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VARIATIONS IN THE QUANTITY AND QUALITY OF PERSIAN WHEAT GENOTYPES UNDER NORMAL IRRIGATED AND RAIN-FED CONDITIONS

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ABSTRACT

The importance of wheat in providing staple food for many populations is not disputed, but drought stress can significantly reduce the yield and quality of the grain. Thirty one genotypes of bread wheat were examined under normal irrigated and rain-fed conditions for their protein, Fe, Zn, Cu, Mn, P, Na and K grain concentrations. The experiment was conducted as a split-plot (irrigated and rain-fed as main plots and 31 cultivars as sub-plots) in a randomized complete block design with three replications in Sanandaj, Kurdistan, Iran, during the 2013–2014 cropping season. Based on a two-way Anova, we found large inter-genotype variations among the traits. Significant differences were also observed for the genotypes between normal irrigated and rain-fed conditions. Except for the grain protein concentration, which showed only a 1.93 % increase, the rain-fed conditions negatively affected each of the other traits significantly. Major effects were found for grain yield, number of grains per spike and grain Zn concentration, showing 43.09 %, 27.74 % and 23.88 % reductions, respectively. Negative correlations were observed between grain yield and grain protein, Fe, Zn, Cu, Mn, P and Na concentrations. Our data show that breeding for higher tonnage-yield during the past 80 years has brought success but at the cost of lower concentrations of protein and microelements in the wheat grains.

Additional key words: Dryland cropping, grain quality, micronutrients, plant nutrition, PCA

RESUMEN

Variación en la cantidad y calidad de genotipos de trigo Persa bajo condiciones de riego o secano

La importancia del trigo como alimento de la población es reconocida a nivel mundial, pero los déficits hídricos pueden reducir drásticamente la cantidad y calidad del grano. Se evaluaron variables de producción y contenidos de proteína y minerales en 31genotipos de trigo bajo condiciones de riego y secano. El experimento se condujo bajo un arreglo en parcelas divididas (condición de humedad en las parcelas principales y los genotipos en las sub-parcelas) en un diseño en bloques completos al azar con tres repeticiones en Sanandaj, Kurdistan, Iran, durante el ciclo de crecimiento 2013-2014. Se encontraron diferencias entre los genotipos y entre las condiciones de humedad para las diferentes variables. Con excepción de la concentración de proteínas, la cual mostró solamente un incremento de 1,93 %, la condición de secano afectó negativamente las otras variables. Los principales efectos se produjeron en el rendimiento del grano, número de granos por espiga, y concentración de Zn, con reducciones de 43,09, 27.74 and 23.88 %, respectivamente. Asimismo, hubo correlaciones negativas entre el rendimiento del grano y las concentraciones de proteína, Fe, Zn, Cu, Mn, P y Na. Los resultados muestran que el mejoramiento genético para aumentar el rendimiento durante los últimos 80 años ha sido exitoso pero a un costo de menores concentraciones de proteína y micronutrientes en el grano de trigo.

Palabras clave adicionales: Calidad del grano, cultivo de secano, micronutrientes, nutrición vegetal, ACP

INTRODUCTION

Domesticated wheat accounts for 28 % of the world edible dry matter and up to 60 % of the world daily energy intake (Cakmak, 2008; Wang et al., 2011). However, domesticated wheat

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cultivars possess a narrow range of genetic variation and contain very low levels of Fe, Zn, Cu, and Mn compared to their wild relatives (Cakmak, 2008; Cakmak et al., 2004; Wang et al., 2011). This deficiency in microelements contributes significantly to a global health problem, as it is estimated that two billion people world-wide suffer from a shortage of key vitamins and minerals including Fe, and Zn (FAO, 2011). White and Broadley (2005) stated that deficiencies in micronutrients will continue to impact societal health and reduce economic productivity. Suffering from micronutrient malnutrition, arising from dietary deficiency of one or more micronutrients has been internationally recognized as a life-threatening health problem. Iron and zinc deficiencies are noticeable ones, ranking 9th and 11th among the leading 20 elements that threaten human's life and health (WHO, 2008).

Due to the fact that wheat is rich in calories, proteins, and bioavailable micronutrients, it plays a significant role in human being's health (Peleg et al., 2008). Utilizing wheat-flour, rich in protein, leads to large loaf volume, high water absorption, and producing good keeping quality loaves (Zanetti et al., 2001). As an illustration, a research conducted by Kalantari et al. (2005) indicated that only 10.4 % of the total Fe intake of Iranian population is gained from meat. The rest is from other food sources and bread wheat, with 45 %, has the greatest part in this regard. Hence, the impact of the constituent and nutritional quality of wheat grain on human's well-being, specifically in developing nations, is inevitable (Chatzav et al., 2010; Wang et al., 2011).

Mineral inadequacy is nowadays considered as a great global concern that threatens human health and well-being. In this regard, a great deal of research, especially in terms of Fe and Zn has been carried out over the last decade. In industrialized nations, strategies employed to tackle the micronutrients shortage are fortifying foods and dietary diversity. In developing countries, adopting such strategies, however, is less socially and economically feasible (Frossard et al., 2000). Given the extent to which bread wheat is consumed world-wide, identifying and selecting for drought resistant genotypes capable of accumulating higher levels of micronutrients, particularly in dry and semi-dry areas, is essential to feeding the world (Clark, 1983).

The importance of wheat in providing staple food for many populations is not disputed. Drought stress can significantly reduce the tonnage-yield of wheat, which is frequently occurring due to global warming. Furthermore, the quality of grains requires improvements through breeding programs for sustainable development. Accordingly, the objective of this study was to evaluate 31 genotypes of bread wheat under normal irrigated and rain-fed conditions to identify productive cultivars with higher plant yield and grain quality.

MATERIALS AND METHODS

Thirty-one genotypes of bread wheat (*Triticum aestivum* L.) (Table 1) were examined during the 2013-2014 growing season at the Islamic Azad University, Sanandaj Branch, Kurdistan, located in Northwestern Iran (35°16' N, 47°01' E; 1380 m.a.s.l.). There were no large differences in temperatures, but the rainfall over the growing season was notoriously lower than the long term average of the zone (Figure 1).

Comparisons between normal irrigated and rain-fed conditions were performed using a split-plot (irrigated and rain-fed as main plots and 31 cultivars as sub-plots) in a randomized complete block design with three replicates.

Cultivation and weeding were done manually starting in late November. Each experimental plot consisted of 5 rows, each with a length of 4 m. The distance between rows was 25 cm with a density of 400 seeds per m^2. Planting under rain-fed conditions was done without irrigation and only relied on natural rainfall. For irrigated conditions, 750 liters (15 cm) of water were applied to each experimental plot during each irrigation. Irrigation occurred during tilling, elongation, flowering, and grain filling stages. No chemical fertilizers, herbicides, and pesticides were utilized.

In order to measure agronomic traits, grain protein and mineral concentrations, the two middle rows of each plot were harvested at physiological maturity. Measurements taken in the field experiments were grain yield biological yield, straw yield, harvest index, thousand grain weight, number of spikes per square meter and number of grains per spike were measured in both fully irrigated and rain-fed conditions. Also, concentrations of grain protein, Fe, Zn, Cu, Mn, P, Na, and K were measured in both fully irrigated and rain-fed conditions.

Table 1. Names, codes, origin, and drought tolerant/susceptibility of 31 bread wheat genotypes

	Genotype	Year of release	Origin	Drought tolerant/susceptible
1	Sardari	1930	Iran	Tolerant
2	Shahpasand	1942	Iran	Sensitive
3	Roshan	1958	Iran	Tolerant
4	Bezostaya	1969	Russia	Sensitive
5	Mughan-1	1973	CIMMYT	-------
6	Kaveh	1980	CIMMYT	-------
7	Sabalan	1981	Iran	Moderate
8	Golestan	1986	CIMMYT	-------
9	Soisson	1988	France	-------
10	Rasad	1989	Iran	Tolerant
11	Heirmand	1991	Iran	Moderate
12	Gaspard	1992	France	Sensitive
13	Gascogne	1992	France	-------
14	MV-17	1993	Hungary	Moderate
15	Alvand	1995	Iran	Moderate
16	Niknejad	1995	ICARDA	Tolerant
17	Zarin	1995	CIMMYT	Tolerant
18	Kavir	1997	Iran	Tolerant
19	Chamran	1997	CIMMYT	Tolerant
20	Marvdasht	1999	Iran	Moderate
21	Azar-2	1999	Iran	Tolerant
22	Shahryar	2002	Iran	-------
23	Pishtaz	2002	Iran	Tolerant
24	Pishgam	2008	Iran	Moderate
25	Sivand	2009	Iran	-------
26	Ohadi	2009	Iran	Tolerant
27	Parsi	2009	Iran	-------
28	Homa-4	2010	Iran	Tolerant
29	Rijaw	2011	Iran	Tolerant
30	WS-82-9	-	Iran	Moderate
31	DN-11	-	Iran	-------

Grain protein concentrations were measured using a near-infrared-reflectance (NIR) spectrometer (Perten Instruments DA7200) approach (Osborne et al., 2007). We followed the protocols of Emami (1996) to identify mineral concentrations. The harvested grain was rinsed with distilled water and oven dried at 50 °C for twenty four hours. The dried grain was milled using a non-rust steel miller (IKA A11 B, Germany) and 2 g of each powdered sample from each genotype were placed in a crucible and incinerated at 550 °C in a muffle furnace. Subsequently, 10 mL of hydrochloric acid (2 N) was added to each crucible, which was then placed in a water bath at 80 °C for an hour. The samples were then diluted to 100 mL with distilled water. An atomic absorption spectrometer was used to measure grain Fe, Zn, Cu, and Mn concentrations (Varian SpectrAA-220). A flame-photometer (Jenway PFP7) was used in order to determine sodium and potassium concentrations at 589 and 766.5 nm wavelength, respectively. The phosphorus concentration of samples were determined at 470 nm using a Cray 100 spectrophotometer.

After seedbed preparation, soil samples were collected from different parts of the field (0-30 cm depth). The samples were subsequently air-dried, crushed to be put through a 2 mm sieve, and saved for more analyses (Table 2). A 1:2 ratio of soil to water suspension was considered to determine pH and EC of soil. Organic matter was assessed utilizing a modified Walkley-Black procedure (Allison et al., 1965). By means of the Kjeldahl method and utilizing a

Kjeltec Auto 1030 Analyzer (Tecator), nitrogen analysis was performed. Also, using a Jenway 6505 spectrophotometer (Olsen procedure) and through the calorimetric method, P analysis was carried out. Following extraction with ammonium acetate, using a Jenway PFP7 flame-photometer, K concentration was determined. Through atomic absorption spectrophotometer, soil Fe and Zn concentrations were measured (Blair et al., 2011).

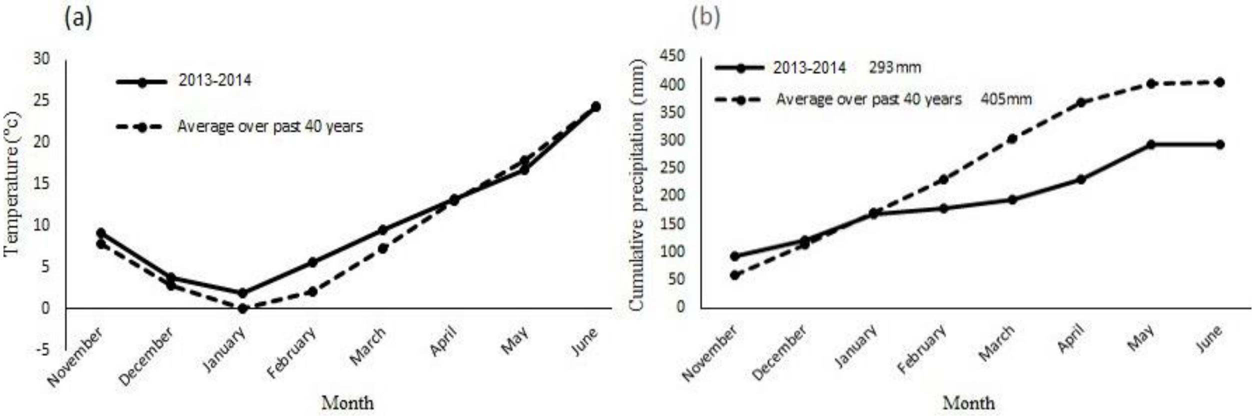

Figure 1. Temperature (a) and cumulative precipitation (b) from wheat sowing (November) to harvesting (June)

Table 2. Properties of the soil (0-30 cm) cropped with wheat under irrigated and rain-fed conditions

Soil texture	Clay loam
Electrical conductivity (dS·m^{-1})	0.868
pH	7.42
Organic carbon (%)	0.78
Total N (%)	0.078
Fe (mg·kg^{-1})	5.35
Zn (mg·kg^{-1})	0.87
Cu (mg·kg^{-1})	1.3
Mn (mg·kg^{-1})	4.3
P (mg·kg^{-1})	9.35
K (mg·kg^{-1})	253

Stress intensity (SI) was calculated using the following Fischer and Maurer (1978) formula:

$$SI = 1 - \left[\frac{\bar{Y}s}{\bar{Y}p}\right]$$

where $\bar{Y}s$ and $\bar{Y}p$ were the mean yields of all genotypes under rain-fed and irrigated conditions, respectively.

Comparisons among the treatments were based on a two-way Anova using SAS software 9.4 (Cary, NC, USA) and means comparison by Duncan's test. Pearson correlation analyses were carried out using SPSS software 23 (Chicago, IL, USA). The GGE-bi-plot software ver. 6.3 (Yan et al., 2000) was used to perform principal component analysis.

RESULTS

Analysis of variance and mean comparison. For each trait, analysis of variance showed that there were significant differences between plants growing under normal irrigated and rain-fed conditions as well as among various genotypes. The interaction of genotype x water availability was significant for GY, BY, SY, HI, TGW, NSPm2, NGPS and Zn (Table 3). For greater clarity, Table 4 also shows the average simple effects of the water availability in all variables.

According to Table 4, drought stress had significant negative effects on grain yield, biological yield, harvest index, number of grains per spike, Fe, Zn, Cu, and Na. Drought stress caused the greatest impacts on grain yield, grains per spike and the amount of Zn per grain, which declined by 43.09 %, 27.74 and 23.88 %, respectively. The stress intensity found (SI=0.4309) suggests that a high level of water stress occurred.

Comparison of mean values of simple effects for traits that were not significantly different (Table 3) regarding the reciprocal effects among the traits in genotypes is shown in Table 5. The comparison of mean values of reciprocal effects for traits that cause genotypes exhibit significant differences between each other (Table 6).

Correlation analysis. The grain yield showed positive correlation with harvest index and negative correlation with Fe, Zn, and P concentrations in plants grown either under irrigated or rain-fed conditions (Table 7), which suggests that the relation between these variables were not affected by the water stress; however, we found positive correlation between grain protein and grain Zn only for irrigated plants, and negative correlation with grain protein and HI only under rain-fed conditions which shows the treatment effect.

Table 3. Mean squares of Anova for agronomic traits and grain concentration of protein and minerals of 31 wheat genotypes under rain-fed and irrigated conditions

Source of variation		GY	BY	SY	HI	TGW	NSPm^2	NGPS
Block (R)	2	634.928	3344.07	1065.86	0.2376	6.056	0.263	948.021
Water availability (W)	1	1043117**	1314096**	15627**	5364**	552.84**	238184**	121610**
Error 1 (R/P)	2	722.70	4679.63	1742	0.276	27.80	478.37	1795
Genotype (G)	30	8599.88**	20768**	21394**	89.36**	264.19**	14275**	10565**
W x G	30	3188.11**	23798**	18877**	30.09**	57.63**	4108**	2061**
Error 2 (R x G/E)	120	300.468	1867.84	1070.94	1.50	17.52	464.17	226.94
CV (%)	-	6.3	4.6	4.9	4.2	12.0	5.4	9.4

Source of variation	DF	PRO	Fe	Zn	Cu	Mn	P	Na	K
Block (R)	2	0.6702	173.710	132.647	1.672	287.058	0.0006	0.003	0.682
Water availability (W)	1	2.60*	8528**	949.76**	42.02**	2588**	0.013**	0.038**	343.03**
Error 1 (R/P)	2	1.65	223.92	89.18	1.30	228.41	0.0008	0.002	39.21
Genotype (G)	30	2.91**	234.81**	36.25**	1.38**	66.14**	0.0006**	0.002**	3.60*
W x G	30	0.763	45.82	18.99**	0.354	21.87	0.0001	0.0004	0.907
Error 2 (R x G/E)	120	0.54	50.25	9.84	0.471	31.69	0.0001	0.001	2.06
CV (%)	-	5.9	8.9	18.8	9.4	15.1	11.4	14.9	8.4

Grain yield (GY); biological yield (BY); straw yield (SY); harvest index (HI); thousand grain weight (TGW); spikes per square meter (NSPm^2); grains per spike (NGPS); protein (PRO). *: $P \leq 0.05$; **: $P \leq 0.01$

Table 4. Comparison of the average simple effects of water availability on agronomic traits and grain concentration of protein and minerals

Treatment	GY(g/m^2)	BY(g/m^2)	SY(g/m^2)	HI(%)	TGW(g)	NSPm^2	NGPS	PRO(%)
Irrigated	347.60 a	1022.7 a	675.13 a	34.0 a	36.58 a	432.74 a	184.3 a	12.27 a
Rain-fed	197.82 b	854.63 b	656.80 a	23.2 b	33.13 a	361.17 a	133.2 b	12.51 a
Variations (%)	43.09	16.44	2.72	31.56	9.43	16.54	27.74	-1.93

Treatment	Fe	Zn	Cu	Mn	P	Na	K
	(mg·kg^{-1})				(g·kg^{-1})		
Irrigated	86.21 a	18.92 a	7.77 a	40.85 a	0.117 a	0.234 a	18.39 a
Rain-fed	72.67 b	14.40 b	6.82 b	33.39 a	0.099 a	0.205 b	15.67 a
Variations (%)	15.71	23.88	12.23	18.26	14.56	12.23	14.77

Grain yield (GY); biological yield (BY); straw yield (SY); harvest index (HI); thousand grain weight (TGW); spikes per square meter (NSPm^2); grains per spike (NGPS); protein (PRO). Means followed by different letters are statistically different according to Duncan's test ($P \leq 0.05$)

Table 5. Average simple effects of wheat genotype on grain concentration of protein and minerals

Genotypes	PRO(%)	Fe($mg \cdot kg^{-1}$)	Cu($mg \cdot kg^{-1}$)	Mn($mg \cdot kg^{-1}$)	P($g \cdot kg^{-1}$)	Na($g \cdot kg^{-1}$)	K($g \cdot kg^{-1}$)
Sardari	11.916fghij	79.838cdefgh	7.545abc	36.629abcdef	0.120abcd	0.205bcdef	16.845abcde
Shahpasand	13.622ab	77.853cdefghi	7.022bcdefg	33.796cdef	0.123ab	0.227abcde	17.095abcde
Roshan	13.549abc	76.409efghi	7.579abc	35.209bcdef	0.098fgh	0.232abcd	**18.256a**
Bezostaya	12.545cdefgh	82.356cdef	7.253abcdefg	37.696abcdef	0.115abcdef	0.245ab	17.981ab
Mughan-1	13.12abcde	79.264cdefgh	7.474abcde	38.966abcde	0.1096abcdefg	0.184ef	16.696abcde
Kaveh	13.214abcd	82.364cdef	7.537abc	36.898abcdef	0.104defgh	0.223abcde	16.955abcde
Sabalan	12.4733defghi	78.003cdefghi	7.1233bcdefg	35.809bcdef	0.112abcdefg	0.221abcde	17.058abcde
Golestan	11.357j	76.723defghi	7.962ab	39.156abcd	0.115abcde	0.232abcd	17.293abcd
Soisson	12.850abcdef	86.608abcd	7.532abcd	38.75abcde	0.106bcdefgh	0.204bcdef	17.619abcd
Rasad	**13.801a**	83.601bcdef	7.875ab	37.521abcdef	0.104cdefgh	0.222abcde	16.027bcde
Heirmand	11.552hij	81.907cdefg	7.647abc	39.709abcd	0.116abcde	0.218abcde	15.606de
Gaspard	12.198efghij	92.211ab	7.870ab	39.658abcd	**0.126a**	**0.253a**	16.869abcde
Gascogne	12.882abcdef	84.71bcde	7.904ab	**44.473a**	0.115abcde	0.217abcdef	17.750abc
MV-17	11.281j	83.349bcdef	6.459fg	36.23bcdef	0.121abc	0.245ab	17.594abcd
Alvand	12.148efghij	71.89hi	7.022bcdefg	31.057ef	0.080i	0.229abcde	16.789abcde
Niknejad	11.769ghij	86.83abc	7.212abcdefg	40.788abc	0.115abcde	0.224abcde	15.950bcde
Zarin	12.28defghij	74.33fghi	6.570defg	32.933cdef	0.096gh	0.243ab	17.949ab
Kavir	12.138efghij	75.695efghi	7.135abcdefg	37.518abcdef	0.098gh	0.224abcde	16.666abcde
Chamran	12.637bcdefg	72.27ghi	7.056bcdefg	38.351abcde	0.112abcdefg	0.186def	16.779abcde
Marvdasht	12.136efghij	68.425i	7.533abcd	36.642abcdef	0.100efgh	0.226abcde	17.4981abcd
Azar-2	11.688ghij	77.801cdefghi	7.249abcdefg	37.865abcdef	0.104defgh	0.226abcde	16.273abcde
Shahryar	12.504defghi	75.138efghi	6.435fg	31.851def	0.105cdefgh	0.214abcdef	17.523abcd
Pishtaz	11.972fghij	70.88hi	6.526efg	30.168f	0.101efgh	0.172f	16.849abcde
Pishgam	11.505ij	76.839defghi	7.521abcd	36.494bcdef	0.097gh	0.206abcdef	17.882abc
Sivand	11.5ij	71.65hi	6.308g	32.814cdef	0.096gh	0.200bcdef	17.627abcd
Ohadi	11.505ij	83.215bcdef	7.372abcdef	34.98bcdef	0.116abcde	0.235abc	17.658abc
Parsi	12.913abcdef	86.653abcd	7.502abcd	39.183abcd	0.092hi	0.235abc	16.621abcde
Homa-4	13.058abcde	72.123ghi	6.791cdefg	42.139ab	0.109abcdefg	0.215abcdef	15.827cde
Rijaw	12.517defghi	81.862cdefg	7.665abc	35.414bcdef	0.116abcde	0.196cdef	15.105e
WS-82-9	12.953abcdef	**94.853a**	**8.104a**	41.886ab	0.116abcde	0.224abcde	17.711abc
DN-11	12.568cdefgh	77.184cdefghi	7.374abcdef	40.355abc	0.113abcdefg	0.216abcdef	17.7901abc

In bold the highest values. Means followed by different letters are statistically different according to Duncan's test ($P \leq 0.05$)

Principal component analysis. The first two principal components for irrigated and rain-fed plants accounted for 42.4 and 45.1% of the variance observed for the variables of interest, respectively. For each treatment, a polygon of “which is best for what” was constructed to identify the best genotype regarding each of the traits measured in this study. Genotypes falling at the top or near the top of a polygon have the highest score with respect to measured traits. Inspection for plants growing under irrigated conditions reveals a six-sectored polygon (i.e., a hexagon) (Figure 2a) identifying genotype 25 (Sivand) as the best performing genotype for spike number, P, Zn, and thousand grain weight. Genotype 5 (Mughan-1) was the best regarding protein, Fe, Cu, Mn, Na, and straw yield. Regarding K and biological yield, genotype 1 (Sardari) was the best. The highest grain yield and the greatest number of grains per spike was observed for genotype 21 (Azar-2). Finally, genotype 23 (Pishtaz) was the best in terms of harvest index (HI).

For plants subjected to water stress, a five segmented polygon (i.e., a pentagon) was observed (Figure 2b). Genotype 7 (Sabalan) was the best regarding the number of grains per spike. Genotype 16 (Niknejad) was best in terms of grain protein concentration, Fe, Zn, Mn, and P. Genotype 5 (Mughan-1) had the highest amount of sodium, straw yield, biological yield and spike number per square meter. For thousand grain weight, genotype 27 (Parsi) was the best. Finally, genotype 29 (Rijaw) was superior regarding harvest index, potassium and grain yield (Figure 2).

Table 6. Comparison of mean interaction effects of wheat genotype *x* water availability on agronomic traits and grain concentration of Zn

	Genotypes	GY(%)	BY($g\cdot m^{-2}$)	SY($g\cdot m^{-2}$)	HI(%)	TGW(g)	NSPm^2	NGPS	Zn($mg\cdot kg^{-1}$)
Irrigated	Sardari	436.3ab	**1200a**	763.6bcdefg	36.3cdef	38.2efghijklmn	361.6stuvw	213cde	12.3pqrstu
	Shahpasand	293.3lm	1020ghijk	726.6fghijk	28.7mno	48.5b	453fghij	125.6stuvw	17defghijklmnop
	Roshan	335.8fghi	970klmno	634.1pqrstu	34.6fg	28.3tuvw	512abc	170.3ghijklmn	16fghijklmnopqrst
	Bezostaya	384.8cd	1071.6cdef	686.8jklmnop	35.8cdef	32.6mnopqrstuv	410klmnop	239b	13.7mnopqrstu
	Mughan-1	421.2ab	1166.6ab	745.4cdefgh	36.1cdef	39.3defghijklm	384.3opqrst	93xyzz1	23abc
	Kaveh	314.6ijkl	1076.6cdef	762bcdefg	29.2lmn	45.7bcd	428hijklm	123tuvw	19.9cdefgh
	Sabalan	314.6ijkl	1000ghijklmn	685.4jklmnop	31.4ijk	30.7opqrstuvw	418.6jklmno	**266.3a**	18.7cdefghijklm
	Golestan	366.1de	1056.6defghi	690.5ijklmno	34.6fg	46.3bc	350.6tuvwxyz	182.6fghij	16.3defghijklmnopqrs
	Soisson	355.3efg	1020fghijk	664.6mnopq	34.8efg	38.8efghijklm	449.6fghij	217.6bcde	19cdefghijkl
	Rasad	354efg	1126.6bc	772.6abcdef	31.4ijk	31.1opqrstuvw	467.6def	160.3ijklmnopq	19.6cdefghij
	Heirmand	271.7mn	1013.3ghijklm	741.6defghi	26.8opq	27.1vwx	349uvwxyz	181fghij	**27.9a**
	Gaspard	232.7op	866.6rst	633.9pqrstu	26.8opq	37.0fghijklmnop	461.6efgh	129rstuvw	19.8cdefgh
	Gascogne	299.8kl	1096.6cde	796.8abc	27.4nop	33.8klmnopqrstu	490cde	148.6mnopqrs	21.2bcde
	MV-17	364de	1020ghijk	656nopqrs	35.7def	33.9klmnopqrstu	414.6klmno	194.6efg	18.2cdefghijklmn
	Alvand	**448.5a**	1113.3bcd	664.8mnopq	40.3b	31.6nopqrstuvw	505.3abc	171ghijklm	21.3bcd
	Niknejad	306.3jkl	980jklmno	673.6lmnopq	31.2jk	28.5tuvw	425.3jklmn	**265a**	20.1cdefgh
	Zarin	329.3ghij	990ijklmn	660.6mnopqrs	33.2ghi	21.5xy	433.3fghijklm	**276a**	16.5defghijklmnopqr
	Kavir	330.2fghi	1013.3ghijklm	683.1lkmnop	32.5hij	44.3bcde	405lmnopq	173.6ghijkl	14.2mnopqrstu
	Chamran	376.1de	1073.3cdef	697.2hijklmno	35efg	26.3vwx	430.6ghijklm	**269a**	15.7ghijklmnopqrst
	Marvdasht	325.8hijk	863.3rstu	537.4wxy	37.7c	36.1ghijklmnopqrs	439.6fghijkl	176.6fghijk	16.8defghijklmnop
	Azar-2	383.5d	1096.6cde	713.1ghijklm	35efg	25.5wxy	311.6$z1z_2z_3$	**279.6a**	14.6jklmnopqrst
	Shahryar	294.6lm	946.6mnopq	652nopqrs	31.1jkl	31.2opqrstuvw	500bc	222.6bcd	23.0abc
	Pishtaz	**439.8a**	886.6qrs	446.8z	**49.6a**	36.2ghijklmnopqr	465.3defg	214cde	16.6defghijklmnopqr
	Pishgam	293.3lm	980jklmno	686.6jklmnop	29.9klm	43.6bcde	422jklmn	171.6ghijklm	19.4cdefghijk
	Sivand	328ghij	950lmnopq	621.9qrstu	34.5fgh	44.0bcde	**540a**	104.6wxyz	**27.2a**
	Ohadi	329.3ghij	1066.6cdefg	737.3efghij	30.8jkl	40.7cdefghij	431.6ghijklm	127.3rstuvw	19.7cdefghi
	Parsi	357.5def	1016.6ghijkl	659.1nopqrs	35.2defg	**56.6a**	526.6ab	76.3$z1z_2$	16.9defghijklmnop
	Homa-4	350.1efgh	943.3nopq	593.2tuv	37.11cd	41.0cdefghi	460.6efghi	166.3hijklmno	25.4ab
	Rijaw	411.6bc	976.6jklmno	565vwx	42.1b	35.8hijklmnopqrs	376.3pqrstuv	228.3bc	13.7mnopqrstu
	WS-82-9	434.2ab	1063.3cdefgh	629.1qrstu	40.8b	36.5ghijklmnopq	363.3stuvw	183fghi	20.9bcdef
	DN-11	292.5lm	1040efghij	747.5cdefgh	28.1mnop	41.7cdefgh	427hijklm	165.3hijklmnop	20.4bcdefg
Rain-fed	Sardari	235op	845stuvw	610stuv	27.7nop	34.6ijklmnopqrst	325.3$xyzz1z_2$	145opqrst	9.3u
	Shahpasand	185tuvw	956.6klmnop	771.6bcdef	19.3za	33.0lmnopqrstuv	400.6mnopqr	108.3wxy	14.6jklmnopqrst
	Roshan	180.6tuvw	690z	509.3y	26.2pq	25.0wxy	426.6ijklmn	150.6lmnopqr	15hijklmnopqrst
	Bezostaya	195stu	860rstu	665mnopq	22.6tuv	38.7efghijklm	331.6$vwxyzz1z_2$	141pqrstuv	11.6rstu
	Mughan-1	226.6pq	1040efghij	813.3ab	21.7tuvw	33.9klmnopqrstu	349.3uvwxyz	89.6yzz_1	15.7ghijklmnopqrst
	Kaveh	181.6tuvw	776.3wxyz	594.6tuv	23.4rst	38.3efghijklmn	421jklmn	80.6$zz1z_2$	16.3defghijklmnopqrs
	Sabalan	150x	733.3yza	583.3uvw	20.4wxyza	27.5uvwx	319.6$zz1z_2$	200def	16.2efghijklmnopqrst
	Golestan	196.6rstu	870rst	673.3lmnopq	22.5tuv	34.0jklmnopqrstu	342.6$vwxyzz_1$	154klmnopq	12.6opqrstu
	Soisson	191.6stuv	983.3jklmno	791.6abcd	19.4yza	30.2qrstuvw	345.3$uvwxyzz_1$	136.6qrstuv	16.1fghijklmnopqrst
	Rasad	185tuvw	796.6uvwxy	611.6rstuv	23.1stu	35.4hijklmnopqrs	351.6tuvwxyz	111wxy	14.0lmnopqrstu
	Heirmand	171.6uvwx	996.6hijklmn	**825a**	17.2z	25.2wxy	299.6z_2z_3	158.3jklmnopq	11.7qrstu
	Gaspard	161.6wx	860rstu	698.3hijklmn	18.7z	30.4pqrstuvw	254z4	124.6stuvw	14.3lmnopqrstu
	Gascogne	165vwx	773.3xyz	608.3stuv	21.3uvwxy	31.4opqrstuvw	361.6stuvw	117vwx	17.5defghijklmno
	MV-17	196.6rstu	730yza	533.3wxy	26.9opq	26.4vwx	378.3pqrstu	176.3fghijk	14.6klmnopqrst
	Alvand	218.3pqrs	863.3rstu	645opqrst	25.2qr	29.6rstuvw	326.6$vxyzz1z_2$	162ijklmnop	15.2hijklmnopqrst
	Niknejad	176.6tuvwx	846.6rstuv	670mnopq	20.8vwxyz	29.8qrstuvw	324$yzz1z_2$	175.3ghijk	17.6defghijklmno
	Zarin	171.6uvwx	863.3rstu	691.6ijklmno	19.8wxyza	19.5y	399mnopqr	164.3hijklmnop	14.4klmnopqrst
	Kavir	227.6pq	976.6jklmno	749cdefgh	23.3rstu	37.2fghijklmno	351.6tuvwxyz	104.6wxyz	12.6opqrstu
	Chamran	216.3pqrs	780vwxyz	563.6vwx	27.7nop	42.6bcdefg	420jklmn	144opqrstu	13.1opqrstu
	Marvdasht	183.6tuvw	846.6rstuv	663mnopq	21.6tuvwx	25.8wxy	402.3mnopq	120.3uvw	15.7ghijklmnopqrst
	Azar-2	203.3qrst	723.3za	520xy	28.0mnop	29.3stuvw	302.6z2z3	146.3nopqrst	13.5nopqrstu
	Shahryar	193.3stu	976.6jklmno	783.3abcde	19.7xyza	30.0qrstuvw	407.6klmnop	109.3wxy	17.0defghijklmnop
	Pishtaz	213.3pqrs	806.6tuvwx	593.3tuv	26.4pq	32.6mnopqrstuv	440.3fghijk	161ijklmnopq	11.4stu
	Pishgam	224pqr	950lmnopq	726fghijkl	23.5rst	40.5cdefghijk	360stuvwx	143.3opqrstu	14.5klmnopqrst
	Sivand	203.3qrst	940nopq	736.6efghij	21.5tuvwx	36ghijklmnopqrs	366.6rstuv	91.3yzz_1	14.3lmnopqrstu
	Ohadi	168.6uvwx	803.3tuvwx	634.6pqrstu	20.9vwxyz	39.4defghijkl	392nopqrs	83zz1	15.3hijklmnopqrst
	Parsi	260.3no	915opqr	654.6nopqrs	28.4mno	**57.9a**	521.6abc	55.6z_2	15.4ghijklmnopqrst
	Homa-4	190.6stuv	890pqrs	699.3hijklmn	21.4uvwxy	31.3opqrstuvw	371.3qrstuv	141.3pqrstuv	13.0opqrstu
	Rijaw	310.6ijkl	846.6rstuv	536wxy	36.6cde	35.9ghijklmnopqrs	264z_4	188.3fgh	11.2tu
	WS-82-9	170.6uvwx	840.6stuvwx	670mnopq	20.2wxyza	34.4ijklmnopqrst	280z_3z_4	155klmnopq	14.7ijklmnopqrst
	DN-11	177.6tuvwx	713.3za	535.6wxy	24.9qrs	30.1qrstuvw	358.6stuvwxy	91yzz_1	16.7defghijklmnopq

In bold the highest values. Means followed by different letters are statistically different according to Duncan's test ($P \leq 0.05$)

Correlation to year of release. Figure 3 illustrates temporal changes in the amounts of Fe, Zn, Cu, and Mn concentration, as well as grain yield and grain protein, starting from the year each cultivar was released. The ordinary least square regression analyses revealed whether each of these traits improved or declined (positive and negative slopes, respectively). Inspections show that, with the exception of grain yield, there has been either no change or a slight decrease in each variable of interest between 1930 and 2011. Thus, continued breeding and selection of bread wheat cultivars has resulted in a decrease in protein concentration and in essential micronutrients concentrations at the expense of increasing grain yield.

Table 7. Pearson correlation coefficients between different traits in wheat genotypes under irrigated and rain-fed conditions (n= 31)

Gen		GY	BY	SY	HI	TGW	NSPm^2	NGPS	PRO	Fe	Zn	Cu	Mn	P	Na	K	
GY		1	0.260	-0.093	0.792**	0.512**	0.071	-0.021	-0.304	-0.457**	-0.461**	-0.081	-0.296	-0.497**	-0.058	0.199	
BY		0.445**	1	0.937**	-0.379*	0.181	-0.043	-0.263	0.105	0.025	-0.098	0.124	0.049	0.025	-0.040	-0.072	
SY		-0.248	0.758**	1	-0.677**	0.002	-0.070	-0.264	0.218	0.191	0.065	0.098	0.157	0.205	-0.020	-0.146	
HI		0.849**	-0.090	-0.716**	1	0.343*	0.090	0.158	-0.337*	-0.465**	-0.390*	-0.001	-0.319	-0.507**	-0.037	0.240	
TGW	Irrigated conditions	-0.058	-0.022	0.018	-0.045	1	0.366*	-0.532**	-0.074	-0.060	-0.118	0.256	-0.171	-0.036	0.095	0.084	Rain-fed condition
NSPm^2		-0.227	-0.355*	-0.218	-0.038	0.191	1	-0.480**	0.133	0.173	0.231	0.090	0.121	0.149	0.019	0.001	
NGPS		0.176	-0.036	-0.167	0.213	-0.727**	-0.404*	1	-0.300	-0.319	-0.302	-0.557**	-0.305	-0.241	-0.015	0.108	
PRO		-0.014	0.120	0.139	-0.093	-0.198	-0.147	-0.060	1	0.222	0.227	0.198	0.231	0.104	-0.025	-0.141	
Fe		-0.383*	-0.003	0.065	-0.112	0.151	-0.026	-0.317	0.211	1	0.655**	0.480**	0.453**	0.613**	0.248	-0.201	
Zn		-0.338*	-0.139	0.096	-0.296	0.022	0.288	-0.399*	0.398*	0.345*	1	0.363*	0.614**	0.805**	0.109	0.130	
Cu		-0.195	0.115	0.266	-0.296	0.288	0.242	-0.508**	0.185	0.516**	0.389*	1	0.200	0.211	0.105	0.066	
Mn		-0.106	0.100	0.185	-0.171	0.139	0.070	-0.321	0.123	0.520**	0.349*	0.680**	1	0.533**	0.076	-0.214	
P		-0.394*	-0.279	-0.014	-0.284	0.046	0.235	-0.326	0.080	0.349*	0.682**	0.227	0.209	1	0.119	0.029	
Na		-0.054	0.036	0.078	-0.095	-0.025	-0.365*	0.170	-0.078	0.313	0.023	0.171	0.165	0.092	1	0.273	
K		0.3323	0.252	0.031	0.229	-0.105	-0.306	0.297	0.031	0.068	-0.398*	-0.253	-0.059	-0.196	0.189	1	

Grain yield (GY); biological yield (BY); straw yield (SY); harvest index (HI); thousand grain weight (TGW); spikes per square meter (NSPm^2); grains per spike (NGPS); protein (PRO). *: P≤0.05 ; **: P≤0.01

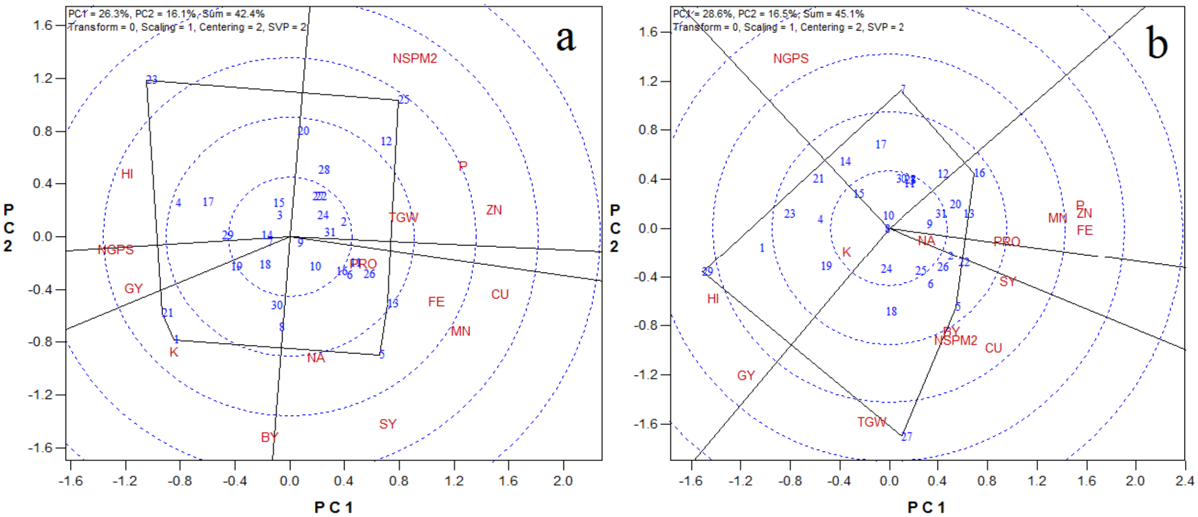

Figure 2. Polygon view of the GGE biplot show the “which is best for what” under: (a) non-stress and (b) stress conditions

DISCUSSION

Our analyses, which have focused on the quality and quantity response of wheat genotypes to the water availability, reveal specifically which one of the 31 bread wheat cultivars performed best under irrigated and water stress conditions. Analyses also reveal significant differences among the genotypes under each of the two conditions. Perhaps most importantly, our analyses indicate that efforts to breed and select for increased grain yield have reduced the concentrations of essential micronutrients.

Clearly, any breeding plan to improve micronutrient concentration must start with the existing germplasm as the source of genetic variation (Nachimuthu et al., 2014). Based on a number of analytical techniques, including analysis of variance, significant differences are revealed among the genotypes currently most grown in Iran. This is hardly surprising since virtually every previous study has reported similar genetic variation for morphological traits and grain quality among commercial wheat cultivars (Zhang et al., 2006, Ortiz et al., 2007, Zhao et al., 2009). Likewise, the interaction between the water availability and genotype is also known to have a significant influence on grain yield, yield components, and grain microelement concentrations.

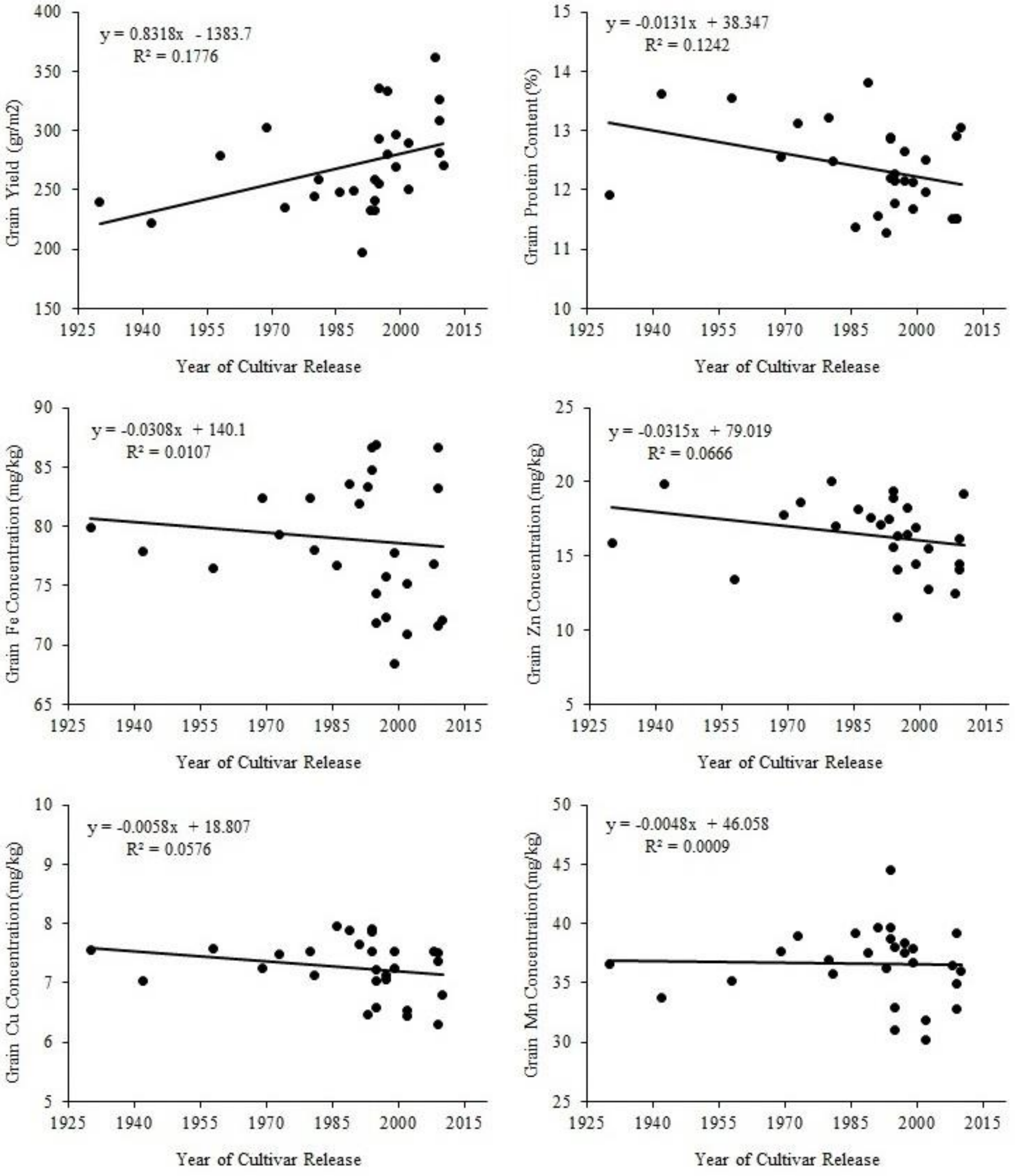

Figure 3. Relationship between grain wheat traits and the year of cultivar released over 80 years (genotypes 30 and 31 were excluded from this analysis as they are elite lines)

Our study differs from these previous studies by its focus on the manifold and simultaneous relationships among grain yield, protein concentration, and a spectrum of micronutrients, which provides a more robust and empirically comprehensive basis for selecting, which among available genotypes should be used for future breeding programs, particularly for cultivation in arid locations.

Our results show that there are statistically significant and negative correlations between grain yield and the concentration of some microelements. Consequently, there is a trade-off between breeding and selecting for improved yield and improved microelement concentration (Zhao et al., 2009; Amiri et al., 2015). This result is consistent with other studies. For example, previous research has shown that there is a positive and significant correlation between plant productivity and Zn and Fe concentration (Chatzav et al., 2010). Yet, there are statistically significant negative correlations between Fe and Zn concentrations, on the one hand, and many morphological traits on the other hand (Oury et al., 2006, Zhao et al., 2009, Wang et al., 2011) that in turn are influenced by numerous environmental factors (White and Broadley, 2009).

Nevertheless, it is clear that older genotypes have higher protein, Fe, Zn, Cu, and Mn concentrations but lower yields compared to recently developed genotypes. It has been suggested that the diminution in microelements concentration at the profit of increasing yield is a result of “dilution” when yields are high, or a “thickening” (concentration) effect when yields are low (Oury et al., 2006, Fan et al., 2008), and thus a consequence of the interplay between soil microelement concentrations and the extent to which these microelements are “thinned out” by grain yield.

CONCLUSION

This study shows that the 31 genotypes of wheat examined herein differ significantly in their grain yield and in their grain protein, Fe, Zn, Cu, and Mn concentrations. The results indicate genetic diversity among these genotypes. Rain-fed conditions significantly reduced grain yield, biological yield, harvest index, number of grains per spike, grain Fe concentration, grain Zn concentration, grain Cu concentration and grain Na concentration. Compared to older cultivars, the new cultivars have higher grain yields but with lower qualities in general. Therefore, it can be suggested that there is a linkage between the genes that increase the quantitative traits and those that reduce the qualitative traits. Accordingly, to produce wheat with higher grain yields and higher quality, breeders should break what appears to be tightly linked genes or seek new sources of germplasm.

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