHPYT\170
47	8HPYT447	QUAIU #1/3/T.DICOCCON PI94625/AE.SQUARROSA (372)//3*PASTOR/4/QUAIU #2/5/CHONTE*2/3/T.DICOCCON PI94625/AE.SQUARROSA (372)//3*PASTOR/6/VALI	CMSS12Y01494T-099TOPM-099Y-099M-099Y-30M-0WGY	MXI16-17\M8THHPYT\173
48	8HPYT448	HGO94.7.1.12/2*QUAIU #1/6/CHIH95.2.6/4/BABAX/LR42//BABAX*2/3/SHAMA/5/2*BABAX/LR42//BABAX*2/3/TUKURU/7/SUP152	CMSS12Y01554T-099TOPM-099Y-099M-099Y-36M-0WGY	MXI16-17\M8THHPYT\192
49	8HPYT449	VILLA JUAREZ F2009/3/T.DICOCCON PI94625/AE.SQUARROSA (372)//3*PASTOR/4/WBLL1*2/BRAMBLING/5/QUAIU #1/3/T.DICOCCON PI94625/AE.SQUARROSA (372)//3*PASTOR/4/QUAIU #2/6/QUAIU #1/SOLALA//QUAIU #2	CMSS12Y01570T-099TOPM-099Y-099M-099Y-11M-0WGY	MXI16-17\M8THHPYT\196
50	8HPYT450	68.111/RGB-U//WARD/3/AE.SQUARROSA (321)/4/INQALAB 91*2/KUKUNA/5/PBW343*2/KUKUNA/6/MUCUY/7/MAYIL	CMSS12Y01594T-099TOPM-099Y-099M-099Y-15M-0WGY	MXI16-17\M8THHPYT\198

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