International Journal of Plant Production (2020) 14:501–510
https://doi.org/10.1007/s42106-020-00100-w

RESEARCH

Biofortification with Zinc and Iron Improves the Grain Quality and Yield of Wheat Crop

Yasir Ramzan[1] · Muhammad Bilal Hafeez[2] · Shahbaz Khan[3] · Majid Nadeem[1] · Saleem-ur-Rahman[1] · Sumaira Batool[4] · Javed Ahmad[1]

Received: 6 November 2019 / Accepted: 10 March 2020 / Published online: 17 March 2020

Abstract
Hidden hunger is emerging as a major challenge for agricultural scientists because world population is increasing and food production is augmenting. Metals deficiencies (micronutrient malnutrition), especially Zn and Fe, are affecting over half of global population because they are depending cereal crops mainly wheat rice and maize for their daily diet. There are various possible techniques to overcome the hidden hunger but agronomic biofortification is one of the major agricultural strategies to enhance the grain concentration of micronutrients. Application of iron sulphate ($FeSO_4$) zinc sulphate ($ZnSO_4$) and as alone or in combination either soil and foliar application increased the height of plants, number of tillers, spike length, number of spikelets per spike, number of grains per spike, thousand grain weight, economical yield, biological yield and harvesting index, calcium, magnesium, iron, zinc, copper and protein contents. Among different Zn and Fe concentrations applied either soil supplement or foliar spray, combine foliar spray of 0.5% $ZnSO_4$ and 1% $FeSO_4$ significantly improved the maximum growth or quality attributes of wheat. Biofortification is one of the major agricultural strategies to enhance the concentration of micronutrients in grains to minimize the malnutrition. Combination of Zn and Fe as foliar spray (0.5% $ZnSO_4$ and 1% $FeSO_4$) increased the yield traits of wheat crop as well as quality parameters of grains. Foliar application method is more appropriate for availability of nutrients to plants for optimum growth as compared to soil application method. Combined application of Zn and Fe (0.5% ZnSO4 and 1% FeSO4) through foliar spray is recommended to enhance the productivity of wheat crop with good quality of grains.

Keywords Foliar spray · Growth · Mineral · Productivity · Protein

Introduction

Hidden hunger (deficiencies in micronutrients) is emerging as a major challenge for agricultural scientists. It is caused by lack of vitamin A, zinc, iodine, folate and iron (Jawaldeh et al. 2019). World population is increasing, and food consumption demand is augmenting. After 1960′s, we are focusing on increasing the productivity not the quality of food. Malnutrition of micronutrient is being effected 2 billion population especially in developing countries (Stein 2010; Cakmak et al. 2010). Metals deficiencies, especially Zn and Fe, are affecting over half of global population because they are depending cereal crops mainly wheat rice and maize for their daily diet (Kenzhebayeva et al. 2019). Zinc is structural part of many enzymes that are used in the metabolism of auxin and carbohydrates, in the synthesis of proteins and integrity of membrane (Cakmak 2000; Rehman et al. 2018). Additionally, it also takes part in pollen development, fertilization and chlorophyll synthesis (Pandey et al. 2006). Moreover, Fe is constituent of ETC (electron transport chain) and cytochrome, and activates many enzymes (Soetan et al. 2010). Malnutrition of micronutrients cause 5 Million. childhood death causalities every year (Anonymous 2007).

✉ Shahbaz Khan
shahbaz2255@gmail.com

[1] Wheat Research Institute, Ayub Agricultural Research Institute, Faisalabad, Pakistan

[2] Department of Agronomy, Northwest A&F University, Yangling 712100, China

[3] Department of Agronomy, Ghazi University, Dera Ghazi Khan, Pakistan

[4] Department of Botany, University of Agriculture, Faisalabad, Pakistan

Wheat is the staple food in many micronutrient deficient regions, which fulfils 50% diet requirements (Cakmak et al. 2010). Cultivation of higher yielding crops with intensive use of fertilizers such as potassium, phosphorous and nitrogen resulted in micronutrient deficiency (Cakmak 2002). About 50% cereals cultivated soils are Zn deficient, and Fe deficiency is often present in calcareous and high pH arid regions. Moreover, irrigation of bicarbonate enriched water often resulted in Fe deficiency (Graham and Welch 1996). According to world scale estimation, Zn and Fe deficiency widespread is approximately 50% and 30% respectively (Cakmak 2002). Zn deficiency is more common in Pakistan, about 70% cultivated land in Zn deficient (Imtiaz et al. 2010). A series of experiments explored that Khyber Pakhtunkhwa soil is 37% Zn, 14% Fe and 60% B deficient, and Punjab soil is 57% Zn, 21% Fe and 50% B deficient (Memon et al. 2012).

Wheat is a staple food in Pakistan, and grown on 43% of cultivated area. About 60% Pakistani people diet is comprised on wheat and annual consumption per capita is 140 kg annum^{-1} (GOP 2017). Wheat production at 25.492 Million. tons during 2017–2018 was surplus than country prerequisite (GOP 2018). West and Central Asian countries, wheat provide about 50% daily calorie on average, probably it is more than 70% in the rural regions (Cakmak 2008). In South Asia, micronutrient deficiencies is highly reported in cropping system of Rice–wheat (Johnson et al. 2005). Rice and wheat are major crops that fills the food requirements all over the world. According to (Jackson 2009) Asian subtropics comprises on 24 Mha, with ~ 13.5 Mha cultivated land, and in South Asia it consisted on Indo-Gangetic floodplains to Himalayan foothills.

There are various possible techniques to overcome the hidden hunger including post-harvest food fortification, mineral supplementation, diversification in dietary habits and biofortification (Borrill et al. 2014). Agronomic biofortification is one of the major agricultural strategies to enhance the grain concentration of Fe and Zn (Cakmak et al. 2010). It is attained by applying micronutrients to soil or/and directly to the foliage of crop (De-Valença et al. 2017) as it is potentially more economical, easily implemented and more sustainable as compared to genetic engineering and other techniques (Cakmak 2008). Agronomic biofortification of crops is an evolving technique to overcome micronutrient malnutrition in developing countries (Ngozi 2013). Exogenous application of micronutrient can be helpful to improve the quality of grains with enhanced productivity of wheat crop. Keeping in view the above notations, current filed base study was performed to overcome the malnutrition of micronutrients by assessing these objectives i) to determine the sole or/and combined effect of Zn and Fe on growth attributes of wheat, ii) to compare the efficacy of foliar and soil supplementation to enhancing the grain yield.

Materials and Methods

Experimental Particulars

A two-year (2016–2017 and 2017–2018) filed study was designed to evaluate the efficacy of foliar and soil supplied Zinc (Zn) and Iron (Fe) on the all the growth and yield attributes of wheat. Wheat Research Institute Farm area, Faisalabad (altitude 184.3 m a.s.l.; 73.87E, 31.87 N) was used for conducting experiment. All the experimental soil is sandy clay loam soil, and the Physico-chemical properties of this soil are represented in Table 1. Randomized complete block design (RCBD) under factorial was used with three replications. The net-plot size was 5 m × 1.62 m.

The following combination of treatment was applied for studding the above mentioned objectives;

- Control
- Foliar spray of 0.5% $ZnSO_4$
- Foliar spray of 1% $FeSO_4$
- Foliar spray of 0.5% $ZnSO_4$ and 1% $FeSO_4$

Table 1 Physical and chemical analysis of soil of field trial site

Characteristics	Unit	Value (2016–2017)		Value (2017–2018)	
Soil depth	(cm)	0–15	15–30	0–15	15–30
Texture	Class	Sandy clay loam	Sandy clay loam	Sandy clay loam	Sandy clay loam
pHe		7.6	7.5	7.5	7.6
ECe	(dS m^{-1})	2.26	2.41	2.42	2.19
Organic matter (Walkley–Black)	(g kg^{-1})	0.084	0.067	0.077	0.063
Total nitrogen	(g kg^{-1})	0.0042	0.0033	0.0038	0.0031
Available phosphorous (Olson)	(mg kg^{-1})	4.9	4.2	4.4	5.3
Extractable potassium (Olson)	(mg kg^{-1})	280	310	360	320
DTPA Zn	(mg kg^{-1})	0.52	0.39	0.62	0.47
DTPA Fe	(mg kg^{-1})	2.78	2.34	2.90	2.61

- Soil supplementation of 10 kg of Zn ha^{-1}
- Soil supplementation of 12 kg of Fe ha^{-1}
- Soil supplementation of 10 kg of Zn ha^{-1} and 12 kg of Fe ha^{-1}

Soil application of Zn and Fe was done at the time of sowing and foliar applications were applied thrice during the course of experimentation at tillering, booting and heading stages and.

Crop Husbandry

After harvesting of rice crop, a deep plough was used to break the hard pan and stubbles were incorporated in the soil. After that, seed bed was prepared by using cultivator twice with same number of planking. During both years wheat was sown in a well prepared fine seedbed on November 21, 2016 and November 25, 2017 help of Norwegian planter. Weather data are presented in Fig. 1. Seed rate was 100 kg ha^{-1}. Moreover, K, N and P fertilization was applied at rates of 60 kg ha^{-1}, 114 kg ha^{-1} and 120 kg ha^{-1}, and respectively. Urea (46% N), diammonium phosphate (18% N and 46% P_2O_5), Zinc sulphate ($ZnSO_4$), Iron sulphate ($FeSO_4$) and muriate of potash (60% K_2O) and were used as micronutrients. At the time of sowing, complete dose of K and P with 1/3rd of N was used as basal dose. Remaining N was supplied with first and second irrigation with equal split. Four irrigation was applied throughout the season of wheat crop. Wheat was harvested on 19 April and 28 April for the 2016–2017 and 2017–2018 seasons respectively.

Growth, Yield and Quality Attributes

Tillers (stem with ear) per unit area was measured accurately before harvest. Plant length and spike length was measured by using meter scale. No. of grains per spike and No. of

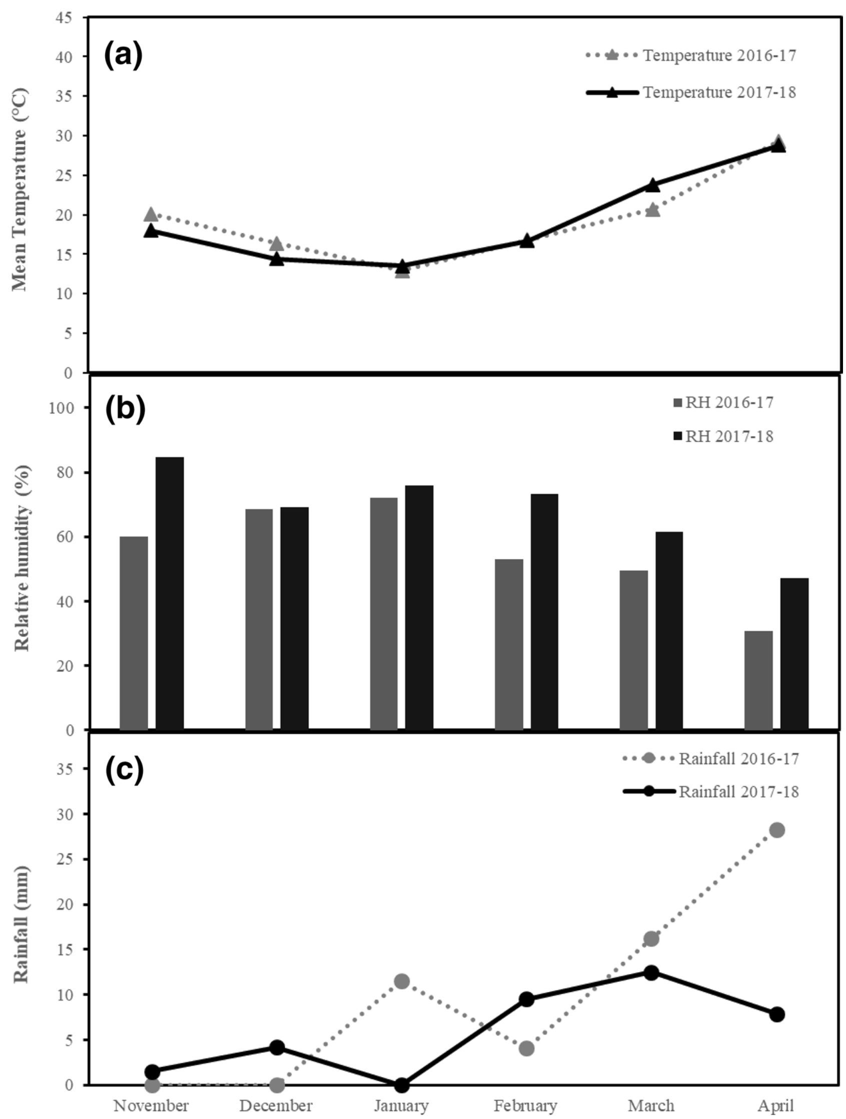

Fig. 1 Weather data of experimental station during the course of experimentation

spikelet was calculated manually. Moreover, weight biomass and 1000 grains weight was recorded by using weight machine. At the fully mature stage, 1m^2 area was harvested for measuring the biological yield. To determine the grain weight, grains obtained from each pot was measured by using electrical balance. The harvest index was calculated by using the following formula (Fig. 1).

$$\text{Harvest index} = \text{Grain yield/Biological yield} \times 100$$

After harvesting, samples of grain were collected for minerals Zn, Fe, Cu, Mg and Ca analysis. Grain samples were dried in air circulated oven at 70 °C to get constant weight. Wet-digested method was followed using HNO_3–$HClO_4$ proposed by Rashid (1986). Supernatant liquid was decanted and was run on Atomic Absorption Spectrophotometer (Shemadzu 7000) to analyze Zn, Fe, Cu, Mg and Ca in the aliquots. Grain protein contents (%) were measured by using Microjeldahl method (protein % = N% × 6.25) proposed by Agrawal et al. (1980).

Statistical Analysis

The data were analyzed statistically using analysis of variance and the means were compared by F-test protected LSD values calculated for P, 0.05 (Steel et al. 1997).

Results

Impact of Zn and Fe on Growth and Yield Parameters of Wheat

Application of zinc sulphate and iron sulphate as a sole and in combination either foliar and soil applied significantly affected No. of tillers, plant height, spike length (Table 2), No. of spikelets per spike, No. of grains per spike, 1000-grain weight (Table 3), biological yield, grain yield and harvesting index (Table 4), calcium, magnesium, iron, zinc, copper and protein contents (Figs. 2, 3). There was a significant difference between the two years for only 1000-grain weight (Table 3). However, sowing season did not affect No. of tillers, plant height, spike length, No. of spikelets per spike, No. of grains per spike, biological yield, grain yield and harvesting index (Tables 2, 3, 4), calcium, magnesium, iron, zinc, copper and protein contents (Figs. 2, 3).

All the foliar and soil supplementation improved the tillers per unit area but maximum improvement was recorded through soil applied Zn and Fe which was statistically at par with Zn and Fe combined foliar spray (Table 2) while least tillers per unit area were noted under control condition in both growing years. Results obtained in the current study regarding tillers, soil supplementation with of 12 kg of Fe ha^{-1} and 10 kg of Zn ha^{-1} produced maximum tillers, and showed statistical par with foliar spray of 0.5% $ZnSO_4$ and 1% $FeSO_4$. Plant height was significantly increased by sole and combine application of Fe and Zn through soil supplementation, which showed statistical par with other Zn and Fe treatments. Highest plant height (104.3 cm) was achieved in combined soil application of Zn and Fe in second year crop whereas lowest (98.8 cm) was observed in control in first year crop (Table 2). No. of spikelets per

Table 2 Mean values of number of tillers, plant height and spike length as influenced by soil and foliar applied zinc and iron

Treatments	Number of tillers (m^{-2})			Plant height (cm)			Spike length (cm)		
	2016–17	2017–18	Mean	2016–17	2017–18	Mean	2016–17	2017–18	Mean
Control	334	322	328 E	98.8	99.7	99.2 C	10.1	10.0	10.0 C
Foliar application of .5% $ZnSO_4$	359	344	351 D	100.9	100.2	100.5 BC	10.5	10.4	10.4 BC
Foliar application of 1% $FeSO_4$	364	353	358 C	102.1	101.7	101.9 AB	10.5	10.2	10.4A BC
Foliar application of .5% $ZnSO_4$ and 1% $FeSO_4$	377	364	370 A	101.0	103.6	102.3 AB	11.1	10.8	10.9 A
Soil application of 10 kg of Zn ha^{-1}	371	358	364 B	101.3	101.5	101.4 AB	10.6	10.2	10.4 ABC
Soil application of 12 kg of Fe ha^{-1}	373	358	365 B	101.6	101.1	101.4 ABC	10.8	10.4	10.6 AB
Soil application of 10 kg of Zn ha^{-1} and 12 kg of Fe ha^{-1}	378	365	372 A	101.6	104.3	103.0 A	10.8	10.8	10.8 AB
Mean	365	352		101.1	101.7		10.6	10.4	
LSD (0.05)	T = 3.3035			T = 2.1600			T = 0.5020		

Different letters within the same column indicate statistically significant differences at $P \leq 0.05$. T; treatment

Table 3 Mean values of number of spikelets per spike, number grains per spike and 1000-grain weight as influenced by soil and foliar applied zinc and iron

Treatments	Number of spikelets per Spike			Number of grains per spike			1000-Grain weight (g)		
	2016–17	2016–17	Mean	2016–17	2017–18	Mean	2017–18	2017–18	Mean
Control	10.1	10.0	10.0 C	43.0	42.3	42.7 C	32.8	32.5	32.6 D
Foliar application of .5% $ZnSO_4$	10.5	10.4	10.4 ABC	47.0	47.3	47.2 B	38.4	37.7	38.0 C
Foliar application of 1% $FeSO_4$	10.5	10.2	10.4 BC	47.0	46.3	46.7 B	39.1	38.7	38.9 BC
Foliar application of .5% $ZnSO_4$ and 1% $FeSO_4$	11.1	10.8	10.9 A	49.3	48.0	48.7 A	40.8	41.3	41.0 A
Soil application of 10 kg of Zn ha^{-1}	10.6	10.2	10.4 ABC	46.7	47.3	47.0 B	39.5	38.1	38.8 BC
Soil application of 12 kg of Fe ha^{-1}	10.8	10.4	10.6 AB	47.3	46.3	46.8 B	39.4	38.7	39.1 B
Soil application of 10 kg of Zn ha^{-1} and 12 kg of Fe ha^{-1}	10.8	10.8	10.8 AB	48.0	47.3	47.7 AB	41.8	41.1	41.4 A
Mean	10.6	10.4		46.9	46.4		38.8 A	38.3 B	
LSD (0.05)	$T=0.5622$			$T=1.0359$			$Y=0.4598$; $T=0.8602$		

Different letters within the same column indicate statistically significant differences at $P \leq 0.05$. T = treatment. Y = year

Table 4 Mean values of biological yield, grain yield and harvest index as influenced by soil and foliar applied zinc and iron

Treatments	Biological yield (t ha^{-1})			Grain yield (t ha^{-1})			Harvest index (%)		
	2016–17	2017–18	Mean	2016–17	2017–18	Mean	2016–17	2017–18	Mean
Control	10.9	10.8	10.8 C	3.20	3.31	3.26 E	29.4	30.8	30.1 C
Foliar application of .5% $ZnSO_4$	11.5	11.4	11.4 B	3.77	3.67	3.72 CD	32.9	31.7	32.3 B
Foliar application of 1% $FeSO_4$	11.8	11.6	11.7 AB	3.76	3.66	3.71 CD	32.0	31.5	31.7 BC
Foliar application of .5% $ZnSO_4$ and 1% $FeSO_4$	11.7	11.8	11.8 AB	4.15	3.99	4.07 A	35.5	33.7	34.6 A
Soil application of 10 kg of Zn ha^{-1}	11.9	11.6	11.8 AB	3.88	3.82	3.85 BC	32.6	32.9	32.8 B
Soil application of 12 kg of Fe ha^{-1}	11.7	11.6	11.7 AB	3.74	3.61	3.68 D	31.9	31.0	31.5 BC
Soil application of 10 kg of Zn ha^{-1} and 12 kg of Fe ha^{-1}	12.1	12.0	12.1 A	3.98	3.92	3.95 AB	33.0	32.7	32.8 AB
Mean	11.7	11.6		3.78	3.71		32.5	32.1	
LSD (0.05)	$T=0.3761$			$T=0.2724$			$T=1.8247$		

Different letters within the same column indicate statistically significant differences at $P \leq 0.05$. T = treatment

spike, spike length, No. of grains per spike were considerably higher through sole and combined application of iron and zinc (Tables 2, 3). Largest spike length (11.1 cm) was measured in combined foliar application of Fe and Zn in year one (Table 2). Significantly maximum No. of spikelets per spike (19.83) were observed in combined foliar spray of Zn and Fe in year one while minimum (18.0) was counted in control of year two (Table 3). Highest No. of grains per spike (49.3) and lowest (42) were observed in combined foliar supplementation of Fe and Zn (year one) and control (year two) respectively (Table 3). All these parameters were not differed during two season and did not have interaction affect (Tables 2, 3). 1000 grain weight was higher in combined and sole supplementation of Fe and Zn. Highest 1000 grain weight (41.8 g) was observed in combined Fe and Zn soil supplementation in year one that showed statistical par with combined Zn and Fe foliar application (41.3 g) year two whereas lowest (32.5 g) was noted in control of crop year two (Table 3). 1000 grain weight was significantly increased in both cropping years (Table 3). Biological yield, grain yield, harvesting index were significantly increased through sole and combined application of iron and zinc (Table 4). While higher biological yield (12.1 t ha^{-1}) was obtained in combined soil application of Zn and Fe (year one) while minimum (10.8 t ha^{-1}) was observed in control (year two) (Table 4). Higher grain yield (4.15 t ha^{-1}) was observed in foliar application of Zn and Fe (year one) whereas minimum yield was observed (3.20 t ha^{-1}) in control of year one (Table 4). The highest harvest index (35.5%) was recorded from combine foliar spray Zn and Fe in year one whereas lowest harvest index (29.4%) was observed in control in year one. There

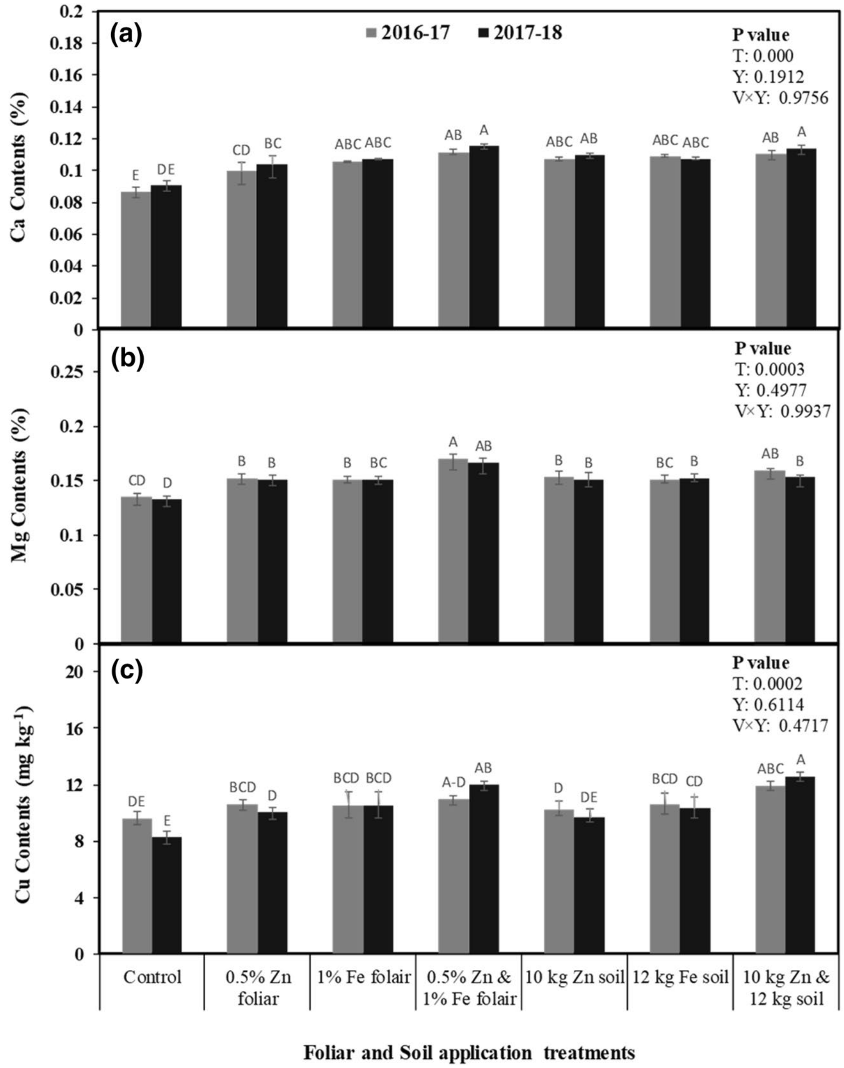

Fig. 2 Impact of soil and foliar applied zinc and iron on calcium, magnesium and copper contents of wheat grain

was no difference in harvest index, grain yield and biological yield across the years (Table 4).

Impact of Zn and Fe on Mineral Elements in Wheat Grain

Sole and combined application of iron and zinc significantly affected the Ca, Mg, Fe, Zn, Cu and protein contents in grains (Figs. 2, 3). There was a no significant difference between the growing years for protein, Ca, Cu, Mg, Fe and Zn contents. Maximum Ca content (0.0115 g kg^{-1}) was found in foliar application of Zn (year two) that was statically at par soil application of Zn (11.4 mg kg^{-1}) and minimum (8.63 mg kg^{-1}) was recorded in control (year one) respectively (Fig. 2a). Highest Mg content (17 mg kg^{-1}) and lowest (13.3 mg kg^{-1}) were observed in foliar application of Zn and Fe (year one) and control (year two) (Fig. 2b). Highest Cu contents (12.6 mg kg^{-1}) and lowest (8.3 mg kg^{-1}) from soil application of Zn and Fe (year two) and control (year two) respectively (Fig. 2c). The maximum Fe contents (78.33 mg kg^{-1}) was recorded from foliar application of Fe in year one whereas minimum Fe contents (43.33 mg kg^{-1}) was observed in control of year one (Fig. 3a). Highest Zn content (61.33 mg kg^{-1}) and lowest Zn content (41.08 mg kg^{-1}) were recorded in foliar application of Zn (year two) and control (year one) respectively (Fig. 3b). Protein contents was also affected by treatments application, maximum protein contents (14.37%) were found in control of year one while minimum protein contents (12.63%) were recorded in combined application of Zn and Fe through soil application method of year one (Fig. 3c).

Discussion

Yield and Its Attributes

Micronutrient might be easily available to plant for metabolism applied via foliar spray. The improvement in

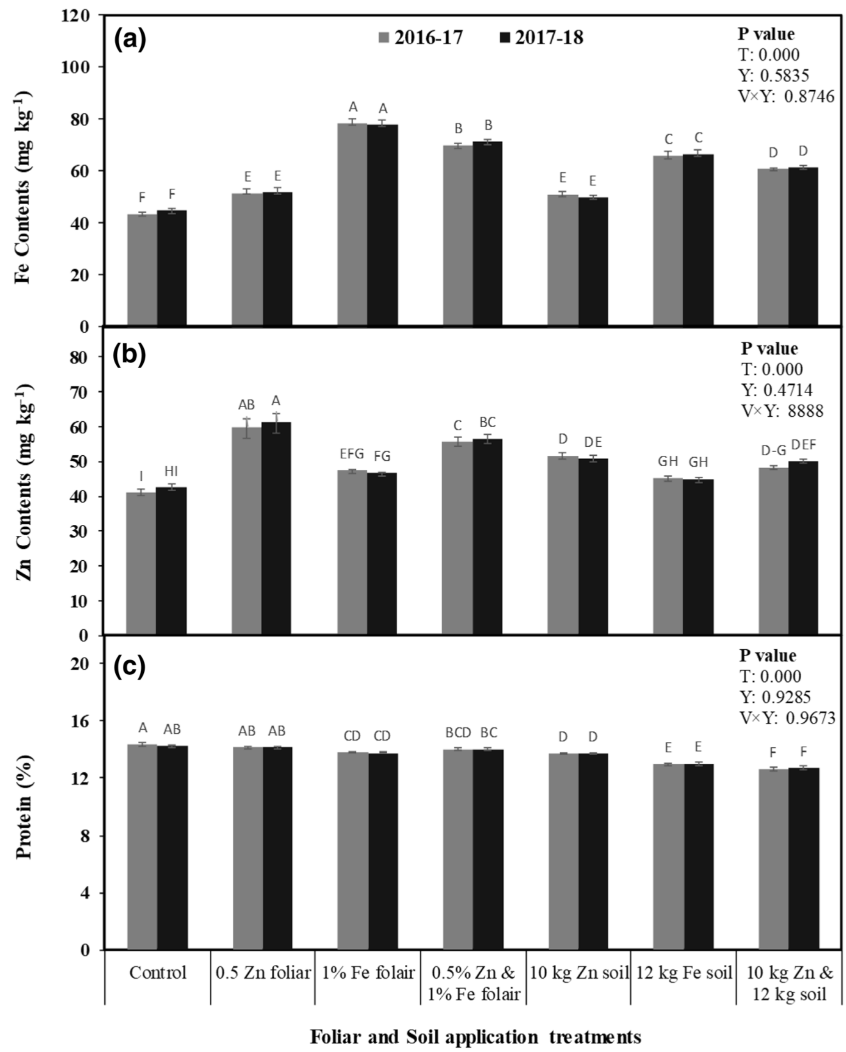

Fig. 3 Impact of soil and foliar applied zinc and iron on iron, zinc and protein contents of wheat grain

components of yield of wheat crop might be due to involvement of Zn and Fe and their critical role in biochemical process including photosynthesis. Findings of current study was in agreement with Niyigaba et al. (2019), they reported that foliar treatment of Zn and Fe significantly improved the yield and quality parameters of wheat crop including thousand kernel weight, crude proteins, spike length, kernels per spike, grain yield, Zn and Fe contents in grains. Sultana et al. (2016) also stated that foliar treatment of Zn played a significant role in enhancing grain yield and other yield components of wheat. They recorded maximum plant height, grain yield, 1000-grain weight, No. of grains per spike and spike length by foliar application Zn @ 0.04%.

Pahlavan-Rad and Pessarakli (2009) reported that highest number of grains were obtained by combined application of Zn and Fe in wheat crop. Hassan et al. (2019) stated that treatment of Zn in wheat crop produced more number of seedlings, biological yield, grain yield and also others yield related parameters. Findings of current research (Table 2) are also supported by Narimani et al (2010) who stated that combined application of Zn, Fe and Cu through foliar spray significantly enhanced plant height, number of fertile florets and number of kernel per spike when compared with control. They also stated that all fertilizers when applied as foliar spray were suggested better to enhance the productivity of durum wheat because of maximum utilization of applied nutrients (Fe + Cu + Zn). This improvement in plant growth is due to the specific role of Zn in enhancing cellular functioning such as carbon metabolism, auxin metabolism, gene expression and functional and maintain structural integrity of cellular membranes. (Marschener 1995).

Moreover, Zn is also involved in seed germination coleoptile development, and early stages of radical (Ozturk et al. 2006). Seed enriched with higher content of Zn showed higher seed germination, and early seeding growth (Cakmak 2008). Zn also play crucial role by being part of many physiological process including respiration and photosynthesis that ensured higher grain yield and early flowering (Zeidan et al. 2010). Results of present experimentation are also supported by Hasina et al. (2011) they concluded that exogenous application of Zn enhanced the number of productive tillers, it may be due the availability of more nutrients for developing tillers. Findings of Soleimani (2006) are also in line with current research (Table 3) that Zn application also increased the number of grains per spike in wheat crop. It may be due to Zn contribution in the cellular enlargement, elongation and cell division process (Cakmak 2000). Moreover, a close relationship was obtained between spike length and number of spikelets i.e. grain numbers increased with increased spike length. The outcomes of this research was also in line with finding of Habib (2009), who deduced that Zn and Fe foliar supplement increased seed yield and other yield components.

Quality Attributes

Findings of our study are supported by Cakmak et al. (2010) who stated that soil and foliar application method of Zn is very effective which increase the Zn concentration three times in the grain. They also stated that application time and application method of Zn treatment is so crucial to improve Zn contents in grains. According to Pahlavan-Rad and Pessarakli (2009), combined application of Zn and Fe was significant regarding Zn concentration in grains. They stated that by application of 1% $FeSO_4$ and 0.5% $ZnSO_4$, Fe and Zn contents were also significantly increased. Xu et al. (2012) reported the results from their studies which against the finding of our study. They stated that there is additive effect for Zn, Fe and protein concentrations in wheat grain but in our study, antagonistic relation is observed. By the increase of Fe and/or Zn contents, protein contents are decreased. Regarding the concentration of Cu in grains, our findings are in line with outcomes of Imtiaz et al. (2003) who concluded that application of Zn showed an adverse impact on Cu contents in wheat plant. Our results are also supported by Zeidan et al. (2010), they stated that foliar application of micro elements including Zn and Fe significantly improved Fe and Zn contents in the grains of wheat as compared to control treatments. Zhao et al. (2014) investigated that, Zn application as foliar is more beneficial in enhancing Zn content in plant tissues as compared to soil supplementation. Same results were found in current study, Zn application proved more effective as compared other supplements. Habib (2009) reported that Zn and Fe application at tillering stage increased plant Zn and Fe content. Zn application as foliar at reproductive stage significantly increased the straw yield and grain productivity, because at these stages it ensures the plant nutrition that is more required at the time of seed filing (Khan et al. 2010). Contrarily, Ozturk et al. (2006) deduced that maximum Zn content was observed in grains by foliar application of Zn at milk stage of wheat crop. Sharma et al. (2008) reported higher protein content with foliar supplied Zn plants, because Cu and Zn are involved in higher protein content. Sole application of Zn increased grain Zn content. Interestingly, grain Zn content is antagonistic to Fe content, when Zn content increased Fe content decreased, vice versa. The combine application of Zn and Fe in different formulation and concentration affect differently the growth and yield parameters. Zuchi et al. (2015) stated that uptake and translocation of Fe to shoot might be prevented by an inadequate supply of other nutrients and Fe deficiency may lead to a high decrease in total nutrients. The interaction among the plant nutrients can be either synergistic, antagonistic, zero-interactive and/or Liebig-synergistic. Above mentioned interactions clarify that the supply of nutrient can affect the function of another nutrient that ultimately influence the crop growth and yield (Rietra et al. 2017). Application of micronutrients and their interactions affect the physiological and biochemical processes of plants, which significantly influence the quality and grain yield (Wang et al. 2015). A thinkable reason for the improvement in quality and yield of wheat crop is that foliar applied Zn may be phloem mobile and can easily translocate into developing grains of wheat (Zuchi et al. 2012). Antagonism is also reported for Zn and Fe when Zn is applied in high concentration and vice versa by Alam et al. (2001). Similar findings are also recorded by Li et al. (2016) in their study that foliar application of Zn and Fe are responsible to improve the concentration of Zn and Fe in wheat flour.

Conclusion

Zinc and iron combination via foliar spray (0.5% $ZnSO_4$ and 1% $FeSO_4$) increased the yield traits of wheat crop as well as quality parameters of grains. Foliar application method is more appropriate for availability of nutrients to plants for optimum growth as compared to soil application method. Combined application of Zn and Fe (0.5% ZnSO4 and 1% FeSO4) through foliar spray is recommended to enhance the productivity of wheat crop with good quality of grains.

Compliance with Ethical Standards

Conflict of interest All Authors declare that they have no conflict of interest.

References

Agrawal, S. C., Jolly, M. S., & Sinha, A. M. (1980). Foliar constituents of secondary food plants of tasar silk *Antheraea mylitta*. *The Indian Forester, 106*, 847–851.

Alam, S., Kamei, S., & Kawai, S. (2001). Effect of iron deficiency on the chemical composition of the xylem sap of barley. *Soil Science and Plant Nutrition, 47*, 643–649.

Anonymous. (2007). Global childhood malnutrition. *Lancet, 367*, 1459.

Borrill, P., Connorton, J., Balk, J., Miller, A. J., Sanders, D., & Uauy, C. (2014). Biofortification of wheat grain with iron and zinc: Integrating novel genomic resources and knowledge from model crops. *Frontiers in Plant Science, 5*, 53.

Cakmak, I. (2000). Possible roles of zinc in protecting plant cells from damage by reactive oxygen species. *New Phytologist, 146*(2), 185–205.

Cakmak, I. (2002). Plant nutrition research: Priorities to meet human needs for food in sustainable ways. *Plant and Soil, 247*(1), 3–24.

Cakmak, I. (2008). Enrichment of cereal grains with zinc: Agronomic or genetic biofortification? *Plant and Soil, 302*, 1–17.

Cakmak, I., Pfeiffer, W. H., & McClafferty, B. (2010). Biofortification of durum wheat with zinc and iron. *Cereal Chemistry, 87*(1), 10–20.

De-Valença, A. W., Bake, A., Brouwer, I. D., & Giller, K. E. (2017). Agronomic biofortification of crops to fight hidden hunger in sub-Saharan Africa. *Global Food Security, 12*, 8–14.

Government of Pakistan (GOP). (2017). *Agriculture sector. Pakistan Economic Survey 2015–2016* (pp. 21–23). Government of Pakistan, Islamabad: Ministry of Finance.

Government of Pakistan (GOP). (2018). *Agriculture sector. Pakistan Economic Survey 2016–2017* (pp. 13–14). Islamabad: Ministry of Finance Government of Pakistan.

Graham, R. D., & Welch, R. M. (1996). *Breeding for staple food crops with high micronutrient density* (Vol. 3). Washington, D.C.: International Food Policy Research Institute.

Habib, M. (2009). Effect of foliar application of Zn and Fe on wheat yield and quality. *African Journal of Biotechnology, 8*(24), 6795–6798.

Hasina, G., Said, A., Saeed, B., Mohammad, F., & Ahmad, I. (2011). Effect of foliar application of nitrogen, potassium and zinc on wheat growth. *Journal of Agricultural Science, 6*, 56–58.

Hassan, N., Irshad, S., Saddiq, M. S., Bashir, S., Khan, S., Wahid, M. A., et al. (2019). Potential of zinc seed treatment in improving stand establishment, phenology, yield and biofortification of wheat. *Journal of Plant Nutrition, 42*(14), 1676–1692.

Imtiaz, M., Alloway, B. J., Shah, K. H., Siddiqui, S. H., Memon, M. Y., Aslam, M., et al. (2003). Zinc nutrition of wheat: II: Interaction of zinc with other trace elements. *Asian Journal of Plant Science, 2*, 156–160.

Imtiaz, M., Rashid, A., Khan, P., Memon, M. Y., & Aslam, M. (2010). The role of micronutrients in crop production and human health. *Pakistan Journal of Botany, 42*(4), 2565–2578.

Jackson, M. T. (2009) Revitalizing the rice wheat cropping systems of the Indo-Gangetic Plains: Adaptation and adoption of resource conserving technologies in India, Bangladesh, and Nepal. Final Report No. DPPC2007–100. International Rice Research Institute, Los Baños, Philippines.

Jawaldeh, A. A., Pena-Rosas, J. P., McColl, K., Johnson, Q., Elmadfa, I., & Nasreddine, L. (2019). Wheat flour fortification in the Eastern Mediterranean Region. Cairo: WHO Regional Office for the Eastern Mediterranean. Licence: CC BY-NC-SA 3.0 IGO.

Johnson, S. E., Lauren, J. G., Welch, R. M., & Duxbury, J. M. (2005). A comparison of the effects of micronutrient seed priming and soil fertilization on the mineral nutrition of chickpea (*Cicer arietinum*), lentil (*Lens culinaris*), rice (*Oryza sativa*) and wheat (*Triticum aestivum*) in Nepal. *Experimental Agriculture, 41*, 427–448.

Kenzhebayeva, S., Abekova, A., Atabayeva, S., Yernazarova, G., Omirbekova, N., Zhang, G., et al. (2019). Mutant lines of spring wheat with increased iron, zinc, and micronutrients in grains and enhanced bioavailability for human health. *Biomedical Research and Science, 2019*, 1–10.

Khan, S., Mirza, K. J., Anwar, F., & Abdin, M. Z. (2010). Development of RAPD markers for authentication of Piper nigrum L. *Environment & We An International Journal of Science & Technology, 5*, 53–62.

Li, M., Wang, S., Tian, X., Li, S., Chen, Y., Jia, Z., et al. (2016). Zinc and iron concentrations in grain milling fractions through combined foliar applications of Zn and macronutrients. *Field Crops Research, 187*, 135–141.

Marschener, H. (1995). Boron. In H. Marschner (Ed.), *Mineral nutrition of higher plants* (2nd ed., pp. 379–396). San Diego: Academic Press.

Memon, M. N., Jamro, G. M., Memon, N. N., Memon, K. S., & Akhtar, M. S. (2012). Micronutrient availability assessment of tomato grown in Taluk Badin, Sindh. *Pakistan Journal of Botany, 44*, 649–654.

Narimani, H., Rahimi, M. M., Ahmadikhah, A., & Vaezi, B. (2010). Study on the effects of foliar spray of micronutrient on yield and yield components of durum wheat. *Archives of Applied Science Research, 2*(6), 168–176.

Ngozi, U. F. (2013). The role of biofortification in the reduction of micronutrient food insecurity in developing countries. *African Journal of Biotechnology, 12*(37), 5559–5566.

Niyigaba, E., Twizerimana, A., Mugenzi, I., Ngnadong, W. A., Ye, Y. P., Wu, B. M., et al. (2019). Winter wheat grain quality, zinc and iron concentration affected by a combined foliar spray of zinc and iron fertilizers. *Agronomy, 9*(5), 250.

Ozturk, L., Yazici, M. A., Yucel, C., Torun, A., Cekic, C., Bagci, A., et al. (2006). Concentration and localization of zinc during seed development and germination in wheat. *Physiologia Plantarum, 128*, 144–152.

Pahlavan-Rad, M. R., & Pessarakli, M. (2009). Response of wheat plants to zinc, iron, and manganese applications and uptake and concentration of zinc, iron, and manganese in wheat grains. *Communications in Soil Science and Plant Analysis, 40*(7–8), 1322–1332.

Pandey, N., Pathak, G. C., & Sharma, C. P. (2006). Zinc is critically required for pollen function and fertilisation in lentil. *Journal of Trace Elements in Medicine and Biology, 20*(2), 89–96.

Rashid, A. (1986). Mapping zinc fertility of soils using indicator plants and soils analysis. PhD Dissertation, University of Hawaii, HI, USA.

Rehman, A., Farooq, M., Ozturk, L., Asif, M., & Siddique, K. H. M. (2018). Zinc nutrition in wheat-based cropping systems. *Plant and Soil, 422*, 283–315.

Rietra, R. P., Heinen, M., Dimkpa, C. O., & Bindraban, P. S. (2017). Effects of nutrient antagonism and synergism on yield and fertilizer use efficiency. *Communications in Soil Science and Plant Analysis, 48*, 1895–1920.

Sharma, R., Agarwal, A., & Kumar, S. (2008). Effect of micronutrients on protein content and productivity of wheat (Triticum aestivum L***). *VEGETOS: An International Journal of Plant Research, 21*(1), 51–53.

Soetan, K. O., Olaiya, C. O., & Oyewole, O. E. (2010). The importance of mineral elements for humans, domestic animals and plants-A review. *African Journal of Food Science, 4*(5), 200–222.

Soleimani, R. (2006). The effects of integrated application of micronutrient on wheat in low organic carbon conditions of alkaline soils of western Iran. 18th World Congress of Soil Science, Philadelphia, Pennsylvania, USA.

Steel, R. G. D., Torrie, J. H., & Dicky, D. A. (1997). *Principles and procedures of statistics: A biological approach* (3rd ed., pp. 352–358). New York: Mcgraw Hill Inc. Book Co.

Stein, A. J. (2010). Global impacts of human mineral malnutrition. *Plant and Soil, 335*, 133–154.

Sultana, S., Naser, H. M., Shil, N. C., Akhter, S., & Begum, R. A. (2016). Effect of foliar application of zinc on yield of wheat grown by avoiding irrigation at different growth stages. *Bangladesh Journal of Agricultural Research, 41*(2), 323–334.

Wang, S., Li, M., Tian, X., Li, J., Li, H., Ni, Y., et al. (2015). Foliar zinc, nitrogen, and phosphorus application effects on micronutrient concentrations in winter wheat. *Agronomy Journal, 107*, 61–70.

Xu, Y., An, D., Liu, D., Zhang, A., Xu, H., & Li, B. (2012). Molecular mapping of QTLs for grain zinc, iron and protein concentration of wheat across two environments. *Field Crops Research, 138*, 57–62.

Zeidan, M. S., Manal, F., & Hamouda, H. A. (2010). Effect of foliar fertilization of Fe, Mn and Zn on wheat yield and quality in low sandy soils fertility. *World Journal of Agricultural Research, 6*, 696–699.

Zhao, A., Tian, X., Cao, Y., Lu, X., & Liu, T. (2014). Comparison of soil and foliar zinc application for enhancing grain zinc content of wheat when grown on potentially zinc-deficient calcareous soils. *Journal of the Science of Food and Agriculture, 94*, 2016–2022.

Zuchi, S., Cesco, S., & Astolfi, S. (2012). High supply improves Fe accumulation in durum wheat plants grown under Fe limitation. *Environmental and Experimental Botany, 77*, 25–32.

Zuchi, S., Watanabe, M., Hubberten, H. M., Bromke, M., Osorio, S., Fernie, A. R., et al. (2015). The interplay between sulfur and iron nutrition in tomato. *Plant Physiology, 169*, 2624–2639.