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INFLUENCE OF ZINC APPLICATION THROUGH SEED TREATMENT AND FOLIAR SPRAY ON GROWTH, PRODUCTIVITY AND GRAIN QUALITY OF HYBRID MAIZE

A. U. Mohsin, A.U. H. Ahmad, M. Farooq and S. Ullah*

Department of Agronomy, University of Agriculture, Faisalabad, Pakistan
*Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Pakistan
Corresponding author's email: attamohsin.bzu@gmail.com

ABSTRACT

Maize (*Zea mays* L.) is high nutrient demanding crop but sensitive to zinc (Zn) deficiency in soil. Application of Zn fertilizers could be a viable option to fulfill the crop demand for Zn and also to increase its contents in grains. Two years field experiments were conducted to evaluate the effect of different Zn application methods on the productivity of maize hybrids on sandy loam soil. Zinc as seed priming (1.0, 2.0% Zn solution) or foliar application (1.0, 2.0% Zn foliar spray) alone and in combinations were evaluated in randomized complete block design with factorial arrangement having three replications. Results showed that maize hybrid Pioneer 30-Y-87, with combined application of Zn as seed priming (2.0%) and foliar spray (2.0%), significantly improved plant height, cob length, cob diameter, 1000-grain weight, biological yield, grain yield and harvest index. Similarly, maize hybrid DK-919, with combined application of Zn as seed priming (2.0%) and foliar spray (2.0%) produced significantly more grain zinc content (mg kg^{-1}). However, Zn application significantly decreased grain protein contents. These results suggested that combined application of Zn as seed priming (2.0%) and foliar spray (2.0%) can improve the performance of maize hybrids.

Key words: Hybrid maize, zinc, seed priming, foliar spray, grain yield, zinc content, grain protein.

INTRODUCTION

Maize contributes about 6.4% in total food grains production of Pakistan. It was grown on an area of 1.08 million hectares with grain production of 4.63 million tones with an average grain yield of 4268 kg ha^{-1} (GOP, 2012-13). Comparing with the genetic yield potential of the existing maize cultivars, this yield is far less than the other countries of the world. For that reason, it is a need of the time to develop proper strategies to improve the production potential of maize crop by making progress in some basic mechanism of the existing maize production technology in Pakistan. Along with the other agro-management practices, balanced and optimum use of fertilizers play a pivotal role in increasing the yields of cereals (Asghar *et al.,* 2010).

Among many other factors causing turn down in maize yield; imbalanced use of fertilizers is very important (Cisse and Amar, 2000). Maize is a high nutrient demanding crop, which also requires micronutrients (in particular the Zn) (Obrador *et al*., 2003) along with major elements for better growth and yield (Verma, 2011). Zinc deficiency is frequently equal in plants and humans. Zinc deficiency regions in human are reported to be Zn deficient soils regions and are prevalent, for instance in India, China, Pakistan, Iran and Turkey (Cakmak *et al*., 1999). Zinc deficiency is usually wide spread in the cereal crops grown on the calcareous soils of semi arid regions; where on the subject of 50% soils are reported to exist scarce in Zn (Singh *et al*., 2005). Worldwide incidence of Zn deficiency in soils is becoming more important due to its impact on human health (Singh *et al*., 2005). The major reason for the incidence of Zn deficiency in human beings in the developing countries is the use of cereal based foods in its place of animal-based diets. Even though animal foods are excellent source of these vital micro elements (Soetan *et al*., 2010) but their use is restricted due to socio-economic constraints in the developing countries. Plants are in general grown-up on soils that are already poor in accessible Zn. Subsequently, the utilization of these foods leads towards Zn paucity in human beings (Batra and Seth, 2002).

To reduce Zn deficiency among the poor people of the developing countries, exercise of Zn enriched food resources is a precondition. Notwithstanding the detail that other strategies such as Zn supplementation, food fortification and food assortment to battle Zn deficiency in human beings are practiced however, they have their restricted use. Zinc supplementation in addition to food enrichment is expensive approach and merely restricted to certain parts of the globe (Frossard *et al*., 2000). On the other hand, to reduce Zn deficiency along with the day by day increasing population of the developing nations, there is a need to nourish them with Zn enriched foodstuff on sustainable basis. Enrichment of plant food material with Zn is termed as agronomic biofortification is compulsory (Nestel *et al*., 2006; Cakmak, 2008).

Biofortification of plant foodstuff can be achieved from fertilizer use, plant breeding and genetic engineering (Sadeghzadeh, 2013). Amendment in plant materials through breeding or genetic engineering is a time-consuming plan and it depends upon the genotypic variance among crop plants. Crop species and even genotypes within a species might be different in their Zn contents (Frossard *et al*., 2000). Difference in Zn contents within the genotypes of the similar species might be attributed to their differences in Zn requirement in addition to consumption efficiencies. Therefore, the choice of plant cultivars/genotypes that are efficient users of the inhabitant soil Zn content may possibly be advantageous for low input agricultural systems. Genotypes having ability to respond quickly and to applied Zn may prove suitable for high input agricultural systems. On the other hand, increasing the mineral content of the food crops through fertilizer application (according to their requisite) possibly is a short time strategy that can be effortlessly attained by the people of the developing countries having limited resources.

Zinc fertilizers are widely used to enhance the yield and Zn contents and quality of edible grains of different crops. Foliar application of Zn enhances the uptake and accumulation of nitrogen and finally increased the maize grain yield (Grzebisz *et al*., 2008). Foliar application of Zn significantly improved starch contents of forage maize (Leach and Hameleers, 2001), and doubled the grain Zn concentration of maize (Peck *et al*., 2008). Foti*et al*. (2008) reported that seed priming with Zn sulphate increased the germination and emergence of maize caryopses both under laboratory and field condition. Ali *et al*. (2008) evaluated the effect of nutrient seed priming on yield and yield components of maize variety ‘Azam’, at different levels of soil P application. Nutrient seed priming resulted in more number of cobs plot^{-1}, grains cob^{-1}, 1000- grain weight and biological yield of maize crop even at lower soil application. Seed priming enhanced the vigorous early seedling growth and better crop stand establishment (Arif*et al*., 2005 and Ali *et al*., 2007). Aboutalebian *et al*. (2012) showed that seed priming with Zn sulphate solution speed up the emergence of crop and finally increased grain yield. Similarly the highest maize grain yield was recorded when the priming of seed was done with the Zn sulphate solution (Tabrizi *et al*., 2011). The response of crop species even the genotypes vary in their response to Zn (Hasisalihoglu and Kochian, 2003; Khosh goftarmanesh *et al*., 2004). Maize hybrids gave more encouraging response as compared to the synthetic variety and their levels of zinc response were different from each other (Kanwal *et al*., 2010). Similarly, variation in response to the Zn by different varieties of maize and other crops has been reported by (Fageria, (2001).

It is evident from previous studies that Zn application not only increased the yield but also improved the Zn content in maize crop. Nonetheless, to best of our knowledge, limited information is available on combined use of Zn application (method and concentration) on maize hybrids. This study was, therefore, conducted to evaluate the most effective method of Zn application for crop growth, yield and grain fortification of maize hybrids.

MATERIALS AND METHODS

Experimental Site: Experiments were conducted at Agronomy Research Farm, University of Agriculture, Faisalabad, Pakistan (31.25º N, 73.06º E and 184 msl) during 1st week of August 2009 and 2010 on soil where wheat was grown in previous seasons. The composite sample was examined for its physico-chemical properties before sowing. The experimental soil texture was sandy loam with pH 8.1, electrical conductivity 1.68 dS m^{-1}, 0.73% of organic matter, total nitrogen 0.050%, available phosphorus 5.29 ppm, available potassium 175 ppm and available Zn 0.98 ppm. For seedbed preparation and better germination of crop, soil was cultivated 2 times with tractor mounted cultivator followed by planking each time. A pre-sowing irrigation was applied and when soil reached at field capacity, again soil was cultivated 2 times with tractor mounted cultivator followed by planking each time. After that 75 cm apart ridges were made with the help of tractor mounted ridger. Sowing was done by dibbling method (by placing 2 seeds manually per hill at 20cm apart hills) on 75 cm apart ridges. Randomized complete block design with factorial arrangement having three replications was used. Two maize hybrids viz. Pioneer 30-Y-87 and DK-919 were used in this study.Zinc as seed priming or foliar application at the rate of 1.0 and 2.0% alone or in combination were used. For seed priming, seeds were soaked in respective concentration of Zn solution for 16 h, keeping seed: solution ratio 1:5 (w/v) at 25±2 °C. After that, seeds were removed, given three surface washings and re-dried with forced air near to its original weight and stored for further use, while standing crop was sprayed with Zn on foliage one month after sowing. Fertilizer was applied at the rate of 250-125-125 kg NPK ha^{-1}. Whole phosphorus, potassium and half of the nitrogen were applied as basal dose, while rest of nitrogen was applied one month after sowing with irrigation. Weather data recorded during the course of experimentation are given in Table 1. The aerial distance of experimental site and the weather station was about 400 m.

Table 1: Meteorological data during the crop seasons

Month	Rain fall (mm)		Relative humidity (%)		Temperature (^{0}C)					
					Daily maximum		Daily minimum		Daily mean	
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
August	116.0	226.6	65.8	74.6	36.6	34.9	27.6	26.1	32.1	30.5
September	20.6	86.5	61.0	66.8	36.3	33.9	24.4	23.3	30.3	28.6
October	17.5	0.0	57.9	59.6	32.7	32.9	17.1	19.7	24.9	26.3
November	0.7	0.0	64.7	62.3	25.7	27.1	10.8	10.5	18.2	18.8
December	0.0	1.0	64.4	70.5	22.1	20.8	07.0	05.9	14.5	13.3

Source: Agricultural Meteorology Cell, Department of Crop Physiology, University of Agriculture, Faisalabad, Pakistan.

Agronomic attributes: Data on various agronomic and yield related traits were recorded at harvestingfollowing the standard procedures. For plant height, ten plants were randomly selected in each plot and measurements were taken from base to the tip. Cob length and cob diameter were recorded from ten randomly selected cobs from each plot and were averaged separately. Data regarding 1000-grain weight from each treatment was recorded in grams. For grain yield, crop from an area of 6 m^2 was harvested and threshed manually, and then clean grains were air dried, bulked and weighed while biological yield from each plot was determined from sundried samples from an area of 6 m^2 and converted into t ha^{-1}

Allometry: Plant samples were collected randomly from each experimental unit starting from 45 days after sowing at fortnight interval until 105 days after sowing. Leaves were separated from the plants and leaf area was measured by using laser leaf area meter (Laser Area Meter CI-203). Plant samples collected sun-dried for 24 h and then dried in an oven at 70°C for 5 days until constant dry weight. Leaf area index, crop growth rate and net assimilation rate were calculated according to the method of Hunt (1978).

Grain protein and Zn content: Maize grain sample from each treatment were collected and grinded. Grain Zn contents were determined by using atomic absorption spectroscopy (Wright and Stuczynski, 1996), while nitrogen contents of maize seed samples were determined by using the micro-Kjeldhal method (Jackson, 1962) and then the crude protein content was calculated by using the following formula.

Crude protein = Nitrogen x 6.25.

The data collected were analyzed statistically by employing Fisher's analysis of variance technique (Steel *et al*., 1997) using computer software M STAT C (1989) and treatment means were compared by applying least significance difference (LSD) test at 5% probability level.

RESULTS AND DISCUSSION

Plant height was significantly improved by Zn application (Table 2). During experimental year 2009 only main factors (Zn application and maize hybrid) were significant and maximum plant height was recorded with combined application of Zn as seed priming (2%) and foliar spray (2%). Maize hybrid Pioneer 30-Y-87 produced taller plants than hybrid DK-919. While during year 2010 interactions were also significant and maximum plant height was recorded in maize hybrid Pioneer 30-Y-87 with combined application of Zn as seed priming (2%) and foliar spray (2%). Increase in plant height was up to 20% and 25% respectively during 2009 and 2010. Increase in plant height (Table 1) might be attributed to internodal distance as reported by Kaya and Heggs (2002) with Zn application. Similar results regarding plant height due to the seed priming with Zn solution were reported by Arif*et al*. (2005) and Ali *et al*. (2007). Also, Badshah and Ayub (2013) and El-Badawy and Mehasen (2011) showed significant increase in plant height with the foliar application of Zn.

Cob length was significantly improved by Zn application (Table 2). During experimental year 2009 only main factors (Zn application and maize hybrid) were significant and maximum cob length was recorded with combined application of Zn as seed priming (2%) and foliar spray (2%). Maize hybrid Pioneer 30-Y-87 produced longer cobs than hybrid DK-919. While during year 2010 interactions were also significant and maximum cob length was recorded in maize hybrid Pioneer 30-Y-87 with combined application of Zn as seed priming (2%) and foliar spray (2%). Cob diameter is an important yield contributing trait and was significantly improved by Zn application (Table 2). Maize hybrid Pioneer 30-Y-87 with combined application of Zn as seed priming (2%) and foliar spray (2%) during study year 2009.While, during experimental year 2010 only main effects were significant and combined application of Zn as seed priming (2%) and foliar spray (2%) produced thicker cobs. Among maize hybrids, Pioneer 30-Y-87 produced thicker cobs than DK-919. Increment in the cob diameter was about 17% during 2009 and 13% during 2010. 1000-grain weight was significantly improved up to 19% by Zn application during both years of experimentation (Table 2). Increase in cob length and cob diameter with combined application of Zn as soil application and foliar spray might have been the result of increase in the availability of Zn due to seed priming and direct absorption of the Zn by the foliar spray. This proper and adequate supply of Zn increased the uptake of N during the grain formation stage and ultimately improved the yield component of maize (Siddiqui*et al.*, 2009). Positive effect on the uptake of nitrogen during the milking and grain formation stage has also been found with the early stage Zn application (Grzebisz *et al*., 2008). Similarly, Potarzycki and Grzebisz (2009) reported Zn application as a positive factor for the maximum productivity of nitrogen fertilizer.

Maximum 1000-grain weight was weighed in maize hybrid Pioneer 30-Y-87 with combined application of Zn as seed priming (2%) and foliar spray (2%) during experimental year 2009. While during experimental year 2010 only main effect were significant. Maximum 1000-grain weight was recorded with combined application of Zn as seed priming (2%) and foliar spray (2%). Maize hybrid Pioneer 30-Y-87 produced heavier grains than hybrid DK-919. Increase in 1000-grai weight might be attributed to the increased in cob length and diameter which ultimately produced healthy and heavier grains. Tahir *et al*., (2009) also reported increased in the cob length (cm), cob diameter and 100-grains weight with foliar application of Zn over the control treatment.

Maximum grain and biological yield (Table 3) were recorded in maize hybrid Pioneer 30-Y-87 with combined application of Zn as seed priming (2%) and foliar spray (2%) during both the years. Improvement in grain yield was 20% and 22%, and biological yield was 13% and 17 % during the year 2009 and 2010, respectively. This increment in the grain yield of maize was due to increase in cob length, cob diameter and 1000-grain weight. Higher yield due to Zn fertilization is also attributed to the enhanced synthesis of carbohydrates and their transport to the site of grain production (Pedda-Babu*et al*., 2007). Increased in the biological yield might beattributed to better nutrition and early seedling growth of the plant seed priming with Zn solution and increased in the dry matter production in maize. Increased in the biological yield is also attributed to increase in plant height and leaves of corn (Fageria *et al*., 2006). Similarly, Trehanand Sharma (2000) reported that using Zn increased the dry matter production in maize. Zinc application also significantly improved harvest index (Table 3). During 2009 only main effects were significant and combined application of Zn as seed priming (2%) and foliar spray (2%) gave maximum harvest index, while among maize hybrid Pioneer 30-Y-87 gave more harvest index than hybrid DK-919. However, during study year 2010 interactions were also significant and maximum harvest index was recorded in maze hybrid Pioneer 30-Y-87 with combined application of Zn as seed priming (2%) and foliar spray (2%). These results are in line with the finding of Afzal*et al*. (2013), who reported increase in the harvest index of maize with seed priming (1.5% ZnSO4) from 26.57% to 34.33%. Similarly, Ghaffari *et al*. (2011) and Sajedi *et al*. (2009) reported increase in the harvest index of maize due to foliar application against the control due to improved plant growth.

Zinc application also significantly improved leaf area index, leaf area duration, crop growth rate and net assimilation rate (Table 3, 4). Interactive effects of Zn application methods and maize hybrids were significant for leaf area index, crop growth rate and net assimilation rate during both years. Higher values of leaf area index, crop growth rate and net assimilation rate were recorded in maize hybrid Pioneer 30-Y-87 with combined application of Zn as seed priming (2%) and foliage spray (2%) during both years of experimentation except for crop growth rate during was maximum in hybrid DK-919. Increased in leaf area index by Zn application might be due to increase in tryptophan amino acid and indole acetic acid hormone which are two main factors in leaf area expansion (Seifi Nadergholi *et al*., 2011). Safyan *et al*. (2012) reported increased in leaf area index (LAI) of maize crop with foliar applied Zn.More crop growth rate and net assimilation rate may be attributed to significant increase in leaf expansion due to better growth of plants as affected by Zn application at early growth stages of crop which finally increased the dry matter of plant. In earlier studies by Afzal *et al*. (2013) reported that the leaf area index (LAI), crop growth rate (CGR) and net assimilation rate (NAR) was increased in maize by seed priming with Zn solution. Similarly, Kaiser *et al*. (2005) pointed that crop growth rate (CGR) was the highest by the seed priming with Zn solution.

Different Zn application methods improved kernel Zn contents (Table 4); however, combined application of Zn as seed priming (2%) and foliage spray (2%) in maize hybrid DK-919 gave 43.61 % and 36.56 % more grain Zn content, respectively during the year 2009 and 2010 than any other. Increased in grain Zn accumulation (Table 4) of maize plants by combined Zn application as soil addition and foliar spray might be attributed to proper Zn application which preferentially moved in the plant to be deposited in the grain Dvorak *et al*. (2003). Similar findings were reported by Soleimani (2012), who exhibited increased in the grain Zn content of maize with combined application of Zn as soil application and foliage spray as compared sole application. However, Zn application significantly reduced grain protein contents (Table 4) and maximum grain protein contents were recorded in maize hybrid DK-919 with no Zn application during experimental year 2009, while during experimental year 2010 only main effect of Zn application was statistically significant and maximum grain protein content were recorded in plots without Zn fertilization. Reduction in grain protein contents with Zn application possibly due to the dilution effect caused by marked increases in grain yield (Ortiz-Monasterio*et al*., 2007). Duvick (1997) reported linear

Table 2: Influence of zinc application through seed treatment and foliar spray on plant height, cob length, cob diameter and 1000-grain weight of maize hybrids.

Zinc Application	2009											
	Plant height (cm)			**Cob length (cm)**			**Cob diameter (cm)**			**1000-Grain weight (g)**		
	Hybrids		**Mean**	**Hybrids**		**Mean**	**Hybrids**		**Mean**	**Hybrids**		**Mean**
	DK-919	**Pioneer 30-Y87**		**DK-919**	**Pioneer 30-Y87**		**DK-919**	**Pioneer 30-Y87**		**DK-919**	**Pioneer 30-Y87**	
CK	180.3	211.1	195.7^{G}	13.69	15.19	14.44^{E}	3.48^{k}	3.63^{ij}	3.55^{F}	209.86^{j}	219.38^{hij}	214.62^{F}
SP_1	196.1	223.8	209.9^{F}	14.01	17.46	15.73^{DE}	3.57^{jk}	3.76^{gh}	3.66^{E}	212.37^{ij}	235.26^{e-g}	223.81^{E}
SP_2	201.9	229.2	215.5^{EF}	14.98	16.14	15.56^{DE}	3.61^{ij}	3.90^{ef}	3.75^{D}	225.34^{g-i}	229.34^{f-h}	227.34^{DE}
F_1	206.1	234.7	220.4^{DE}	14.32	18.20	16.26^{C-E}	3.70^{hi}	3.82^{fg}	3.76^{D}	218.55^{h-j}	242.15^{c-f}	230.35^{DE}
F_2	218.7	242.9	230.8^{B}	17.24	19.78	18.51^{A-C}	3.87^{efg}	4.11^{bc}	3.99^{B}	237.55^{d-g}	249.8^{a-d}	243.72^{BC}
$SP_1 + F_1$	210.6	237.7	224.1^{CD}	15.92	19.12	17.52^{B-D}	3.78^{gh}	3.97^{de}	3.87^{C}	231.14^{f-h}	238.44^{d-g}	234.79^{CD}
$SP_1 + F_2$	222.4	246.7	234.5^{AB}	18.10	21.38	19.74^{AB}	4.02^{cd}	4.20^{ab}	4.11^{A}	243.69^{c-f}	260.67^{ab}	252.18^{AB}
$SP_2 + F_1$	213.8	244.2	229.0BC	16.74	21.04	18.89^{AB}	3.95^{de}	4.05^{cd}	4.00^{B}	239.82^{d-g}	255.91^{a-c}	247.86^{AB}
$SP_2 + F_2$	227.2	251.5	239.3^{A}	19.28	22.60	20.94^{A}	4.09^{bc}	4.25^{a}	4.17^{A}	248.27^{b-e}	264.35^{a}	256.31^{A}
Mean	208.5^{B}	235.7^{A}		16.03^{B}	18.99^{A}		3.78^{B}	3.96^{A}		229.62^{B}	243.93^{A}	
LSD at P 0.05	Treatment: 6.16, Hybrid: 1.78, Interaction: NS			Treatment: 2.60, Hybrid: 0.75, Interaction: NS			Treatment: 0.071, Hybrid: 0.020, Interaction: 0.114			Treatment: 9.03, Hybrid: 2.61, Interaction: 14.53		
	2010											
Zinc Application	**Plant height (cm)**			**Cob length (cm)**			**Cob diameter (cm)**			**1000-Grain weight (g)**		
	Hybrids		**Mean**	**Hybrids**		**Mean**	**Hybrids**		**Mean**	**Hybrids**		**Mean**
	DK-919	**Pioneer 30-Y87**		**DK-919**	**Pioneer 30-Y87**		**DK-919**	**Pioneer 30-Y87**		**DK-919**	**Pioneer 30-Y87**	
CK	175.2 ^{k}	178.5 ^{jk}	176.5 ^{H}	11.12 ^{n}	12.67 l	11.89 ^{I}	3.58	3.62	3.60 ^{F}	206.78	219.46	213.12^{D}
SP_1	181.7 $^{i-k}$	184.3 $^{h-k}$	183.0 ^{GH}	12.07 ^{m}	14.46 h	13.26 ^{H}	3.65	3.74	3.69 ^{E}	213.14	233.67	223.41^{CD}
SP_2	185.8 $^{h-k}$	189.1 $^{g-j}$	1$^{87.4\ FG}$	13.23 k	13.74 j	13.48 ^{G}	3.70	3.81	3.75 ^{DE}	220.37	227.57	223.97^{CD}
F_1	192.3 f-i	194.8 $^{f-h}$	193.5 ^{EF}	12.76 l	15.07 f	13.91 ^{F}	3.74	3.88	3.81 ^{CD}	217.64	237.08	227.36^{C}
F_2	204.7 $^{c-f}$	207.8 $^{c-}$e	206.2 ^{CD}	15.84 e	16.64 d	16.24 ^{C}	3.88	4.03	3.95 ^{B}	235.41	249.34	242.38^{AB}
$SP_1 + F_1$	196.4^{e-h}	202.4^{d-f}	199.4^{DE}	14.12^{i}	15.84^{e}	14.98^{E}	3.81	3.92	3.86^{C}	224.96	242.13	233.55^{BC}
$SP_1 + F_2$	208.9^{c-e}	221.6^{ab}	215.2^{AB}	16.54^{d}	18.13^{b}	17.33^{B}	3.96	4.09	4.02^{AB}	238.55	259.78	249.17^{A}
$SP_2 + F_1$	199.6^{e-g}	215.3^{bc}	207.4^{BC}	14.78^{g}	17.35^{c}	16.06^{D}	3.93	3.98	3.95^{B}	230.62	253.92	242.27^{AB}
$SP_2 + F_2$	213.4^{b-d}	229.7^{a}	221.5^{A}	17.31^{c}	18.96^{a}	18.13^{A}	4.01	4.13	4.07^{A}	243.77	266.23	255.00^{A}
Mean	195.3^{B}	202.6^{A}		14.19^{B}	15.87^{A}		3.80^{B}	3.91^{A}		225.69^{B}	243.24^{A}	
LSD at P 0.05	Treatment: 7.88, Hybrid: 2.28, Interaction: 12.68			Treatment: 0.17, Hybrid: 0.04, Interaction: 0.27			Treatment: 0.071, Hybrid: 0.020, Interaction: NS			Treatment: 13.93, Hybrid: 4.03, Interaction: NS		

Means sharing the same case letters for main and interaction effects don't differ significantly. NS = Non-significant

CK = No Zn application, SP_1 = Seed priming (1% Zn), SP_2 = Seed priming (2% Zn), F_1 = Foliar application (1% Zn), F_2 = Foliar application (2% Zn)

Table 3: Influence of zinc application through seed treatment and foliar spray on grain yield, biological yield, harvest index, and leaf area index of maize hybrids.

Zinc Application	2009											
	Grain yield (t ha^{-1})			Biological yield (t ha^{-1})			Harvest index (%)			Leaf area index		
	Hybrids			Hybrids			Hybrids			Hybrids		
	DK-919	Pioneer 30-Y87	Mean	DK-919	Pioneer 30-Y87	Mean	DK-919	Pioneer 30-Y87	Mean	DK-919	Pioneer 30-Y87	Mean
CK	5.60^{m}	6.01^{i-l}	5.80^{G}	17.96^{n}	18.57^{k}	18.26^{G}	31.20	32.363	31.78^{D}	4.52^{j}	4.67^{i}	4.60^{G}
SP$_1$	5.76^{lm}	6.42^{d-h}	6.09^{F}	18.14^{m}	19.47^{g}	18.80^{F}	31.79	32.99	32.39^{CD}	4.69^{i}	4.93^{gh}	4.81^{F}
SP$_2$	5.99^{j-l}	6.28^{f-j}	6.14^{F}	18.52^{k}	19.02^{i}	18.77^{F}	32.36	33.05	32.70^{B-D}	4.82^{h}	4.99^{g}	4.91^{E}
F$_1$	5.88^{k-m}	6.60^{c-e}	6.24^{EF}	18.30^{l}	19.76 f	19.03^{E}	32.13	33.42	32.77^{A-D}	5.11^{f}	5.16^{f}	5.14^{D}
F$_2$	6.30^{e-i}	6.89^{bc}	6.60^{CD}	19.31^{h}	20.42^{d}	19.86^{C}	32.66	33.77	33.21^{A-C}	5.67^{c}	5.85^{b}	5.76^{B}
SP$_1$ + F$_1$	6.11^{h-k}	6.71^{cd}	6.41^{DE}	18.84^{j}	20.09^{e}	19.46^{D}	32.45	33.40	32.92^{A-C}	4.97^{g}	5.2^{ef}	5.09^{D}
SP$_1$ + F$_2$	6.44^{d-g}	7.19^{ab}	6.81^{AB}	19.65^{f}	20.84^{b}	20.24^{B}	32.77	34.51	33.64^{AB}	5.31^{de}	5.55^{c}	5.43^{C}
SP$_2$ + F$_1$	6.22^{g-j}	7.11^{ab}	6.66^{BC}	19.03^{i}	20.59^{c}	19.81^{C}	32.68	34.54	33.61^{AB}	5.42^{d}	5.59^{c}	5.51^{C}
SP$_2$ + F$_2$	6.59^{c-f}	7.34^{a}	6.96^{A}	20.14^{e}	21.08^{a}	20.61 A	32.72	34.85	33.78^{A}	5.87^{b}	6.10^{a}	5.99^{A}
Mean	6.10^{B}	6.73^{A}		18.87^{B}	19.98^{A}		32.30^{B}	33.65^{A}		5.15^{B}	5.34^{A}	
LSD at P 0.05	Treatment: 0.19, Hybrid: 0.05, Interaction: 0.31			Treatment: 0.084, Hybrid: 0.024, Interaction: 0.135			Treatment: 1.03, Hybrid: 0.29, Interaction: NS			Treatment: 0.075, Hybrid: 0.022, Interaction: 0.12		

Zinc Application	2010											
	Grain yield (t ha^{-1})			Biological yield (t ha^{-1})			Harvest index (%)			Leaf area index		
	Hybrids		Mean	Hybrids		Mean	Hybrids		Mean	Hybrids		Mean
	DK-919	Pioneer 30-Y87		DK-919	Pioneer 30-Y87		DK-919	Pioneer 30-Y87		DK-919	Pioneer 30-Y87	
CK	5.18^{n}	5.87^{ij}	5.52^{G}	15.54^{l}	16.72^{i}	16.13^{G}	33.33^{f}	35.10^{de}	34.22^{C}	4.43 l	4.49^{kl}	4.46^{H}
SP$_1$	5.39^{m}	6.27^{fg}	5.83^{F}	15.92^{k}	17.28^{g}	16.60^{F}	33.85^{f}	36.28^{bc}	35.07^{AB}	4.59^{jk}	4.68^{ij}	4.64^{G}
SP$_2$	5.61^{kl}	6.10^{h}	5.85^{EF}	16.38^{j}	17.04^{gh}	16.71^{EF}	34.25^{ef}	35.79^{cd}	35.02^{B}	4.73^{hij}	4.76^{hi}	4.75^{F}
F$_1$	5.48^{lm}	6.41^{ef}	5.94^{E}	16.03^{k}	17.63^{f}	16.83^{E}	34.18^{ef}	36.36^{a-c}	35.27^{AB}	4.98^{g}	4.94^{g}	4.96^{E}
F$_2$	6.02^{hi}	6.69^{cd}	6.35^{C}	17.59^{f}	18.16^{d}	17.87^{C}	34.22^{ef}	36.84^{ab}	35.53^{AB}	5.46^{cd}	5.57^{bc}	5.51^{B}
SP$_1$ + F$_1$	5.72^{jk}	6.57^{de}	6.14^{D}	16.82^{hi}	17.91^{e}	17.36^{D}	34.01^{f}	36.68^{a-c}	35.34^{AB}	4.85^{gh}	4.92^{g}	4.89^{E}
SP$_1$ + F$_2$	6.16^{gh}	6.96^{b}	6.56^{B}	18.06^{de}	18.86^{b}	18.46^{B}	34.10^{f}	36.90^{ab}	35.50^{AB}	5.16^{f}	5.27 ef	5.22^{D}
SP$_2$ + F$_1$	5.88^{ij}	6.82^{bc}	6.35^{C}	17.14^{g}	18.49^{c}	17.81^{C}	34.30^{ef}	36.88^{ab}	35.59^{AB}	5.27 ef	5.34 de	5.31^{C}
SP$_2$ + F$_2$	6.34^{f}	7.13^{a}	6.73^{A}	18.62^{bc}	19.12^{a}	18.87^{A}	34.05^{f}	37.29 a	35.67^{A}	5.67^{ab}	5.80^{a}	5.73^{A}
Mean	5.75^{B}	6.53^{A}		16.90^{B}	17.91^{A}		34.03^{B}	36.46^{A}		5.01^{B}	5.08^{A}	
LSD at P 0.05	Treatment: 0.10, Hybrid: 0.02, Interaction: 0.16			Treatment: 0.154, Hybrid: 0.044, Interaction: 0.248			Treatment: 0.60, Hybrid: 0.17, Interaction: 0.97			Treatment: 0.088, Hybrid: 0.025, Interaction: 0.14		

Means sharing the same case letters for main and interaction effects don't differ significantly. NS = Non-significant

CK = No Zn application, SP$_1$ = Seed priming (1% Zn), SP$_2$ = Seed priming (2% Zn), F$_1$ = Foliar application (1% Zn), F$_2$ = Foliar application (2% Zn)

Table 4: Influence of zinc application through seed treatment and foliar spray on crop growth rate, net assimilation rate, grain Zn and protein content of maize hybrids.

2009

Zinc Application	Crop growth rate (g m^{-2} d^{-1})			Net assimilation rate (g m^{-2} d^{-1})			Grain Zn content (mg kg^{-1})			Grain protein content (%)		
	Hybrids			Hybrids			Hybrids			Hybrids		
	DK-919	Pioneer 30-Y87	Mean	DK-919	Pioneer 30-Y87	Mean	DK-919	Pioneer 30-Y87	Mean	DK-919	Pioneer 30-Y87	Mean
CK	23.77 ^{de}	23.33 ^{e}	23.55 ^{E}	6.24 ^{h}	6.50 ^{g}	6.37 ^{G}	19.92 ^{m}	19.85 ^{m}	19.88 ^{G}	11.16 ^{a}	10.95 ^{bc}	11.05 ^{A}
SP_1	24.08 ^{cde}	24.14 $^{c-e}$	24.11 ^{DE}	6.51 ^{g}	6.76 ^{f}	6.64 ^{F}	22.08 ^{k}	22.96 ^{j}	22.52 ^{F}	10.76 ^{d}	10.50 ^{f}	10.63 ^{C}
SP_2	25.67 $^{a-e}$	25.53 $^{a-e}$	25.61 $^{B-E}$	6.78 ^{f}	7.12 ^{de}	6.95 ^{D}	23.11 ^{j}	22.03 ^{k}	22.57 ^{F}	10.45 ^{fg}	10.37 ^{g}	10.41 ^{D}
F_1	24.92 $^{b-e}$	24.67 $^{b-e}$	24.80 $^{C-E}$	6.69 ^{f}	6.98 ^{e}	6.83 ^{E}	25.12 ^{g}	21.11 ^{l}	23.11 ^{E}	10.90 ^{c}	10.81 ^{d}	10.85 ^{B}
F_2	27.86 ^{ab}	27.35 $^{a-d}$	27.61 ^{AB}	7.45 ^{c}	7.55 ^{c}	7.50 ^{B}	28.23 ^{b}	25.85 ^{f}	27.04 ^{B}	10.28 ^{h}	10.06 ^{j}	10.17 ^{F}
$SP_1 + F_1$	26.13 $^{a-e}$	26.55 $^{a-e}$	26.34 $^{A-D}$	7.17 ^{d}	7.39 ^{c}	7.28 ^{C}	24.09 ^{h}	23.87 ^{i}	23.98 ^{D}	11.03 ^{b}	10.65 ^{e}	10.84 ^{B}
$SP_1 + F_2$	27.32 $^{a-d}$	27.61 $^{a-c}$	27.47 ^{AB}	7.20 ^{d}	7.77 ^{b}	7.48 ^{B}	27.15 ^{d}	26.98 ^{d}	27.06 ^{B}	10.14 ^{ij}	10.22 ^{hi}	10.18 ^{F}
$SP_2 + F_1$	26.21 $^{a-e}$	26.89 $^{a-e}$	26.55 $^{A-C}$	7.20 ^{d}	7.45 ^{c}	7.33 ^{C}	26.19 ^{e}	24.91 ^{g}	25.55 ^{C}	10.61 ^{e}	9.93 ^{k}	10.27 ^{E}
$SP_2 + F_2$	28.76 ^{a}	28.17 ^{ab}	28.46 ^{A}	7.54 ^{c}	7.99 ^{a}	7.77 ^{A}	29.16 ^{a}	27.94 ^{c}	28.55 ^{A}	10.12 ^{k}	10.00 ^{l}	10.06 ^{G}
Mean	26.08	26.02		6.98 ^{B}	7.28 ^{A}		25.00 ^{A}	23.94 ^{B}		10.58 ^{A}	10.36 ^{B}	
LSD at P 0.05	Treatment: 2.24, Hybrid: NS, Interaction: 3.60			Treatment: 0.10, Hybrid: 0.029, Interaction: 0.16			Treatment: 0.136, Hybrid: 0.039, Interaction: 0.219			Treatment: 0.054, Hybrid: 0.015, Interaction: 0.088		

2010

Zinc Application	Crop growth rate (g m^{-2} d^{-1})			Net assimilation rate (g m^{-2} d^{-1})			Grain Zn content (mg kg^{-1})			Grain protein content (%)		
	Hybrids			Hybrids			Hybrids			Hybrids		
	DK-919	Pioneer 30-Y87	Mean	DK-919	Pioneer 30-Y87	Mean	DK-919	Pioneer 30-Y87	Mean	DK-919	Pioneer 30-Y87	Mean
CK	22.63^{e}	22.84^{de}	22.74^{D}	6.42 ^{k}	6.65 ^{j}	6.54 ^{H}	22.78 ^{k}	20.11 ^{n}	21.44 ^{G}	11.31	11.26	11.28^{A}
SP_1	23.26^{c-e}	23.71^{b-e}	23.49^{CD}	6.70 ^{j}	6.89 ^{i}	6.79 ^{G}	23.96 ^{i}	23.08 ^{j}	23.52 ^{F}	10.87	10.76	10.81^{A-C}
SP_2	25.05^{a-e}	25.42^{a-e}	25.24^{B-D}	7.02 ^{hi}	7.29 $^{e-g}$	7.16 ^{E}	25.07 ^{h}	22.26 ^{l}	23.66 ^{F}	10.71	10.47	10.59^{BC}
F_1	24.67^{a-e}	24.05^{b-e}	24.36^{CD}	6.96 ^{hi}	7.12 ^{gh}	7.04 ^{F}	27.02 ^{e}	21.19 ^{m}	24.10 ^{E}	11.14	10.89	11.01^{AB}
F_2	26.67^{a-e}	27.96^{ab}	27.32^{AB}	7.50 ^{cd}	7.95 ^{a}	7.72 ^{B}	29.57 ^{b}	25.91 ^{fg}	27.74 ^{B}	10.45	10.31	10.38^{CD}
$SP_1 + F_1$	25.42^{a-e}	26.55^{a-e}	25.99^{A-C}	7.22 ^{fg}	7.37 $^{d-f}$	7.30 ^{D}	26.15 ^{f}	24.16 ^{i}	25.15 ^{D}	11.02	11.08	11.05^{AB}
$SP_1 + F_2$	27.54^{a-c}	28.13^{ab}	27.83^{AB}	7.64 ^{bc}	7.72 ^{b}	7.68 ^{B}	28.74 ^{c}	26.85 e	27.79 ^{B}	10.54	10.17	10.35^{CD}
$SP_2 + F_1$	27.19^{a-d}	27.88^{ab}	27.5^{AB}	7.44 ^{de}	7.47 ^{cd}	7.46 ^{C}	27.98 ^{d}	25.80 g	26.89 ^{C}	10.26	10.62	10.44^{CD}
$SP_2 + F_2$	28.09 ^{ab}	28.75 ^{a}	28.42^{A}	7.73 ^{b}	8.06 ^{a}	7.90 ^{A}	30.63 ^{a}	27.94 ^{d}	29.28 ^{A}	10.04	9.98	10.01^{D}
Mean	25.61	26.14		7.18 ^{B}	7.39 ^{A}		26.87 ^{A}	24.14 ^{B}		10.70	10.61	
LSD at P 0.05	Treatment: 2.76, Hybrid: NS, Interaction: 4.45			Treatment: 0.11, Hybrid: 0.032, Interaction: 0.18			Treatment: 0.159, Hybrid: 0.046, Interaction: 0.256			Treatment: 0.478, Hybrid: NS, Interaction: NS		

Means sharing the same case letters for main and interaction effects don't differ significantly. NS = Non-significant

CK = No Zn application, SP_1 = Seed priming (1% Zn), SP_2 = Seed priming (2% Zn), F_1 = Foliar application (1% Zn), F_2 = Foliar application (2% Zn) decrease in grain protein percent as grain yield increased. Similarly, Kaya *et al*. (2002) exhibited decreased in protein content of wheat grain with soil application of Zn.

The correlation data for yield growth and quality attributes is given in Table 5. All the yield related traits showed linear highly positive correlation grain yield during both years of study. These finding are quite in consonance with the outcomes of Rafiq*et al*. (2010) and Potarzycki and Grzebisz (2009). All the growth parameters when compared with each other, yield associated traits and grain Zn contents showed highly significant positive correlation whereas, grain protein content was highly negatively correlated with growth attributes. The higher CGR and NAR might be due to better nutrient uptake (Wu *et al*., 2005). The results are in accordance with the findings of Shahhosseini *et al.* (2012). Grain Zn contents in association with 1000-grain weight and grain yield showed non-significant correlation. Whereas grain protein contents showed highest negative correlation with all the yield and growth parameters during both years of experimentation. More accumulation of starch in endosperm due to better growth might be reason for decreasing the protein content. These results are supported by findings of Mousavi *et al*. (2013) and Nemati *et al*. (2009).

Table 5. Correlation among agronomic, quality and growth parameters

Parameters	Plant height (cm)	Grain yield (t ha^{-1})	1000-grain weight (g)	Cob diameter (cm)	Cob length (cm)	Grain Zn content (mg kg^{-1})	Grain protein content (%)	LAI	CGR (g m^{-2} d^{-1})	NAR (g m^{-2} d^{-1})
Plant height	**1.00**	0.96**	0.90**	0.93**	0.90**	0.49ns	-0.73**	0.77**	0.63**	0.85**
Grain yield	0.82**	**1.00**	0.96**	0.99**	0.91**	0.55*	-0.77**	0.80**	0.69**	0.88**
1000-grain weight	0.93**	0.97**	**1.00**	0.97	0.95**	0.70**	-0.80**	0.88**	0.80**	0.93**
Cob diameter	0.96**	0.92**	0.98**	**1.00**	0.93**	0.61**	-0.78**	0.84**	0.74**	0.90**
Cob length	0.96**	0.87**	0.94**	0.96**	**1.00**	0.76**	-0.80**	0.90**	0.85**	0.96**
Grain Zn content	0.68**	0.22ns	0.43ns	0.58*	0.60**	**1.00**	-0.71**	0.87**	0.92**	080**
Grain protein content	-0.77**	-0.63**	-0.73**	-0.78**	-0.81**	-0.65**	**1.00**	-0.80**	-0.79**	-0.78**
LAI	0.90**	0.69**	0.81**	0.87**	0.90**	0.79**	-0.83**	**1.00**	0.90**	0.91**
CGR	0.94**	0.74**	0.85**	0.90**	0.94**	0.75**	-.082**	0.91**	**1.00**	0.91**
NAR	0.93**	0.79**	0.88**	0.92**	0.96**	0.67**	-0.85**	0.92**	0.96**	**1.00**

Upper diagonal represents the correlation values for year 2009 and Lower diagonal for year 2010

*, ** and ns are significant at the 5%, 1% probability levels and non-significant respectively.

LAI = Leaf Area Index, CGR = Crop Growth Rate, NAR = Net Assimilation Rate

Conclusions: From this study it is concluded that Zn (2%) applied in combination to maize as seed priming and subsequently at eight leaf stage as foliar application imparts better growth, quality and grain yield to maize. The maize hybrid Pioneer 30-Y-87 remained better for yield and growth attributes whereas, Zn concentration was higher in grains of hybrid DK-919.

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