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ZINC APPLICATION IMPROVES THE PRODUCTIVITY AND GRAIN BIO-FORTIFICATION OF FINE RICE

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Zinc (Zn) deficiency is a major problem in food crops, and it is severely affecting humans globally. Therefore, the current investigation was conducted to determine influence of soil and foliar applied Zn on productivity, quality and kernel bio-fortification of basmati rice. The study contained various combinations of soil and foliar Zn application i.e., T_1= No Zn application (control), T_2 = soil application of Zn @ 25 kg/ha, T_3 = soil application of zinc @ 50 kg/ha, T_4 = foliar application of Zn @ 0.5%, T_5 = foliar application of Zn @ 1.0%, T_6 = soil application of Zn @25 kg/ha + foliar application of zinc @ 0.5%, T_7 = soil application of Zn @25 kg/ha + foliar application of Zn @ 1.0%, T_8 = soil application of Zn @50 kg/ha + foliar application of zinc @ 0.5% and T_9 = soil application of Zn @50 kg/ha + foliar application of Zn @ 1.0%. The Zn application by any method increased the rice yield and kernel Zn concentration. However, soil + foliar application of Zn (25 kg/ha + 1%) remained at the top with maximum fertile tillers (361, 367), kernel weight (28.50 g, 32.20 g), paddy yield (5.80 t ha^{-1}, 6.00 t ha^{-1}) kernel protein content (11.34%, 11.46%) and kernel Zn concentration (49.80 mg kg^{-1},53.80 mg kg^{-1}) during both years. In conclusion, soil + foliar Zn application (25 kg/ha + 1%) can increase the yield and kernel Zn of basmati rice.
Keywords: Rice, zinc, bio-fortification, productivity, zinc concentration.

INTRODUCTION

Rice is imperative crop cultivated globally, and it fulfills the more than 21% protein and energy requirements of human population and it feed more than 50% world's population (McLean *et al.,* 2002). Zinc (Zn) is important micro-nutrient required for humans, however, its deficiency is wide spread problem globally. For instance, it has been reported that 60-70% Asian and >2 billion people globally are suffering from Zn deficiency (Gibson, 2006; Kumssa *et al.,* 2015), however, more than 1.1 billion people around the globe under the higher menace of Zn paucity (Kumssa *et al.,* 2015).
Zinc plays an important role in living organism as it maintains the structure and function of membranes, detoxify the reactive oxygen species, and improves the gene expression and synthesis of proteins (Marschner, 1995). However, Zn deficiency is major problem for growing of cereals, and, it has been reported that more than 50% soils used for cultivation of cereal crops have Zn deficiency (Peleg *et al.,* 2008). Additionally, deficiency of Zn both in direct and transplanted rice leads to substantial reduction in the yield (Gao *et al.,* 2006). This problem is associated with poor Zn availability and higher Zn adsorption on soil particles owing to soil calcareousness and higher pH (Alloway, 2009). In addition, Zn also precipitates as ZnS under flooding condition and in calcareous soils as $ZnCO_3$ which in turns reduced the Zn availability to plants (Johnson-Beebout *et al.,* 2009). Inadequate Zn supply reduced the production and grain Zn concentration (Alloway, 2009) therefore, to produce better quantity with optimum Zn, the application of Zn is necessary (Rehman *et al.,* 2012).
Thus, in current scenario; bio-fortification is a promising and cost effect approach to combat the Zn deficiency in humans. Different agronomic and breeding approaches are being used globally to improve the grain Zn contents. Breeding techniques involved the development of genotypes with desirable level of grain Zn concentration nonetheless, breeding techniques are costly and time taking (Cakmak, 2008; Chattha *et al.,* 2017a). Conversely, the fertilizer application in different forms (agronomic approach) is cost effective and provides quick solution to the problem and substantially improved the grain Zn (Cakmak, 2008).
Zn can be applied to rice crop by different methods including, soil and foliar application and seed treatments (seed priming, seed coating) (Johnson *et al.,* 2005). However, soil application is major practice being used by the farmers to supply Zn to rice crop in transplanted rice production system. Nonetheless, higher application rates, high cost of Zn fertilizers and Zn fixation makes the soil application un-economical in some circumstances (Jiang *et al.,* 2008). Foliar application is also important method being used globally, and foliar applied Zn considerably improves the Zn concentration in grains (Chattha *et al.,* 2017a). The Zn applied in different ways had variable results (Rehman *et al.,* 2012), e.g., soil applied Zn produced more yield compared to the foliar feeding (Ghoneim, 2016). Conversely, it was noted foliar feeding leads to more kernel yields as compared to soil applied Zn (Ghoneim, 2016). Soil plus foliar applied Zn is

also an important approach used to increase the productivity and grain Zn bio-fortification. For instance, Chattha *et al.* (2017a) noticed that soil+ foliar application produced the highest yield and kernel Zn as compared to alone soil and foliar applied Zn. Thus, we hypothesized that the combined soil and foliar Zn would improve the productivity and kernel bio-fortification of basmati rice. Therefore, the current study was conducted to sort out the best combination of soil and foliar application of Zn to improve rice growth, productivity, and kernel bio-fortification.

MATERIALS AND METHODS

Location**:** The two years study was precisely performed at the research area of Institute of Agricultural Sciences, University of the Punjab, Lahore in 2015 and 2016 to evaluate role of Zn as soil and foliar application and together (basal+foliar) application on production, quality and kernel bio-fortification of aromatic rice. Composite soil samples from a depth (30 cm) were taken and subjected to determine various physical and chemical characteristics (Homer and Pratt 1961). The soil was sandy loam having pH (7.75), electrical conductivity (1.06 dS m^{-1}), 0.85% organic matter (OM), (0.85%), available nitrogen (N) (0.033%), available phosphorus (P) (21 mg kg^{-1}) 130 mg kg^{-1} potassium (K) (130 mg kg^{-1}) DTPA extractable Zn (32 mg kg^{-1}). The experimental site has semi-arid climate and further conditions during both growing seasons are given in Fig 1.

Experimental details**:** The randomized complete block design (RCBD) having three replicates was used for this study during 2105 and same was repeated during successive year 2016 without any change. There were different treatments i.e., T_1= No Zinc Application (Control), T_2 = soil application of zinc ($ZnSO_4 \cdot 7H_2O$) @ 25 kg/ha, T_3 = soil application of Zn @ 50 kg/ha, T_4 = foliar application of zinc @ 0.5%, T_5 = foliar application of Zn @ 1.0%, T_6 = soil application of Zn @25 kg/ha + foliar application of Zn @ 0.5%, T_7 = soil application of Zn @25 kg/ha + foliar application of zinc @ 1.0%, T_8 = soil application of Zn @50 kg/ha + foliar application of Zn @ 0.5% and T_9 = soil application of Zn @50 kg/ha + foliar application of Zn @ 1.0%. Same set of treatments was used during 2015 and repeated during 2016 in this experiment. For soil application; different rates of Zn were applied as basal application and in foliar application the Zn was applied at tillering stage (Lancashire *et al*., 1991).

Crop management**:** The experimental field was flooded and cultivated thrice and leveled with wooden leveler to create the puddled conditions. After transplanting of rice nursery, the field was kept flooded for seven days and afterwards, field was drained completely and kept in flooded condition until physiological maturity stage. The NPK fertilizers sources were urea (46%N), DAP (46% P, 18% N) and SOP (50% K) and they were applied @ 120:88:68 kg ha^{-1}. The chemical Butachlor (N-butoxymethly-2-chloro-2, 6-diethylacetanilide) (600 g ha^{-1}) was used to control weeds.

Observations and measurements**:** Two rows having length of 2 feet were harvested and plant leaves and stem were separated; a sub-sample of 5 g leaves were taken and leaf area was meausred by meter and leaf area index (LAI) was calculated as ratio of leaf and ground areas. Moreover, leaf

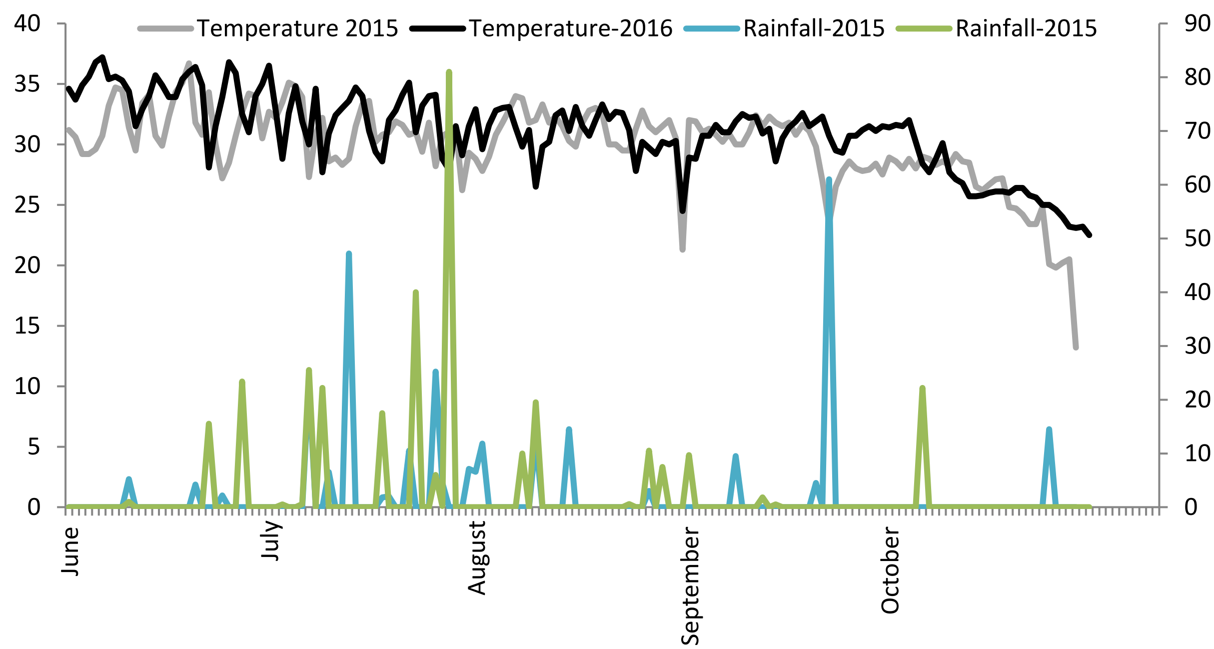

Figure 1. Weather conditions during the 2015 and 2016

area duration (LAD) and crop growth rate (CGR) were determined by the methods of Watson (1947) and Hunt (1978), respectively. Ten plants were selected and plant height was measured and averaged and similarly, 10 panicles were taken and kernels per panicle were counted. A unit area was chosen and number of fertile tillers was counted. A sub-sample of 1000 kernels was taken from harvested kernels and weighed to determine the 1000 kernel weight.

Lastly, crop was hand harvested and weighed to measure the biological yield and later on beat manually and weighed again to govern the kernel yield and converted into t ha^{-1}.The sterile kernels were visually counted and for determination of opaque kernels; 20 kernels were placed in front of light, the kernels which were not translucent to light were considered as opaque kernel and later on percentage was taken. Likewise, 20 kernels were taken and placed in front of light, and categorized as normal kernels (attained the fill size and translucent) and abortive kernels (not attained the full size and not translucent). The N concentration in rice kernels was estimated by Kjeldhal method. This N concentration was multiplied with 6.25 to determine the protein content (AOAC, 1990). The concentration of amylose in rice kernel was estimated by methods of Juliano (1971). The rice kernels were oven dried (60°C) for 48 hours and afterwards grinded. One gram of each grinded sample was digested by using di-acid mixture ($HClO_4$: HNO_3) in 3:10 ratios on digestion plate (Prasad, 2006) and atomic absorption spectro-photometer was used to determine the kernel Zn contents.

***Data analysis*:** The data on collected traits were analyzed by analysis of variance and LSD (least significant difference) test at 5% probability was used to sort out the difference amid the different means (Steel *et al.*, 1997). The net benefit and cost ratios was determined by the using the standard protocols of CIMMYT (1998).

RESULTS

***Growth attributes*:** Zn application had substantiated impact on the growth attributes (Table 1). The maximum LAI, LAD and CGR was recorded with soil applied Zn (25 kg/ha) + foliar applied Zn (1%), however, the lowest LAI, LAD and CGR was noted with no Zn during both consecutive years (2015 and 2016) (Table 1). Likewise, the maximum plant height was also noticed with soil applied Zn (50 kg/ha) + foliar application (1%) and it was at par with soil + foliar (50 kg/ha+ 0.5%), meanwhile, lowest plant height (89.37 cm) was

Table 1. Influence of variable levels and methods of Zn application on the growth attributes of basmati rice

Treatments	Leaf Area Index		Leaf area duration (days)		Crop growth rate (g m^{-2} day^{-1})		Plant height (cm)	
	2015	2016	2015	2016	2015	2016	2015	2016
T_1	3.76D	3.90D	256.60D	261.10D	8.24D	8.40D	86D	92E
T_2	4.46B	4.45C	270.40BC	275.00BC	12.42B	12.52B	102B	106C
T_3	4.39C	4.49C	270.20BC	275.20BC	12.51B	12.63B	101B	105C
T_4	4.40C	4.58C	261.80CD	265.90CD	10.48C	10.58C	94C	100D
T_5	4.40C	4.52C	242.00E	250.30E	10.43C	10.50C	95C	99D
T_6	5.03C	5.17B	279.30AB	284.40AB	14.57A	14.65A	109A	115AB
T_7	5.40A	5.55A	284.50A	287.40A	14.46A	14.54A	109A	113B
T_8	5.37A	5.49A	279.57AB	287.10A	14.55A	14.65A	111A	115AB
T_9	5.34A	5.46A	279.70AB	286.64A	14.51A	14.56A	111A	117A
LSD ($P \leq 0.05$)	0.22	0.23	10.72	10.33	0.21	0.11	4.38	2.13

Means with different letters differed at *P* 0.05.

Table 2. Influence of variable levels and methods of Zn application on the yield and yield attributes of basmati rice

Treatments	Fertile tillers (m^{-2})		Kernels per panicle		1000 KW (g)		Paddy yield (t ha^{-1})		Biological yield (t ha^{-1})		Harvest index (%)	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
T_1	315D	321E	43E	46E	19.80F	22.30F	3.19F	3.35G	11.22F	11.52E	28.43F	29.07F
T_2	332B	340C	60C	65C	21.10EF	23.20E	4.70D	4.84E	13.38D	13.72C	34.86D	35.27D
T_3	334B	342C	60C	67C	22.20DE	24.80D	4.75D	4.98D	13.36D	13.58C	35.55D	36.67C
T_4	323C	331D	54D	58D	22.27DE	24.70D	3.70E	3.78F	12.12E	12.44D	30.52E	30.38E
T_5	322CD	332D	54D	58D	23.32CD	24.20D	3.65E	3.85F	12.15E	12.40D	30.04E	31.04E
T_6	358A	366AB	68B	73B	27.40B	29.50B	5.35B	5.55B	14.61B	14.95A	36.61C	37.12BC
T_7	361A	367A	70AB	73B	29.1A	32.70A	5.80A	6.00A	15.02A	15.20A	38.54A	39.47A
T_8	355A	363AB	74A	78A	26.10B	27.30C	5.26BC	5.46BC	13.94C	14.40B	37.73AB	37.91B
T_9	354A	362B	70AB	72B	24.40C	26.80C	5.20C	5.38C	13.90C	14.22B	37.41BC	37.83B
LSD ($P \leq 0.05$)	7.63	4.64	4.23	2.22	1.30	0.71	0.15	0.11	0.33	0.43	0.96	1.05

Means with different letters differed at *P* 0.05.

recorded without Zn application in 2015 and following year 2016 (Table 1).

***Yield attributes and yield*:** The productive tillers and kernels/panicle were considerably increased with all the Zn application methods and rates. However, soil applied Zn (25 kg/ha) + foliar application (1%) was remained at top; and it produced the maximum tillers and kernels/panicle during 2015 and 2016 (Table 2). Moreover, a significant reduction in tillers and kernels/panicle was recorded without Zn application in 2015 and 2016. The matching trends in consecutive years can be attributed due to similar location of execution of research trial.

The highest 1000 kernel weight was obtained with soil + foliar Zn (25 kg/ha + 0.5%) that was comparable with soil applied Zn (25 kg/ha) + foliar applied Zn (1%) and lowest 1000 kernels weight was obtained without Zn in 2015 and 2016 (Table 2). All the Zn application levels and methods clearly increased the kernel yield, biological yield and harvest index in 2015 and 2016.The soil + foliar Zn (25 kg/ha + 1.0%) produced the highest kernel yield (5.80 t ha^{-1}, 6.00 t ha^{-1}), biological yield (15.02 t ha^{-1}, 15.20 t ha^{-1}), and harvest index (HI) (38.62%, 39.47%), however, it remained at par with soil + foliar Zn (25kg/ha + 0.5%) during 2015 and 2016. Moreover, the lowest kernel yield, biomass production and harvest index was recorded without Zn application during 2015 and 2016 (Table 2).

***Quality attributes*:** The maximum kernel sterility, opaque kernels and abortive kernels were recorded without Zn application in 2015 and 2016, however, all the Zn application methods reduce the kernel sterility, opaque and abortive kernels during both years (2015 and 2016) (Table 3). The maximum normal kernel (85.90%, 88.30%) was noticed in soil + foliar application (25 kg/ha + 1.0%) and lowest was obtained without Zn during 2015 and 2016. Likewise, there was remarkable difference amongst treatment for the kernel protein and amylose contents in 2015 and 2016. The maximum kernel protein (11.46%, 11.60%) was noted with soil applied Zn (50 kg/ha) + foliar application (1.0%) and maximum kernel amylose (28.68%, 29.10%) was recorded with Zn (25 kg/ha) + foliar zinc (1.0%) in 2015 and 2016 and lowest kernel protein and kernel amylose was recorded in control during 2015 and 2016 (Table 3). Similar site and comparable environmental conditions during 2015 and following year 2016 can be the main sources of matching results during both years.

***Kernel Zn concentration*:** The Zn application methods remarkably increased the kernel Zn concentration. The Zn applied through to soil + foliar (25 kg/ha + 1.0%) gave the maximum kernel Zn concentration and the lowest kernel Zn in rice kernels was recorded without Zn during 2015 and 2016 (Figure 2).

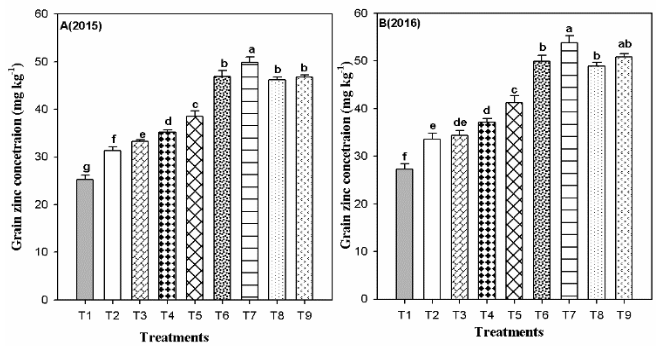

Figure 2. **Effect of different Zn treatments on kernel Zn concentration (mg kg^{-1}) during 2015 (A) and 2016 (B)**

Table 3. Influence of variable levels and methods of Zn application on the qualitative attributes of basmati rice

Treatments	Spikelet sterility (%)		Opaque kernel (%)		Abortive kernel (%)		Normal kernel (%)		Kernel protein (%)		Kernel amylose (%)	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
T_1	12.29A	12.71A	15.57A	15.75A	7.85A	8.02A	64.81F	66.13F	9.56E	9.68E	22.72F	23.73H
T_2	9.45D	9.51C	13.90B	14.26B	6.45B	6.75B	72.31E	73.35E	10.66C	10.78C	27.01C	27.41E
T_3	9.36D	9.40C	13.62C	13.90C	6.35C	6.44C	73.39E	73.07E	10.68C	10.78C	27.24C	27.88DE
T_4	10.50B	10.64B	12.61D	12.71D	4.94D	5.07D	78.49D	79.47D	10.43D	10.55D	25.00D	25.92F
T_5	10.30C	10.69B	12.62D	12.70D	4.92D	4.96E	78.46D	79.48D	10.40D	10.48D	24.20E	24.80G
T_6	7.79E	7.87D	11.22E	11.34E	3.82F	4.02G	81.00C	83.28C	11.25B	11.35B	30.20A	31.38A
T_7	7.47F	7.41F	11.20E	11.16F	3.88EF	4.19F	85.90A	88.30A	11.34AB	11.46AB	28.68B	29.10C
T_8	7.78E	7.70E	11.12E	11.18F	3.92E	4.13FG	83.70B	84.30BC	11.37AB	11.47AB	27.40C	28.34D
T_9	7.67E	7.61E	10.91F	10.99G	3.89EF	4.12H	82.88BC	84.88B	11.46A	11.60A	28.50B	30.00B
LSD (P≤0.05)	0.18	0.16	0.18	0.09	0.08	0.06	2.07	1.17	0.16	0.18	0.74	0.56

Means with different letters differed at P 0.05.T_1= No Zinc Application (Control), T_2 = Soil application of zinc @ 25 kg/ha, T_3 = Soil application of zinc @ 50 kg/ha, T_4 = Foliar application of zinc @ 0.5%, T_5 = Foliar application of zinc @ 1.0%, T_6 = Soil application of Zinc @25 kg/ha + Foliar application of zinc @ 0.5%, T_7 = Soil application of Zinc @25 kg/ha + Foliar application of zinc @ 1.0%, T_8 = Soil application of Zinc @50 kg/ha + Foliar application of zinc @ 0.5% and T_9 = Soil application of Zinc @50 kg/ha + Foliar application of zinc @ 1.0%.

***Trait inter-relationship and Economic analysis*:** A significant positive co-relation was observed between all the traits. Likewise, fertile tillers, kernel weight, kernels/panicle and normal kernels, kernel protein, and kernel amylose were significantly positively associated with the kernel yield during successive years 2015 and 2016. Moreover, the kernel Zn concentration was positively co-related with the kernel yield and vice versa during 2015 and following year 2016 (Table 4,5). The variable rates and methods of applied Zn significantly increased the net benefit and benefit cost ratios. The soil + foliar Zn (25 kg/ha + 1%) gave maximum return, however, it remained similar with soil + foliar applied Zn (25 kg/ha + 0.5%) in 2015 and 2016 and lowest net benefit and cost ratios were recorded without Zn application during both years (2015 and 2016) of experimentation (Table 6,7).

Table 4. Co-relation among the different traits during 2015

	LAI	LAD	CGR	PH	FT	KPP	TKW	KY	BY	HI	SS	OK	AK	NK	KP	KA	K-Zn
LAI	1.00																
LAD	0.60*	1.00															
CGR	0.87**	0.74**	1.00														
PH	0.90**	0.70**	0.99**	1.00													
FT	0.90**	0.78**	0.92**	0.91*	1.00												
KPP	0.93**	0.68*	0.97**	0.98*	0.90**	1.00											
TKW	0.77**	0.43**	0.66*	0.64*	0.81**	0.68*	1.00										
KY	0.79**	0.82**	0.94**	0.91**	0.92*	0.88**	0.66**	1.00									
BY	0.76**	0.75**	0.92**	0.88*	0.90*	0.84**	0.71**	0.98**	1.00								
HI	0.78**	0.83**	0.95*	0.93**	0.88**	0.90**	0.56**	0.98**	0.92**	1.00							
SS	0.92*	0.68*	0.98*	0.98**	0.93**	0.97*	0.74**	0.93*	0.91**	0.91**	1.00						
OK	0.88*	0.35**	0.71*	0.73**	0.72*	0.77**	0.77*	0.56**	0.57**	0.53*	0.79**	1.00					
AK	0.81**	0.27**	0.61**	0.62^{NS}	0.63**	0.68^{NS}	0.77**	0.46**	0.50**	0.42^{NS}	0.70**	0.98**	1.00				
NK	0.85**	0.30**	0.63**	0.64^{NS}	0.64*	0.72**	0.78**	0.52**	0.54**	0.49**	0.73**	0.95**	0.96**	1.00			
KP	0.94**	0.64**	0.96**	0.97**	0.89**	0.97**	0.69**	0.86**	0.84**	0.86**	0.98*	0.84*	0.75**	0.78**	1.00		
KA	0.66**	0.73**	0.90**	0.84^{NS}	0.83**	0.77**	0.59^{NS}	0.88**	0.91*	0.84**	0.86*	0.55^{NS}	0.47^{NS}	0.45*	0.81**	1.00	
K-Zn	0.91*	0.41**	0.73**	0.75*	0.82**	0.78**	0.90**	0.65**	0.67**	0.59**	0.82**	0.95**	0.92**	0.92**	0.83**	0.59**	1.00

LAI; leaf area index, LAD; leaf area duration, CGR; crop growth rate, PH; plant height, FT; fertile tillers, KPP; kernels/panicle, TKW; 1000 kernel weight, BY; biological yield, HI; harvest index, SS; spikelet sterility, OP; opaque kernel, AK; abortive kernel, NK; normal kernels, KP; kernel protein, KA; kernel amylose, K-Zn; kernel Zn

Table 5. Co-relation among the different traits during 2016

	LAI	LAD	CGR	PH	FT	KPP	TKW	KY	BY	HI	SS	OK	AK	NK	KP	KA	K-Zn
LAI	1.00																
LAD	0.66**	1.00															
CGR	0.82**	0.81**	1.00														
PH	0.86**	0.81**	0.98**	1.00													
FT	0.90**	0.80**	0.94**	0.94**	1.00												
KPP	0.81*	0.75*	0.97**	0.93**	0.89**	1.00											
TKW	0.70**	0.49*	0.57**	0.53**	0.73**	0.51*	1.00										
KY	0.74**	0.83**	0.94**	0.88**	0.92**	0.89**	0.66	1.00									
BY	0.75**	0.80**	0.94**	0.88**	0.93**	0.88**	0.71**	0.98**	1.00								
HI	0.71**	0.83**	0.93*	0.86**	0.86**	0.89*	0.57**	0.98**	0.92**	1.00							
SS	0.88**	0.78**	0.99*	0.97*	0.95*	0.96**	0.63**	0.93*	0.93**	0.91**	1.00						
OK	0.90**	0.40^{NS}	0.66*	0.72**	0.74*	0.66**	0.62*	0.52*	0.57**	0.48**	0.74**	1.00					
AK	0.80**	0.28^{NS}	0.56^{NS}	0.61^{NS}	0.63**	0.57^{NS}	0.56^{NS}	0.42*	0.48^{NS}	0.36^{NS}	0.64**	0.98**	1.00				
NK	0.88**	0.35**	0.59**	0.62^{NS}	0.69**	0.59^{NS}	0.71**	0.50*	0.55**	0.45*	0.69**	0.97**	0.95**	1.00			
KP	0.91**	0.73**	0.96*	0.97*	0.92*	0.93**	0.58*	0.85**	0.86**	0.84^{NS}	0.98*	0.81**	0.71*	0.75**	1.00		
KA	0.64*	0.77*	0.88**	0.88^{NS}	0.85**	0.77**	0.52^{NS}	0.82**	0.86**	0.78**	0.84*	0.54^{NS}	0.46^{NS}	0.45^{NS}	0.81**	1.00	
K-Zn	0.93**	0.46**	0.71**	0.75**	0.83**	0.67**	0.77**	0.64**	0.68*	0.57**	0.78*	0.94**	0.89*	0.94**	0.81**	0.58**	1.00

LAI; leaf area index, LAD; leaf area duration, CGR; crop growth rate, PH; plant height, FT; fertile tillers, KPP; kernels/panicle, TKW; 1000 kernel weight, BY; biological yield, HI; harvest index, SS; spikelet sterility, OP; opaque kernel, AK; abortive kernel, NK; normal kernels, KP; kernel protein, KA; kernel amylose, K-Zn; kernel Zn

Table 6. Economic analysis for the effect of different Zn application treatments during 2015.

Treat.	Kernel yield (t ha^{-1})	Adjusted kernel yield (t ha^{-1})	Straw yield (t ha^{-1})	Adjusted straw yield (t ha^{-1})	Kernel Value	Straw value	Gross income (Rs)	Permanent cost (Rs.)	Variable cost (Rs.)	Total cost (Rs.)	Net benefit	Benefit cost ratio
T_1	3.19	2.87	8.03	7.23	165082.5	4516.88	169599	93290	0	93290	76309	1.82
T_2	4.70	4.23	8.68	7.81	243225.0	4882.50	248108	93290	3333	96623	151485	2.57
T_3	4.75	4.28	8.61	7.75	245812.5	4843.13	250656	93290	6666	99956	150700	2.51
T_4	3.70	3.33	8.42	7.58	191475.0	4736.25	196211	93290	1296	94586	101625	2.07
T_5	3.65	3.29	8.50	7.65	188887.5	4781.25	193669	93290	2594	95884	97785	2.02
T_6	5.35	4.82	9.26	8.33	276862.5	5208.75	282071	93290	4629	97919	184152	2.88
T_7	5.80	5.22	9.22	8.30	300150.0	5186.25	305336	93290	5927	99217	206119	3.08
T_8	5.26	4.73	8.68	7.81	272205.0	4882.50	277088	93290	7962	101252	175836	2.74
T_9	5.20	4.68	8.70	7.83	269100.0	4893.75	273994	93290	9260	102550	171444	2.67

Table 7. Economic analysis for the effect of different Zn application treatments during 2016.

Treat.	Kernel yield (t ha^{-1})	Adjusted kernel yield (t ha^{-1})	Straw yield (t ha^{-1})	Adjusted straw yield (t ha^{-1})	Kernel Value	Straw value	Gross income (Rs)	Permanent cost (Rs.)	Variable cost (Rs.)	Total cost (Rs.)	Net benefit	Benefit cost ratio
T_1	3.35	3.02	8.17	7.35	173362.5	4595.63	177958	93290	0	93290	84668	1.91
T_2	4.84	4.36	8.88	7.99	250470.0	4995.00	255465	93290	3333	96623	158842	2.64
T_3	4.98	4.48	8.60	7.74	257715.0	4837.50	262553	93290	6666	99956	162597	2.63
T_4	3.78	3.40	8.66	7.79	195615.0	4871.25	200486	93290	1296	94586	105900	2.12
T_5	3.85	3.47	8.55	7.70	199237.5	4809.38	204047	93290	2594	95884	108163	2.13
T_6	5.55	5.00	9.40	8.46	287212.5	5287.50	292500	93290	4629	97919	194581	2.99
T_7	6.00	5.40	9.20	8.28	310500.0	5175.00	315675	93290	5927	99217	216458	3.18
T_8	5.46	4.91	8.94	8.05	282555.0	5028.75	287584	93290	7962	101252	186332	2.84
T_9	5.38	4.84	8.84	7.96	278415.0	4972.50	283388	93290	9260	102550	180838	2.76

DISCUSSION

Leaf area index (LAI) is critical for light interception and in our study, combination of soil + foliar Zn substantially improved LAI than control during both years (2015 and 2016) of experimentation and year effect was non-significant. LAI indicates the size of crop assimilatory system to capture the sun light for assimilates production; higher LAI provided the more area for carbon fixation and thus resulting in the higher CGR (Sarwar *et al.* 2017). Crop establishment is significantly important to obtain higher plant population and final yield of rice (Rahman *et al.,* 2011). Among the various components of yield, number of productive tillers is extremely important as final rice yield depends upon the panicles bearing healthy tillers per unit areas (Kulhare *et al.*, 2017). In current study, soil applied Zn significantly increased number of fertile tillers than other treatments during 2015 and 2016 and a same results were recorded without any statistical difference during both years. Beside genotypic dependent trait, fertile tillers may also be, significantly, affected by the balanced use of nutrients. Zn application improved the auxin metabolism, enzymatic activities (Hassan *et al.,* 2020) and translocation of photo-synthates, and thus increased the production of productive tillers (Khan *et al.,* 2006).

Zn application also significant improved the number of kernels and 1000 kernel weight during 2015 and similar finding were achieved when experiment was repeated during 2016 (Table 2). Zn application improves the yield contributing traits (Chattha *et al.,* 2017b; Ilyas *et al.,* 2020) owing to improvement in the carbohydrate metabolism, indole acetic acid, and ribosomal functions (Khalifa *et al.,* 2011). Moreover, continuous Zn supply and its continuousness in loading of endosperm from xylem during the later stages of crop life remarkably improves the plant growth, seed setting and resultantly leads to the better crop production (Yin *et al.,* 2016; Rehman *et al.*, 2018). The bigger assimilatory system owing to improvement in LAI and CGR by Zn application resulted in the maximum dry matter production (Table 1). The application of Zn improved the tillers, kernels/panicle, kernel weight during 2015 and similar results were attained during subsequent year 2016 (Table 2) and reduced the kernel sterility, abortive kernels in (Table 3) and thus resulted in remarkable improvement in kernel yield in both years (2015 and 2016) of experimentation.

The results indicated that Zn application reduced the panicle sterility, abortive kernel, opaque kernel and enhanced the normal kernel in 2015 and 2016 without any statistical difference between two successive years (Table 3). Zn application substantially enhanced the pollination in plants thus influence the fertilization and development of pollen tubes and thereby leads to production of more seeds and less sterility (Kaya and Higgs, 2002). Additionally, availability of

Zn during the later stages improves the process of fertilizations and appreciably reduces the kernel related abnormalities (Dobberman and Fairhurst, 2000) and results in more production of normal kernels.

The results showed that exogenously applied Zn remarkably enhanced the kernel Zn contents in 2015 and same results were obtained when the experiment was repeated during 2016, however, combined soil + foliar Zn leads to appreciable improvement in the kernel Zn contents during 2015 and 2016 (Fig. 2). Foliar applied Zn increases the grain Zn concentration, although a small quantity of Zn is used in foliar feeding, compared with soil application (Cakmak *et al.*, 2010). Alternatively, Zn applied by soil application quickly gets fixed with soil particles due to higher pH and leads to poor Zn mobility and thus reduces the plant Zn availability (Alloway, 2008). The uptake of Zn significantly decreases during the later growth stages and leads to production of grain with less Zn concentration (Zhang *et al.*, 2012). However, foliar applied Zn during later stage maintains, higher pools of Zn availability with the tissues of plant during and thereby leads to remarkable improvement in the kernel Zn contents and kernel yield (Zhang *et al.*, 2012; Chattha *et al.*, 2017; Hassan *et al.*, 2019). Some authors reported soil+ foliar application is a good practice to get the higher grain production with addition benefits of appreciable increase in kernel Zn as compared to the alone soil, and foliar application (Ghoneim, 2016). Likewise, Chattha *et al.* (2017) also reported soil + foliar application performed better in terms of kernel yield and kernel Zn contents. Therefore, soil plus foliar Zn application appear to be a promising strategy to enhance the basmati rice production kernel Zn. The highest benefit cost ratio (BCR) and net returns were obtained with 25 kg Zn ha^{-1} and 1% foliar application owing to maximum kernel yield during consecutive both years of study 2015 and 2016.

***Conclusion*:** Zn applied through different methods, considerably improved the growth, yield, kernel Zn concentration and profitability. However, the combined soil + foliar applied Zn resulted in maximum kernel yield and kernel Zn concentration. Therefore, the soil + foliar application (25 kg/ha +1%) of Zn may be opted by the farmers to enhance the basmati rice productivity and kernel Zn concentration.

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