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Evaluation of Efficacy of Zinc Metalosate and Boron Metalosate Foliar Supplements for Enhancing Yield through Balanced Nutrition of Important Crops in Grown in India






Cooperating centres

CSKHPKV, Palampur, ICAR-IARI, New Delhi, ICAR-CISH, Lucknow, GKVK, Bengaluru, ICAR-NRRI Cuttack and ICAR-IISS, Bhopal

All India Coordinated Research Project on

Micro- and Secondary Nutrients and Pollutant Elements in Soils and Plants

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Evaluation of Efficacy of Zinc Metalosate and Boron Metalosate Foliar Supplements for Enhancing Yield through Balanced Nutrition of important crops in grown in India

1. INTRODUCTION

Role of micronutrients in crop production is well recognized and documented as most of the nutrients that are required for human health come from the soil either through plants or animal products consumed by humans. An insufficient supply of these nutrients or low phytoavailability in soils often limits crop production. Many agricultural soils are poor in phytoavailable content of Zn and B to supply enough of these elements for the rapid growth of crop plants during their early growth. Crops require a sufficient, but not excessive, supply of essential nutrients for optimal productivity. Hence, these elements are supplied as fertilizers in both intensive and extensive agricultural systems. In addition, in areas where mineral deficiencies occur in animals and/or humans, fertilizers are applied not only to increase crop production but also to increase concentrations of essential mineral elements in edible portions. Sustainable crop production is achieved when stable levels of food production and quality are maintained without compromising economic profitability or the environment. Agronomic nutrient use efficiency is generally defined as the crop dry matter yield per unit of nutrient available in the soil, which is equivalent to the product of the plant nutrient content per unit of available nutrient, often referred to as plant nutrient uptake efficiency, and the yield per unit plant nutrient content often referred to as the nutrient utilization efficiency. Micronutrient deficiencies, especially Zn (36.5%) and B (23.2%) are rampant in the country. Besides their individual deficiency, the combined deficiency of these two elements (Zn+B) is coming up in many cropping systems as an alarm for future in most of the soils.

Among the several chemical and synthetic Zn sources evaluated for their efficiency under different soil-crop situations, by and large, $ZnSO_4.7H_2O$ proved better or equal to the other sources in correcting the Zn deficiency (Shukla and Behera, 2011). However, there is still dearth of economically suitable source of Zn supplementation which has greater nutrient use efficiency. Despite the greater effectiveness of Zn-EDTA in combating the Zn deficiency in crops on a Zn-deficient soil, its availability and cost effectiveness is questionable. In addition, the optimum rates of Zn application varied with severity of its deficiency, soil types and nature of crops. In some crops, Zn deficiency can be alleviated either by soil or foliar application. However, in some crops, both the methods are employed to fulfil Zn requirement of the crop.

As mentioned above, B deficiency in some regions is becoming a serious constraint to sustainable agricultural productivity and it is proved to be more critical nutrient in highly calcareous soils, sandy leached soils, limed acid soils or reclaimed lateritic soils. Soil application of borax or sodium tetra-borate is commonly used to correct its deficiency though, both granubor and borax also proved equally effective in mitigating B deficiency. However, there is still need to evaluate more number of B carriers in different crops and cropping systems to enhance its use efficiency. In order to explore the suitability of new Zn and B based products/ carriers for supplementation in different crops and cropping systems, two products developed by Albion Plant Nutrition, U.S.A. were evaluated through a contractual research project funded by M/s Indofil Industries Limited, Mumbai.

As informed by manufacturer, Albion's Metalosate products are patented. These products contain chelated minerals (elemental minerals bound to organic molecules (mainly amino acids) in a chelated form) specifically designed for foliar application on plants. Chelation is the process of attaching a specific organic molecule to a mineral in two or more places to form a ring (for example EDTA, DTPA, EDDHA). The molecule holds the mineral like a claw, surrounding and protecting it from adverse interactions. Since amino acids are the basic building blocks of protein found in all living organisms, the chelation of minerals with amino acids may prove advantageous in enhancing the efficiency of absorption and translocation of minerals within plants. These products are designed for foliar application on plants to prevent or correct the deficiencies of corresponding nutrient that may limit crop growth and yields. These products are water soluble and non-toxic to plants when applied. However, there are both financial and environmental costs associated with the use of these mineral fertilizers. It is therefore important to optimize the efficiency with which fertilizers are to be used in crop production. Increased fertilizer use efficiency can be achieved agronomically, through improved fertilizer-management practices.

The rationale behind taking this contractual project was to generate data on Zn and B containing foliar supplements for enhancing crop yield and produce quality; optimize Zn and B input rate for increasing crop yields and thereby benefiting the farmers, industrialist, research institution and nation as a whole; and development of balance fertilization package for different crops and cropping systems.

2. OBJECTIVE

To evaluate the efficacy of Zinc Metalosate and Boron Metalosate foliar supplements for enhancing crop productivity and produce quality of different crops.

3. MATERIALS AND METHODS

3.A. EVALUATION OF EFFICACY OF METALOSATE® ZINC

These materials were evaluated in two separate experiments i.e. one each for Zn metalosate and B metalosate.

Evaluation material

Zinc metalosate was evaluated for different crops and cropping systems with respect to yield, and its use efficiency in comparison to standard Zn sources i.e. $ZnSO_4$ and Zn-EDTA. The material specifications of Zinc Metalosate are mentioned below:

Metalosate® Zinc (6.8% Zn)	
Ingredient	Zinc amino acid chelate
Approx. % by WT	100%
Physical state	Liquid
Colour	Brown
Odour	Sweet proteinaceous
pH	4.0-5.5 (1% distilled water)
Melting point and Boiling point	Not available
Density	1.2 – 1.28 g/mL
Solubility in water	Water soluble
The above specifications are given on an indicative basis only.	

Experiments were conducted in cereal crops (rice, wheat, maize), vegetable crops (tomato, potato) and fruit crops (mango, grapes, pomegranate) at six locations across the country. The details of crops and cooperating centers are mentioned below.

Crop/ Cropping system	Cooperating Centre
1. Rice- Rice	ICAR-NRRI, Cuttack
2. Tomato- Capsicum	ICAR-IARI, New Delhi
3. Grape, Pomegranate	GKVK, Bengaluru
4. Apple, Potato	CSKHPKV, Palampur
5. Mango and Basic and biochemical studies	ICAR-CISH, Lucknow/ LU, Lucknow
6. Maize-Wheat	ICAR-IISS, Bhopal

Treatment Details

Evaluation material	:	**Zinc Metalosate 6.8% Zn**
Experimental design	:	RBD
Replications	:	3 (minimum)
Treatments	:	12
Frequency of spray	:	3
Treatments details	:	Same for both the crops except treatment no 2 & 3, where succeeding crops will be grown with NPK only

S. No.	Details	Zn added in each application (g)	Total Zn added (g)	Total product added (kg or L)
T_1	NPK	-	-	-
T_2	NPK + Soil Zn	5000	5000	25.00
T_3	NPK + FYM	-	-	-
T_4	NPK + foliar spray of 0.050% Zn through $ZnSO_4$	250	750	3.75
T_5	NPK + foliar spray of 0.100% Zn through $ZnSO_4$	500	1500	7.50
T_6	NPK + foliar spray of 0.150% Zn through $ZnSO_4$	750	2250	11.25
T_7	NPK + foliar spray of 0.010% Zn through Zn Metalosate	50	150	2.21
T_8	NPK + foliar spray of 0.025% Zn through Zn Metalosate	125	375	5.51
T_9	NPK + foliar spray of 0.050% Zn through Zn Metalosate	250	750	11.03
T_{10}	NPK + foliar spray of 0.10% Zn through Zn Metalosate	500	1500	22.06
T_{11}	NPK + foliar spray of 0.025% Zn through Zn-EDTA	125	375	3.13
T_{12}	NPK + foliar spray of 0.050% Zn through Zn-EDTA	250	750	6.25

NOTE:

- Though standard spray volume for each hectare area was kept as 500 L, Zn supplied in each spray (g) might have changed corresponding to change in volume of spray as per crop.
- T_5 is the recommended practice i.e. 0.5% $ZnSO_4$ which supplies 0.1% Zn while T_4 = ½ of T_5 and T_6 =1.5 times of T_5. T_{10} is the equivalent dose of Zn adopted in T_5 while T_9 = ½ of T_{10}; T_8 = ¼ of T_{10}; T_7 = $^1/_{10}$ of T_{10}
- 3 sprays were done at critical growth stages of each crop.

Observations:

i. Collection of representative surface soil (0-15 cm) samples before the application of fertilizers (treatments) and sowing of crops and post-harvest of crops from each plot (36 plots) of the experiment. Analysis of initial soil samples for pH, EC, OC, available N, P, K, S, Zn, Cu, Fe, Mn, B and of the post-harvest soil samples for N, P, K, S, Zn and B.
ii. Initial concentration of Zn, B and other micronutrients of seed/ planting materials, if applicable.
iii. Chemical analysis for N, P, K, S, Zn, B, Cd, Pb and F of all input materials (evaluation materials i.e. Zn Metalosate, organic manure and irrigation water).
iv. Analysis of plant samples (tissue concentration analysis) one day before spray and one week after each spray as well as after harvest.
v. Yield attributing characteristics of crops and total above ground biomass and economic yield.
vi. Analysis of related quality parameters.
vii. Nutrient use efficiency of applied nutrients for all the treatments.
viii. Economics (additional profit or BC ratio).

Note: Some of the observations were taken during the experiments in first year however, some computational observations shall be performed at the end of the second year experiments.

Initial properties of soil at different centers

The initial soil samples from the fields where crops were grown, were processed and analyzed for different fertility parameters, using standard analytical procedures as indicates below:

Parameters	Method/ Reagents
Soil pH and electrical conductivity	1:2.5 soil-water suspension
Soil organic carbon (SOC)	Wet-oxidation (Walkley and Black method)
Available N	Alkaline $KMnO_4$ method
Available P	0.5 *M* $NaHCO_3$ (Olsen's)
Available K	Ammonium acetate method
Available S	0.15% $CaCl_2$-extractable
DTPA-extractable Fe , Zn , Cu, Mn	0.005*M* DTPA + 0.01*M* $CaCl_2.2H_2O$ + 0.1*M* TEA
Available B	Hot water/ $CaCl_2$-extractable

Analysis of initial soil samples collected at different experimental locations exhibited sandy loam to black clay loam texture of the soils at most of the locations except at Palampur where soils were silty clay loam (Table 1). Soils at NRRI, Cuttack, IISS, Bhopal and CSKHPKV, Palampur centres were reported as sandy clay loam, black clayey, silty clay loam in texture, respectively. While the texture of soils at IARI, New Delhi, GKVK, Bengaluru and CISH, Lucknow centre was sandy loam. In general, soil reaction of all the soils were acidic to neutral as pH varied from 5.7 at Palampur to 7.81 at New Delhi.

In most of the experimental sites, soil organic carbon content was low to medium except at Palampur where it was high (1.26%). Electrical conductivity of soil ranged from 0.13 to 0.79 dS m^{-1}. At most of the sites, DTPA- extractable Zn content was below the critical limit and varied from 0.49 to 1.49 mg kg^{-1}. However, soils of Palampur and New Delhi experimental sites were having high Zn content. Similarly, B content at most of the experimental sites varied from 0.32 to 0.67 mg kg^{-1}. All the soils were adequate in available P and K content while low to medium in available S content. Quantitatively, available N ranged from 210.0 to 325 kg ha^{-1} while available P, K and S ranged from 26.50- 186.6 kg ha^{-1}, 301.0-560.0 kg ha^{-1} and 8.7-18.77 mg kg^{-1}, respectively. Likewise, Mn, Fe and Cu content was adequate in almost all the soils and ranged from 8.60-21.1, 9.70-45.60, 0.70-4.60 mg kg^{-1} respectively across the locations.

Table 1. Initial properties of soil at different centres (For Zn Metalosate experiment)

Centre	Cuttack	Bhopal	Palampur		New Delhi	Bengaluru		Lucknow
Crop	Rice	Maize-Wheat	Potato	Apple	Tomato	Grape	Pomegranate	Mango
Texture	*Sandy*	*Black*	*Silty clay loam*		*Sandy*	*Sandy loam*		*Sandy loam*

	clay loam	*clay soil*			*loam*			
pH (1:2.5)	6.0	7.69	5.70	6.13	7.81	6.45	6.28	7.20
EC (1:2.5) dS/m	0.65	0.13	0 .79	0.56	0.48	0.54	0.15	-
SOC (%)	0.61	0.65	1.26	1.23	0.63	0.29	0.58	0.45±0.05
Available N (kg ha^{-1})	225.4	325.00	235.2	211.7	210.0	230.8	311.0	-
Available P_2O_5 (kg ha^{-1})	28.7	26.50	124.9	186.6	114.0	57.71	54.3	27.20±2.31
Available K_2O (kg ha^{-1})	301	415	306	301.0	560	375.2	376.8	224.4±20.3
Available S (mg kg^{-1})	16.20	14.30	8.90	8.7	15.60	18.77	17.51	-
DTPA-Fe (mg kg^{-1})	45.60	36.50	23.40	13.4	15.50	16.94	13.64	9.70±1.73
DTPA-Mn (mg kg^{-1})	16.40	12.62	17.0	21.1	8.60	17.06	15.16	11.62±1.01
DTPA-Zn (mg kg^{-1})	0.72	0.56	1.33	1.49	1.07	0.54	0.49	0.60±0.22
DTPA-Cu (mg kg^{-1})	3.70	2.31	1.29	0.70	4.60	1.07	2.34	2.03±0.34
HWS-B (mg kg^{-1})	0.56	0.55	0.32	0.61	0.67	0.34	0.46	-

4. RESULTS

The field experiments were carried out as per technical programme at six centers *viz*., CSKHPKV, Palampur (HP); IARI, New Delhi; CISH, Lucknow (UP); GKVK, Bengaluru (Karnataka); CRRI Cuttack (Odisha); and IISS, Bhopal (MP) under the aegis of All India Coordinated Research Project on Micro-and Secondary Nutrients and Pollutant Elements in Soils and Plants during the year 2015-16 and 2016-17. Predominant cereal, fruit and vegetable crops of the region (Cuttack: rice-rice; Bhopal: maize-wheat; New Delhi: tomato & capsicum; Palampur: potato & apple; Lucknow: mango; Bengaluru: grape & pomegranate) were selected to evaluate the efficacy of Zn Metalosate fertilizers against the standard Zn sources. The results of the experiments are summarized below under appropriate subheads.

Crop yields

In general, application of Zn through either of the methods or sources has increased the crop productivity over recommended NPK application (no Zn). The extent of increase varied with soil Zn level and crop type. The detailed crop response to various Zn supplements including Zn Metalosate are furnished below:

1. Cereal crops

During the year 2015-16, all three major cereal crops *viz*. rice, wheat and maize responded positively to Zn supplementation either through $ZnSO_4$ or Zn Metalosate or Zn-EDTA; however, the extent of response varied among the crops. As expected, application of recommended dose of FYM also had positive bearings on enhanced yield of these cereal crops. Individually, grain yield of rice crop var. Naveen grown in *kharif* as well as *rabi* season at Cuttack varied from 4.1 to 5.1 t ha^{-1} and 4.3 to 5.4 t ha^{-1}, respectively. Among the Zn treatments, application of Zn through soil yielded the highest rice production. Among the foliar Zn application, $ZnSO_4$ @ 0.1% Zn concentration was at par with 0.05% Zn through Zn Metalosate and 0.05% through Zn- EDTA (i.e.

half of the standard Zn concentration supplied through $ZnSO_4$). This indicated that application Zn Metalosate even at half concentration of Zn through standard source resulted in same yield. It is also noteworthy that concentration of Zn higher than the recommended level could not enhance the rice grain productivity significantly.

Similar to the rice crop, methods and source of Zn application resulted in increased maize (var. Shaktiman-5) yield in accordance to the quantity of Zn supplied in each treatment. A perusal of the results pertaining to maize yield presented in Table 2 indicated that though the highest yield was obtained through application of 0.15% Zn through $ZnSO_4$, 0.10% Zn through Zn Metalosate and 0.050% Zn through Zn- EDTA however, standard rate of foliar Zn application through either of the sources produced comparable yields of the maize.

Similar to the *kharif* cereal crops like rice and maize, wheat grown in *rabi* season at two sites of Bhopal, also responded to different sources and rate of Zn fertilization. Depending upon the nature of wheat cultivars, the grain yield ranged from 3.36 to 4.13 t ha^{-1} (HD2987) and 4.39 to 5.52 t ha^{-1} (Lok 1) respectively. Different foliar Zn supplements had the similar effect as in case of maize crop (Table 2).

Table 2. Yields of cereal crops (t ha^{-1}) as influenced by different sources of Zinc ($ZnSO_4$, Zn Metalosate and Zn-EDTA) at different locations during *kharif* 2015 and *rabi* 2015-16

Treatment	Rice -Rice		Maize- wheat		
	Kharif Rice (Naveen)	*Rabi* Rice (Naveen)	Maize (Shaktiman 5)	Wheat (HD2987)	Wheat (Lok 1)
Location	Cuttack		Bhopal		
1. NPK	4.10	4.30	5.17	3.36	4.39
2. NPK+ Soil Zn	5.10	5.40	6.84	3.87	5.34
3. NPK+FYM	5.00	5.30	7.14	4.07	5.52
4. NPK+0.050% through $ZnSO_4$	4.30	4.40	5.25	3.69	4.65
5. NPK+0.100% through $ZnSO_4$	4.60	4.80	5.91	4.07	4.78
6. NPK+ 0.150% through $ZnSO_4$	4.20	4.50	6.15	4.13	4.95
7. NPK+0.010% through Zn Metalosate	4.30	4.50	5.33	3.59	4.51
8. NPK+0.025% through Zn Metalosate	4.50	4.70	5.66	3.74	4.72
9. NPK+ 0.050% through Zn Metalosate	4.80	4.70	5.99	3.93	5.03
10. NPK+0.10% through Zn Metalosate	4.60	4.80	6.32	4.08	5.30
11. NPK+ 0.025% through Zn- EDTA	4.40	4.60	5.58	3.61	4.76
12. NPK+ 0.050% through Zn- EDTA	4.70	4.90	6.33	3.87	4.97
CD (P=0.05)	**0.30**	**0.32**	**0.60**	**0.45**	**0.51**

Response of *kharif* rice, maize, *durum* wheat (HD 2987) and *aestivum* wheat (Lok 1) to Zn supplements through $ZnSO_4$, Zn Metalosate and Zn-EDTA is depicted in Figure 1. In general, 14.13, 16.12, 19.15 and 16.37% increase in yield was recorded respectively using 0.10% Zn through $ZnSO_4$, 0.05% Zn through Zn Metalosate, 0.10% Zn through Zn Metalosate, 0.05% Zn through Zn- EDTA over recommended NPK. As evident from the graph, crop response in maize and wheat was maximum with Zn supplementation through Zn Metalosate @ 0.1% Zn. However, in rice the half dose of Zn supplied through Zn Metalosate resulted in the highest grain production.

Similar to the first year experimentation, the application of recommended dose of FYM also improved the yield of these cereal crops in the second year of experimentation (2016-17). methods and sources of Zn application resulted in a transition in the yield of crops in accordance

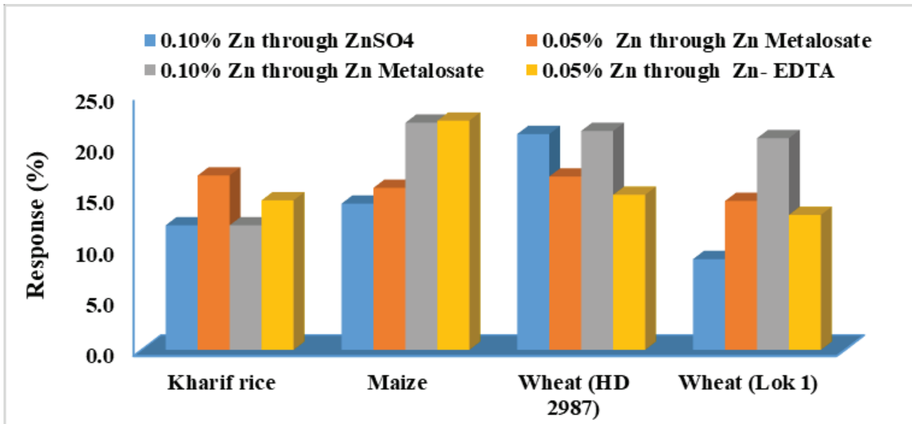


Figure 1. Response of different cereal crops to foliar supplementation of Zn through $ZnSO_4$, Zn Metalosate and Zn-EDTA

to the quantity of Zn supplied in each treatment to different extents. The results pertaining to yield of rice var. Naveen, maize crop var. Shaktiman 5 and Nath Samrat 1144 grown in *kharif* season at Bhopal is presented in Table 3. The response of rice crop var. Naveen was the highest to the application of FYM in both *kharif and rabi* seasons. Foliar spray of $ZnSO_4$ at the rate of 0.1% Zn, Zn Metalosate at the rate of 0.05% Zn and Zn-EDTA at the rate of 0.05% Zn resulted in significantly higher grain yield. The highest yield of maize crop var. Shaktiman 5 was obtained with the application of 0.15% Zn through $ZnSO_4$, 0.10% Zn through Zn Metalosate and 0.050% Zn through Zn- EDTA. Apart from that, the highest yield of maize crop var. Nath Samrat 1144 was recorded with the application of zinc at the concentration of 0.10% through $ZnSO_4$, 0.050% Zn through Zn Metalosate and 0.050%Zn through Zn- EDTA. However, the other concentrations enhanced the yield at comparable rates. Similar to the *kharif* cereal crops like rice and maize, wheat grown in *rabi* season at two sites of Bhopal, also responded to different sources and rate of Zn fertilization. Depending upon the nature of wheat cultivars, the grain yield ranged from 3.59 to 4.58 t ha^{-1} (HD2987) and 5.52 to 6.44 t ha^{-1} (Lok 1) respectively. Different foliar Zn supplements had the similar effect as in case of maize crop (Table 3).

Table 3. Yields of cereal crops (t ha^{-1}) as influenced by different sources of Zinc ($ZnSO_4$, Zn Metalosate and Zn-EDTA) at different locations during *kharif* 2016 and *rabi* 2016-17

Treatment	Rice -Rice		Maize- wheat			
	Kharif Rice (Naveen)	*Rabi* Rice (Naveen)	Maize (Shakti-man 5)	Maize (Nath Samrat 1144)	Wheat (HD2987)	Wheat (Lok 1)
Location	**Cuttack**		**Bhopal**			
1. NPK	4.27	4.21	5.38	4.58	3.59	5.52
2. NPK+ Soil Zn	5.32	5.22	6.55	5.83	4.58	6.35
3. NPK+FYM	5.42	5.44	6.88	5.63	4.10	6.43
4. NPK+0.050% through $ZnSO_4$	4.49	4.38	5.72	5.19	3.72	5.72
5. NPK+0.100% through $ZnSO_4$	4.83	4.68	5.84	5.48	4.32	5.81
6. NPK+ 0.150% through $ZnSO_4$	4.41	4.61	6.15	5.19	4.20	6.22
7. NPK+0.010% through Zn Metalosate	4.47	4.66	5.47	5.08	3.46	5.93
8. NPK+0.025% through Zn Metalosate	4.61	4.56	5.61	5.11	3.60	6.22
9. NPK+ 0.050% through Zn Metalosate	4.88	4.89	6.47	6.24	4.38	6.44
10. NPK+0.10% through Zn Metalosate	4.71	4.88	6.78	6.18	4.19	6.44
11. NPK+ 0.025% through Zn-EDTA	4.51	4.71	5.64	5.15	3.57	5.42
12. NPK+ 0.050% through Zn-EDTA	4.85	5.00	6.14	5.50	4.17	6.08
CD (P=0.05)	**0.61**	**0.68**	**0.67**	**0.53**	**0.40**	**0.44**

During the year 2016-17, the cereal crops responded to the standard zinc supplementation through foliar zinc supplements very well irrespective of the sources of zinc (Figure 2). The response of half dose of zinc supplied through Zn Metalosate and Zn-EDTA were encouraging in improving rice yields at Cuttack. However, the highest response of 27.9 % was registered using FYM to the yield of maize var. Shaktiman5.The other variety of maize i.e. Nath Samrat 1144 and both the cultivars of wheat i.e HD 2987 and Lok 1 responded to the half and standard zinc supplementations through Zn Metalosate more effectively.

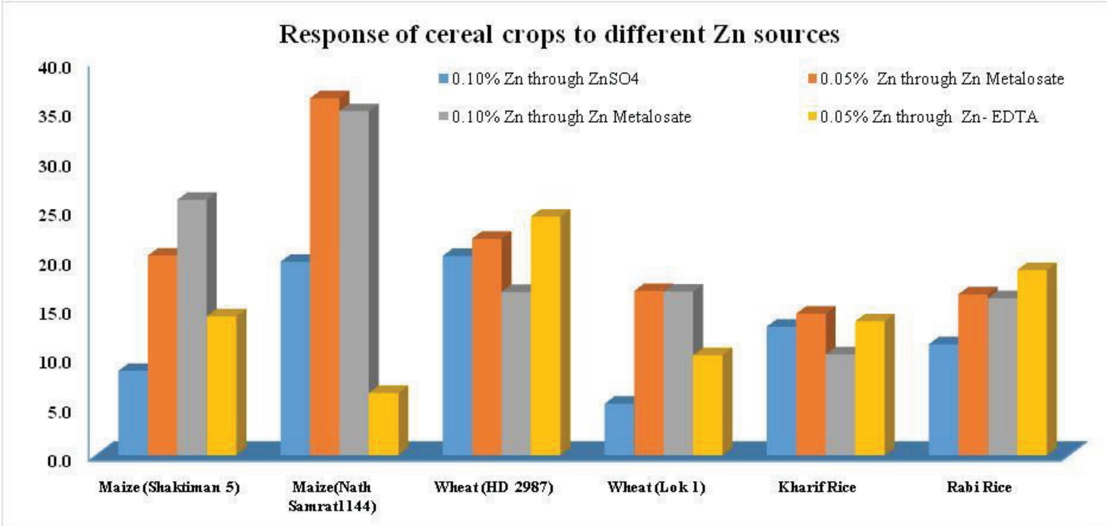


Figure 2. Response of different cereal crops to foliar supplementation of Zn through $ZnSO_4$, Zn Metalosate and Zn-EDTA

2. Vegetable crops

During the year 2015-16, the effect of Zn Metalosate was evaluated on two vegetable crops *viz*. Potato (Kufri Jyoti) and Tomato (GS600 under polyhouse and Devika in open field) at Palampur and New Delhi, respectively. Like cereal crops, tuber yield of potato, which ranged from 12.53 to 17.03 t ha^{-1}, was the highest in the treatment receiving FYM along with recommended dose of NPK (Table 4). Among the treatments involving foliar feeding of Zn through different Zn supplements, the treatment receiving Zn concentration @ 0.1% Zn through Zn Metalosate recorded the highest potato tuber yield which was comparable to the tuber yield under 0.10% Zn through $ZnSO_4$, 0.05% Zn through Zn Metalosate and 0.15% Zn through $ZnSO_4$. Application of Zn through Zn-EDTA at equal concentration proved inferior compared to Zn Metalosate.

Table 4. Yields of vegetable crops (t ha^{-1}) as influenced by different sources of zinc ($ZnSO_4$, Zn Metalosate and Zn-EDTA) at different locations during *kharif* 2015 and *rabi* 2015-16

Treatment	Potato (*Kufri Jyoti*)	Tomato	
		Polyhouse (GS 600)	Open field (Devika)
Location	*Palampur*	*New Delhi*	
1. NPK	12.53	126.2^{d}	48.1^{g}
2. NPK+ Soil Zn	14.72	145.7^{a}	48.9^{defg}
3. NPK+FYM	17.03	126.7^{d}	48.3^{efg}
4. NPK+0.050% through $ZnSO_4$	13.50	129.5^{d}	48.2^{fg}
5. NPK+0.100% through $ZnSO_4$	14.31	143.4^{ab}	49.0^{def}
6. NPK+ 0.150% through $ZnSO_4$	14.53	144.6^{ab}	49.4^{d}
7. NPK+0.010% through Zn Metalosate	13.67	131.5^{cd}	49.8^{d}
8. NPK+0.025% through Zn Metalosate	13.97	144.8^{a}	50.8^{c}
9. NPK+ 0.050% through Zn Metalosate	14.50	150.5^{a}	51.7^{b}

10. NPK+0.10% through Zn Metalosate	15.00	145.7[a]	54.12[a]
11. NPK+ 0.025% through Zn- EDTA	13.81	137.3[bc]	49.2[de]
12. NPK+ 0.050% through Zn- EDTA	14.03	149.2[a]	49.6[d]
CD (P=0.05)	**0.69**	**-**	**-**

Tomato (var. GS 600) grown inside polyhouse gave almost 3 times higher yield than tomato (var. Devika) grown under open field conditions. In contrast to potato, the tomato grown in polyhouse produced highest fruit yield of tomato when 0.05% Zn was supplied through Zn Metalosate which was comparable to its lower as well as higher concentrations and soil Zn treatment. However, under open field conditions, the treatment receiving 0.1% Zn through Zn Metalosate proved superior over all other treatment. Reduction in foliar Zn concentration supplied through Zn Metalosate had significant negative effect on tomato yield under open field conditions.

Plate 1. Effect of sources of Zn on potato

In general, vegetable crops responded variably with respect to level and sources of different Zn supplements (Figure 3). For instance, 0.1% Zn supplied through Zn Metalosate resulted in 19.71% increase in potato tuber yield at Palampur and tomato fruit yield under open field conditions at New Delhi. While under polyhouse conditions, the highest increase was registered when half of the recommended Zn supplied (0.05% Zn) through Zn Metalosate. A scrutiny of the figure 3 revealed that 14.2, 15.7, 19.7 and 12.0% increase in yield was recorded with application of 0.10% Zn through $ZnSO_4$, 0.05% Zn through Zn Metalosate, 0.10% Zn through Zn Metalosate, 0.05% Zn through Zn- EDTA, respectively over no Zn control. Similar results were also obtained in tomato grown in open field condition though the effect of Zn supplementation through Zn Metalosate was more pronounced in comparison to their counterpart sources. It is noteworthy that under polyhouse conditions the performance of Zn Metalosate at half of the standard Zn dose recorded maximum response in terms of fruit yield.

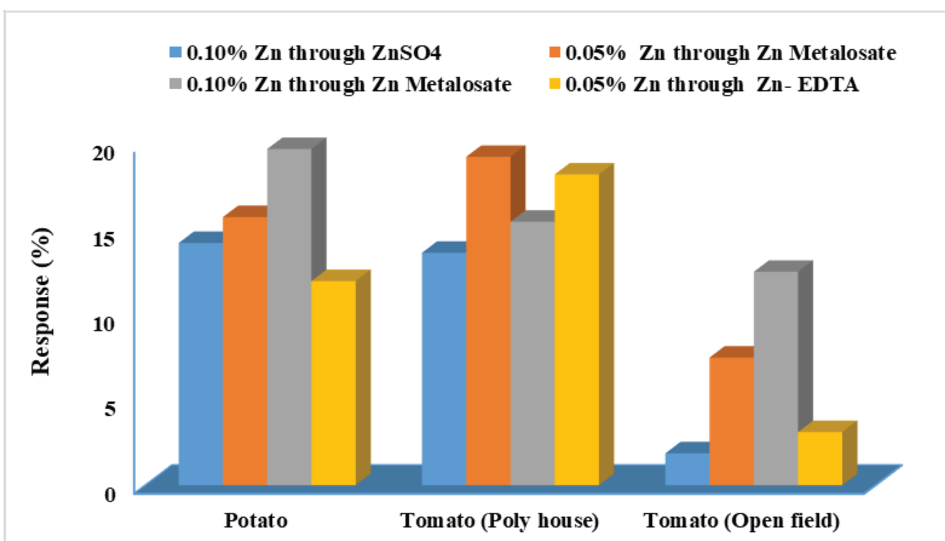


Figure 3. Response of different vegetable crops to foliar supplementation of Zn through $ZnSO_4$, Zn Metalosate and Zn-EDTA

In the second year of study during 2016-17, Zn Metalosate was also again evaluated on two vegetable crops *viz*. Potato (Kufri Jyoti) and Okra and; Tomato (GS600 under polyhouse and Devika in open field) & Capsicum at Palampur and; New Delhi, respectively. The yield data of different crops are presented in Table 5. Tuber yield of potato, which ranged from 10.69 to 15.95 t ha^{-1} was the highest in the treatment receiving FYM along with recommended dose of NPK. Among the treatments involving foliar feeding of Zn through different Zn supplements, the potato tuber yield was recorded highest in the treatment receiving Zn concentration @ 0.1% Zn through Zn Metalosate which was comparable to 0.05% Zn through Zn Metalosate and also with soil zinc application with NPK. Application of Zn through Zn-EDTA at equal concentration proved inferior to Zn Metalosate.

Table 5. Yields of vegetable crops (t ha^{-1}) as influenced by different sources of Zinc ($ZnSO_4$, Zn Metalosate and Zn-EDTA) at different locations during *kharif* 2016 and *rabi* 2016-17

Treatment	Potato (*Kufri Jyoti*)	Okra	Tomato		Capsicum
			Polyhouse (GS 600)	Open field (Devika)	Polyhouse
Location	***Palampur***		***New Delhi***		
1. NPK	10.69	8.93	38.0	25.0	15.9
2. NPK+ Soil Zn	13.20	11.44	48.3	26.3	19.1
3. NPK+FYM	15.95	12.49	44.2	25.4	18.8
4. NPK+0.050% through $ZnSO_4$	11.86	10.39	45.6	25.8	19.6
5. NPK+0.100% through $ZnSO_4$	12.87	10.90	47.5	25.7	20.0
6. NPK+ 0.150% through $ZnSO_4$	12.35	10.64	49.3	30.6	20.5
7. NPK+0.010% through Zn Metalosate	12.19	10.48	56.9	30.3	23.5
8. NPK+0.025% through Zn Metalosate	12.43	10.70	54.3	30.7	23.6
9. NPK+ 0.050% through Zn Metalosate	12.98	11.06	54.4	29.2	23.3
10. NPK+0.10% through Zn Metalosate	13.82	11.58	54.0	30.2	23.6
11. NPK+ 0.025% through Zn- EDTA	11.53	9.88	51.5	28.0	23.3
12. NPK+ 0.050% through Zn- EDTA	11.84	10.09	51.2	27.9	23.7
CD (P=0.05)	**0.84**	**1.03**	**7.39**	**4.41**	**2.18**

Similar to potato, the highest yield of okra crop was recorded on application of FYM. A maximum increase in yield by 39% was noted using FYM. It ranged from 8.93 t ha^{-1} to 12.49 t ha^{-1} at Palampur. Among the foliar applications also, the treatment receiving Zn concentration @ 0.1% Zn through Zn Metalosate or Zinc Sulphate produced the highest yield of okra crop. Tomato (var. GS 600) grown inside polyhouse gave almost 2 times more yield than tomato (var. Devika) grown under open field conditions. The application of zinc either through soil or foliar spray significantly influenced the yield of tomato under polyhouse cultivation. The foliar application of Zn through $ZnSO_4$ in all the concentrations commensurate with the zinc supplied directly to the soil. Zinc Metalosate applied to the tomato plant produced highest fruit yield of tomato even when one tenth i.e 0.010% Zn was supplied. However, other concentrations were at par with each other and Zn applied @ 0.025 and 0.050% through Zn-EDTA. Under open field conditions, all the treatments of zinc either through soil application or foliar spray were equally effective. The foliar application of 1.5 times higher dose of zinc through $ZnSO_4$ and Zn Metalosate and Zn-EDTA in all doses were better, although other applications were comparable. Capsicum crop yield under polyhouse conditions improved over control and all the zinc doses were equally effective. However, among the foliar applications of Zn through $ZnSO_4$, Zn Metalosate and Zn-EDTA, Zn Metalosate and Zn-EDTA were more promising.

In general, vegetable crops responded variably with respect to level and sources of different Zn supplements (Figure 4). For instance, 0.1% Zn supplied through Zn Metalosate resulted in 29% increase in potato tuber and okra yield at Palampur. A remarkable increased yield of tomato was recorded on foliar application of zinc @ 0.05 and 0.1 % Zn through Zn Metalosate under polyhouse and open field conditions at New Delhi (Figure 4). On an average, 47.8 % increment in the yield of Capsicum was noted using either of Zn Metalosate and Zn-EDTA using any of the zinc concentrations.

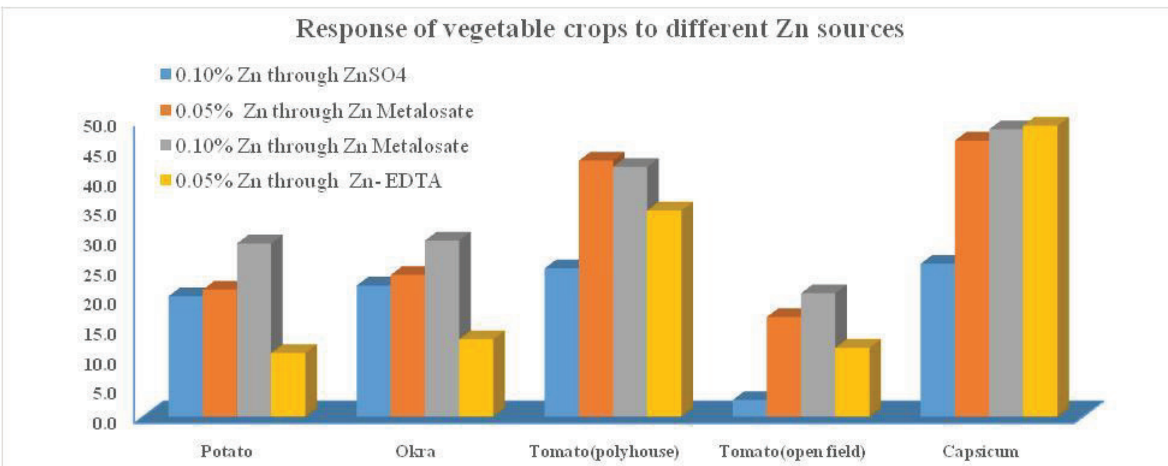


Figure 4. Response of different vegetable crops to foliar supplementation of Zn through $ZnSO_4$, Zn Metalosate and Zn-EDTA

3. Fruit Crops

The efficacy of zinc Metalosate was also evaluated in prominent fruit crops like grape (var. Dilkush) and pomegranate (var. Bhagwa) at Bengaluru, Mango (var. Mallika) at Lucknow, and Apple (var. Royal Delicious) at Bajaura, Palampur during 2015-16 and 2016-17. In the first year of study, the fruit yield of grape ranged from 16.12 to 40.50 kg per plant increased with increasing concentration of foliar Zn supplied through any of the Zn sources. Being fruit crop, the response of foliar supplementation was more prominent than its soil application as well as FYM (Table 6). Interestingly, foliar spray @ 0.1% Zn through Zn Metalosate gave almost 2 to 2.5 times higher fruit yield than lower concentration of Zn Metalosate and no Zn control treatments. Similarly, pomegranate yield under the treatment 0.1% Zn through Zn Metalosate was 3 times higher than the soil application and 1.5 times higher than 0.1% Zn supplied through $ZnSO_4$. The lower concentration of Zn Metalosate i.e. 0.010% and 0.025 Zn as well as both the concentrations of Zn-EDTA proved inferior to Zn supplied through $ZnSO_4$ in enhancing both grape and pomegranate yield.

In mango (cultivar: Mallika) grown at Lucknow, the foliar supplementation of Zn through any of the sources at all the levels of Zn concentrations, except the lowest dose of Zn through Zn Metalosate i.e. 1/10 the recommended Zn proved to be vital in enhancing fruit yield in comparison with soil Zn application. In apple, the highest yield was recorded in treatment receiving 0.1% Zn through Zn Metalosate which was comparable to its lower concentrations i.e. ¼, ½ of recommended Zn as well as 0.05% Zn through Zn-EDTA. Application of Zn through $ZnSO_4$ proved much inferior in enhancing the apple yield as compared to similar concentration of Zn supplied through Zn Metalosate and Zn-EDTA. Application of FYM and soil Zn could not influence apple fruit yield at Bajaura, Palampur.

Table 6. Yields of fruit crops (kg per plant) as influenced by different sources of Zinc ($ZnSO_4$, Zn Metalosate and Zn-EDTA) at different locations during first year of study

Treatment	Grape (Dilkush)	Pomegranate (Bhagwa)	Mango (Mallika)	Apple (Royal Delicious)
Location	***Bengaluru***		***Lucknow***	***Palampur***
1. NPK	16.12	13.90	29.46	59.93
2. NPK+ Soil Zn	21.49	15.90	31.57	65.43
3. NPK+FYM	19.47	15.46	37.65	63.83
4. NPK+0.050% through $ZnSO_4$	28.72	28.21	38.59	69.33
5. NPK+0.100% through $ZnSO_4$	31.17	30.34	41.79	71.83
6. NPK+ 0.150% through $ZnSO_4$	31.99	32.79	43.27	72.70
7. NPK+0.010% through Zn Metalosate	23.02	21.17	34.58	74.43
8. NPK+0.025% through Zn Metalosate	24.67	23.79	38.16	77.13
9. NPK+ 0.050% through Zn Metalosate	34.44	39.10	43.89	79.83
10. NPK+0.10% through Zn Metalosate	40.50	42.74	43.17	83.00
11. NPK+ 0.025% through Zn- EDTA	24.36	22.81	40.22	76.90
12. NPK+ 0.050% through Zn- EDTA	26.06	24.54	44.49	78.13
CD (P=0.05)	**3.30**	**3.43**	**9.47**	**6.94**

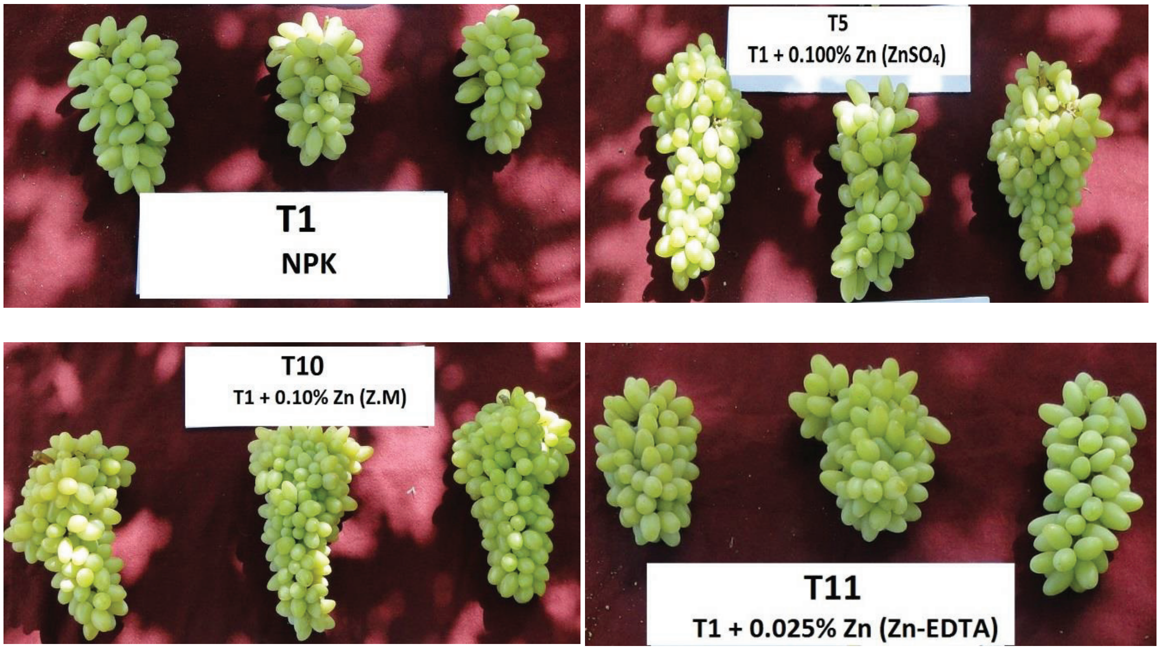


Plate 2. Effect of sources of Zn on grape

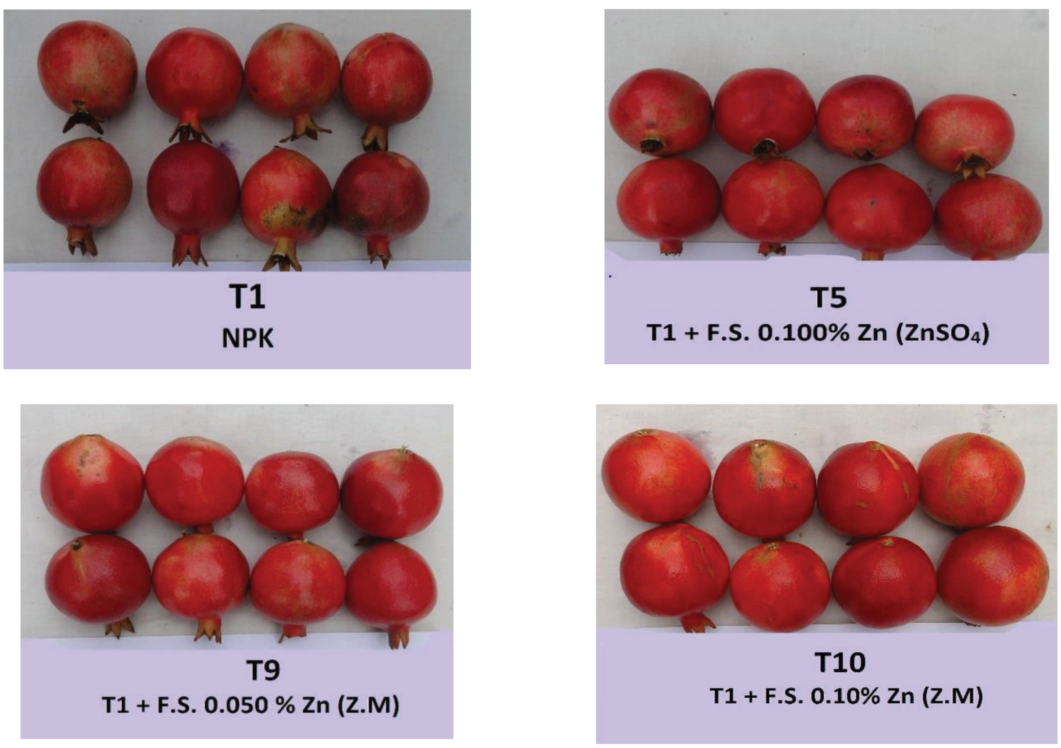


Plate 3. Effect of sources of Zn on pomegranate

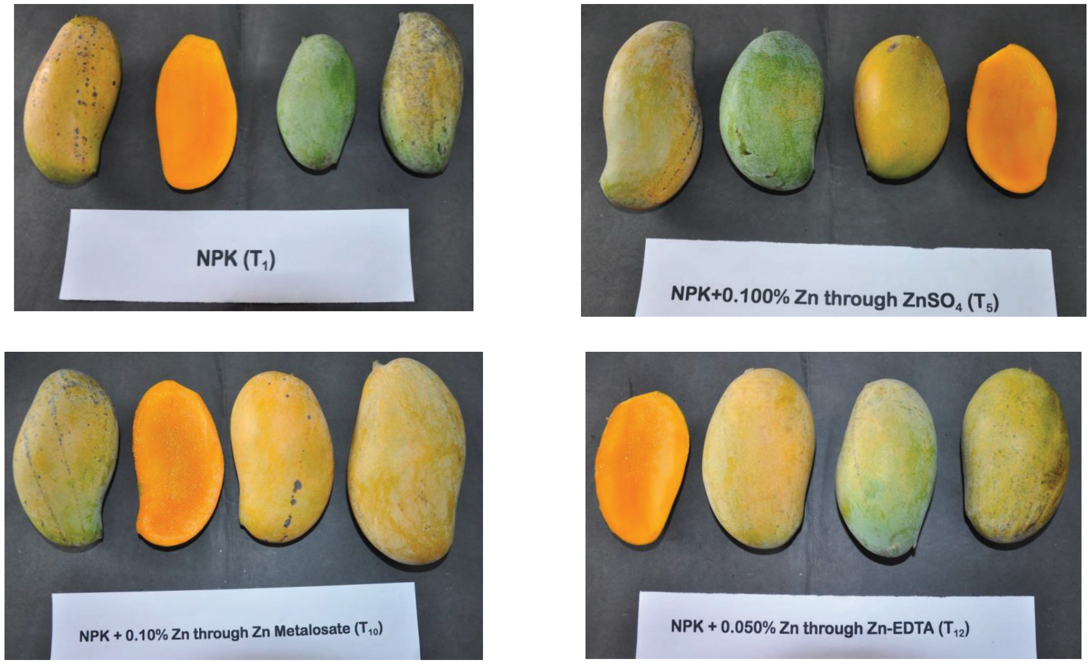


Plate 4. Effect of sources of Zn on mango

As compared to cereal and vegetable crops, fruit crops responded much prominently to Zn Metalosate as compared to other sources of Zn supply (Figure 5). On average, application of Zn Metalosate at 0.1% Zn concentration registered 151, 207 and 38% increase in grapes, pomegranate, and apple fruit yields while in mango half of this dose was sufficient to enhance the fruit yield by maximum extent i.e. 49.0%.

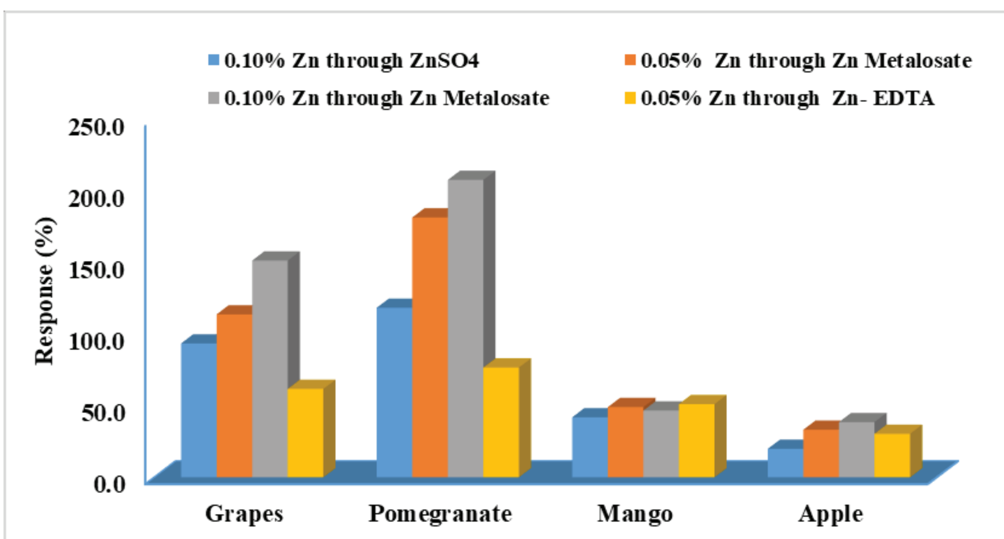


Figure 5. Response of different fruit crops to foliar supplementation of Zn through $ZnSO_4$, Zn Metalosate and Zn-EDTA

In the second year of study, the fruit yield of grape ranged from 20.35 to 44.01 kg per plant increased with increasing concentration of Zn supplied foliarly through any of the Zn sources (Table 7). On the contrary to the cereal and vegetable crops, the soil application of zinc as well as FYM was less prominent than its foliar application. Interestingly, foliar spray @ 0.1% Zn through Zn

Metalosate gave tremendously higher fruit yield than lower concentration of Zn Metalosate and no Zn control treatments. Similarly, in pomegranate, increase in yield in treatment receiving 0.1% Zn through Zn Metalosate was more than 1.5 times greater than the soil application and 1.25 times greater than 0.1% Zn supplied through $ZnSO_4$. The lower concentration of Zn Metalosate i.e. 0.010% and 0.025% Zn as well as both the concentrations of Zn-EDTA proved inferior to Zn supplied through $ZnSO_4$ in enhancing both grape and pomegranate yield.

Table 7. Yields of fruit crops (kg per plant) as influenced by different sources of Zinc ($ZnSO_4$, Zn Metalosate and Zn-EDTA) at different locations in the second year of study

Treatment	Grapes (Dilkush)	Pomegranate (Bhagwa)	Mango (Mallika)	Apple (Royal Delicious)
Location	***Bengaluru***		***Lucknow***	***Palampur***
1. NPK	20.35	25.22	39.47	62.1
2. NPK+ Soil Zn	25.97	27.84	40.52	67.6
3. NPK+FYM	24.40	27.50	46.62	66.0
4. NPK+0.050% through $ZnSO_4$	31.66	34.49	47.32	71.5
5. NPK+0.100% through $ZnSO_4$	33.87	35.66	52.71	73.4
6. NPK+ 0.150% through $ZnSO_4$	35.79	37.01	52.82	74.9
7. NPK+0.010% through Zn Metalosate	26.97	30.52	45.57	76.6
8. NPK+0.025% through Zn Metalosate	28.55	31.96	49.22	79.3
9. NPK+ 0.050% through Zn Metalosate	38.79	41.67	56.20	82.0
10. NPK+0.10% through Zn Metalosate	44.01	45.00	55.19	85.2
11. NPK+ 0.025% through Zn- EDTA	28.24	31.39	48.22	79.1
12. NPK+ 0.050% through Zn- EDTA	29.71	32.51	51.41	80.3
CD (P=0.05)	**2.40**	**2.45**	**5.47**	**5.80**

The mango grown in Lucknow gave similar response that obtained in first year of study. Apple fruit yield was significantly affected by different levels of zinc application and improved on increasing zinc contents. Apple fruit yield ranged from minimum of 62.1 kg $plant^{-1}$ with NPK to maximum of 85.2 kg $plant^{-1}$on zinc applied @0.10 % through Zn Metalosate (Table 7). The maximum fruit yield recorded under the treatment receiving Zn from ZnSO4 was found statistically at par with the fruit yield obtained with half concentration of Zn applied through Zn Metalosate and Zn-EDTA. Among the three sources of foliar application of zinc, the application of Zn metalosate was found superior to the application of Zn-EDTA and $ZnSO_4$ at same level of zinc application. This improvement in the yield to applied zinc might be due to the fact that Zn is involved in many enzyme systems and biochemical reactions required for bud development and flowering while; the poor supply of zinc restricts leaf and bud growth and development, leading to bare bark or rosettes of spindly leaves.

In the second year of study, the fruit crops also responded much prominently to Zn Metalosate as compared to other sources of Zn supply (Figure 6). On average, application of Zn Metalosate at 0.1% Zn concentration registered 116 and 78.5% increase in grapes and pomegranate, while in mango half of this dose was sufficient to enhance the fruit yield by 42 %.

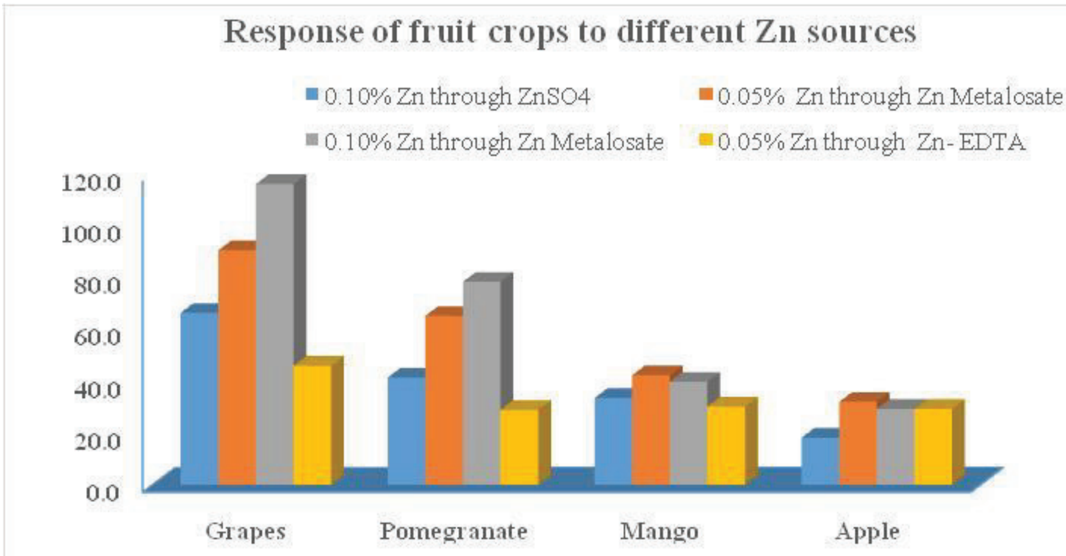


Figure 6. Response of different fruit crops to foliar supplementation of Zn through $ZnSO_4$, Zn Metalosate and Zn-EDTA

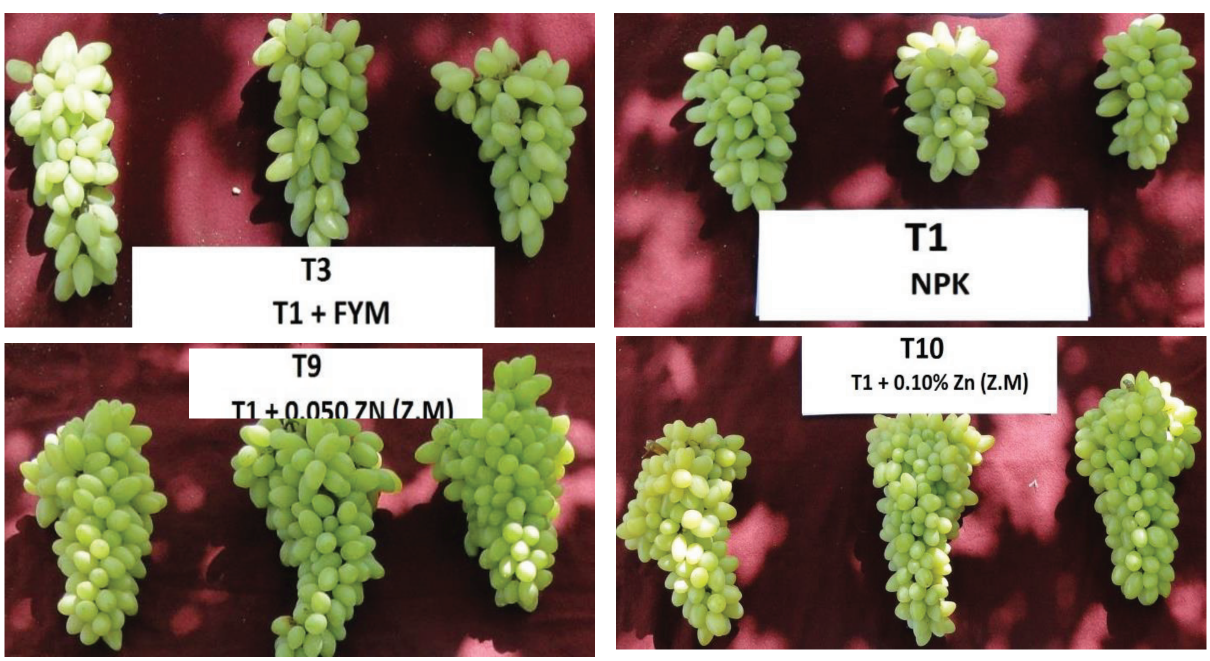


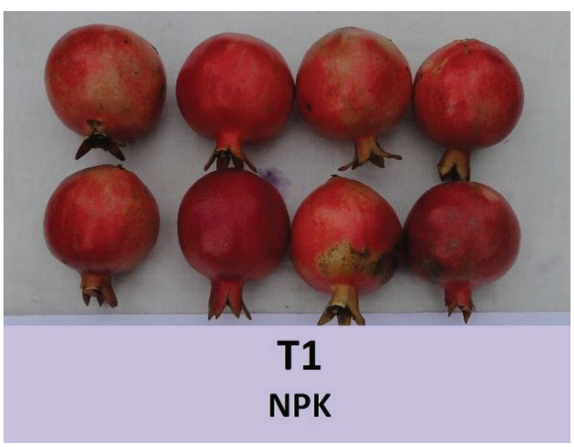
Plate 5. Effect of sources of Zn on grapes

NPK + foliar spray of 0.050% Zn through Zn Metalosate

NPK + foliar spray of 0.100% Zn through Zn Metalosate

NPK + foliar spray of 0.050% Zn through Zn-EDTA

Plate 6. Effect of sources of Zn on apple



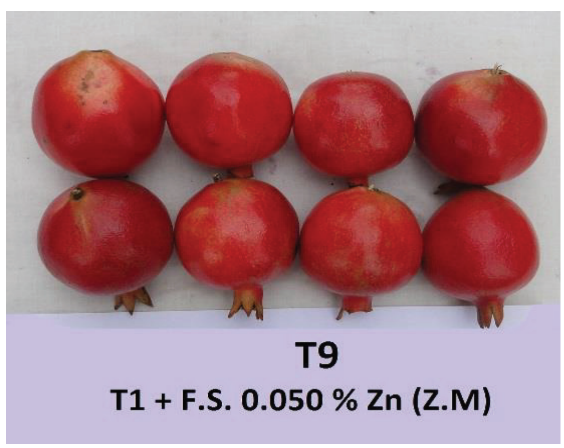


Plate 7. Effect of sources of Zn on pomegranate

Zinc concentration in edible plant parts

1. Cereal Crops

Performance of Zn Metalosate has also been evaluated in terms of enhanced Zn concentration in edible plant parts. In general, Zn concentration in cereals increased with application of Zn through either of Zn containing supplements, however, the extent of increase varied with crop and cultivars during first year of study (Table 8). Among cereals, significant enhancement in grain Zn concentration of wheat has been recorded with standard dose of Zn supplied through either Zn Metalosate or $ZnSO_4$ or Zn-EDTA. Grain Zn concentration ranged between 23.6 to 32.6 mg kg^{-1} in maize (Shaktiman 5), 40.8 to 54.6 mg kg^{-1} in *durum* wheat (HD 2987) and 34.8 to 49.7 mg kg^{-1} in *aestivum* wheat (Lok 1), and 28.1 to 31.7 mg kg^{-1} in rice (Naveen). However in maize, the treatment 0.1% Zn through Zn Metalosate and 0.15% Zn through $ZnSO_4$ were equally effective in enhancing grain Zn concentration. Lower concentration of these products i.e. $^{1}/_{10}$ and ¼ of Zn Metalosate and ½ of $ZnSO_4$ and Zn-EDTA could not increase the Zn concentration in maize. Application of either of sources could not influence grain Zn concentration in rice.

Table 8. Grain Zn concentration (mg kg^{-1}) of cereal crops as influenced by different sources of Zinc ($ZnSO_4$, Zn Metalosate and Zn-EDTA) at different locations during first year of study

Treatment	Rice (Naveen)	Maize- wheat		
		Maize (Shaktiman 5)	Wheat (HD2987)	Wheat (Lok 1)
Location	*Cuttack*	*Bhopal*		
1. NPK	31.6	23.6	40.8	34.8
2. NPK+ Soil Zn	28.7	32.5	53.6	46.0
3. NPK+FYM	28.1	29.0	49.7	42.9
4. NPK+0.050% through $ZnSO_4$	29.2	25.5	47.9	45.3
5. NPK+0.100% through $ZnSO_4$	30.6	28.4	48.7	46.3

6. NPK+ 0.150% through $ZnSO_4$	31.7	32.6	51.0	47.6
7. NPK+0.010% through Zn Metalosate	29.9	24.7	46.0	43.8
8. NPK+0.025% through Zn Metalosate	29.4	25.9	48.4	46.1
9. NPK+ 0.050% through Zn Metalosate	29.7	28.5	49.3	48.4
10. NPK+0.10% through Zn Metalosate	30.4	31.8	54.6	49.7
11. NPK+ 0.025% through Zn- EDTA	29.6	24.8	47.1	43.8
12. NPK+ 0.050% through Zn- EDTA	29.2	28.4	48.4	47.4
CD (P=0.05)	**1.9**	**4.0**	**3.5**	**4.1**

In the second year, significant enhancement in grain Zn concentration of wheat was recorded with standard dose of Zn supplied through either Zn Metalosate or $ZnSO_4$ or Zn-EDTA (Table 9). The application of zinc to soil through conventional zinc source and FYM also has apparently influenced the concentration of zinc. Grain Zn concentration ranged between 17.8 to 26.7 mg kg-1 in maize (Shaktiman 5), 19.1 to 30.0 mg kg-1 in maize (Nath Samrat 1144), 34.1 to 44.8 mg kg-1 in durum wheat (HD 2987) and 27.9 to 38.4 mg kg-1 in aestivum wheat (Lok 1), and 31.2 to 38.9 mg kg-1 in rice (Naveen). However, in maize the treatment 0.1% Zn through Zn Metalosate and 0.15% Zn through ZnSO4 were equally effective in enhancing grain Zn concentration. Lower concentration of these products i.e. 1/10 and ¼ of Zn Metalosate and ½ of ZnSO4 and Zn-EDTA could not increase the Zn concentration in maize. The standard dose of zinc supplied through Zn Metalosate was the best in improving the zinc contents in the durum wheat (HD2987) grains. Application of either of zinc applied either through Zn Metalosate and Zn- EDTA sources could not influence grain Zn concentration in aestivum wheat (Lok1) except 0.10 and 0.15% Zinc supplied through ZnSO4.

Table 9. Grain Zn concentration (mg kg^{-1}) of cereal crops as influenced by different sources of Zinc ($ZnSO_4$, Zn Metalosate and Zn-EDTA) at different locations during second year of study

Treatment	**Rice (Naveen)**	**Maize- wheat**			
		Maize (Shaktiman 5)	**Maize (Nath Samrat1144)**	**Wheat (HD2987)**	**Wheat (Lok 1)**
Location	***Cuttack***	***Bhopal***			
1. NPK	31.20	17.83	19.10	34.09	27.96
2. NPK+ Soil Zn	36.01	23.40	23.31	41.04	33.90
3. NPK+FYM	36.51	23.87	24.33	37.30	29.18
4. NPK+0.050% through $ZnSO_4$	35.67	22.81	21.93	38.99	32.91
5. NPK+0.100% through $ZnSO_4$	36.24	26.74	29.96	41.43	37.22
6. NPK+ 0.150% through $ZnSO_4$	36.44	23.99	30.05	42.83	38.37
7. NPK+0.010% through Zn Metalosate	38.97	21.07	21.77	38.71	27.88
8. NPK+0.025% through Zn Metalosate	36.87	21.16	21.93	40.11	31.87

9. NPK+ 0.050% through Zn Metalosate	37.97	22.75	28.35	41.98	32.49
10. NPK+0.10% through Zn Metalosate	37.83	25.89	29.21	44.80	32.71
11. NPK+ 0.025% through Zn- EDTA	36.86	20.53	21.77	39.80	31.29
12. NPK+ 0.050% through Zn- EDTA	36.53	25.56	25.73	41.18	29.25
CD (P=0.05)	**3.68**	**3.24**	**3.23**	**3.25**	**3.38**

2. Vegetable crops

Similar to cereals, Zn concentration of potato tuber and tomato fruits got influenced to Zn application (Table 10) in the first year. However, magnitude of increase was much higher as compared to cereal crops. In potato tubers, Zn concentration varied from 20.1 to 33.4 mg kg^{-1} while in tomato it ranged from 29.95 to 43.74 mg kg^{-1} under polyhouse conditions and 20.2 to 38.1 mg kg^{-1} under open field conditions (Table 10). The recommended Zn supplied through either of the sources enhanced concentration of Zn in potato tubers with the same pace. However, in tomato, the standard foliar concentration of Zn applied through Zn Metalosate proved much superior in enhancing tomato fruit Zn concentration as compared to standard dose of Zn supplied through Zn sulphate. Among the lower concentration of Zn Metalosate i.e. 1/10, ¼, and ½, the ½ of the standard dose was at par with full dose of Zn supplied through Zn Metalosate.

Table 10. Zn concentration (mg kg^{-1}) of edible parts of vegetable crops as influenced by different sources of Zn ($ZnSO_4$, Zn Metalosate and Zn-EDTA) at different locations during first year of study

Treatment	**Potato (*Kufri Jyoti*)**	**Tomato**	
		Polyhouse (*GS 600*)	**Open field (*Devika*)**
Location	***Palampur***	***New Delhi***	
1. NPK	20.1	29.95^{f}	20.2
2. NPK+ Soil Zn	29.6	37.74^{bcd}	33.2
3. NPK+FYM	24.9	34.12^{def}	21.9
4. NPK+0.050% through $ZnSO_4$	28.7	32.84^{ef}	23.1
5. NPK+0.100% through $ZnSO_4$	31.7	37.26^{bcd}	26.2
6. NPK+ 0.150% through $ZnSO_4$	33.4	39.02^{bc}	36.6
7. NPK+0.010% through Zn Metalosate	24.7	33.63^{def}	31.3
8. NPK+0.025% through Zn Metalosate	25.3	38.90^{bc}	34.0
9. NPK+ 0.050% through Zn Metalosate	27.6	41.24^{ab}	35.1
10. NPK+0.10% through Zn Metalosate	31.3	43.74^{a}	38.1
11. NPK+ 0.025% through Zn- EDTA	25.8	36.13^{cde}	30.6
12. NPK+ 0.050% through Zn- EDTA	28.8	39.25^{bc}	33.0
CD (P=0.05)	**5.3**	**-**	**2.4**

In the second year, Zn concentration varied from 19.8 to 33.4 mg kg^{-1} in potato tubers while in okra it ranged from 28.7 to 38.9 mg kg^{-1} (Table 11). The recommended Zn supplied either through $ZnSO_4$ or Zn Metalosate enhanced concentration of Zn in potato tubers with the same pace.

However, in tomato, 1.5 times higher dose than the standard Zn concentration applied through Zn Metalosate proved comparable in enhancing tomato fruit Zn concentration as compared to standard dose of Zn supplied through Zn Metalosate as well as $ZnSO_4$. Among the lower concentration of Zn Metalosate i.e. ½ and ¼ of the standard dose through any of the sources were at par with each other. However, application of 1/10 dose of zinc supplied by Metalosate significantly decreased the zinc contents in potato tuber. The okra crop zinc contents were also found to improve on supplying standard zinc doses by Zn Metalosate in distinct manner. In general zinc contents in tomato crop improved on application of zinc at all concentrations. The highest zinc concentration was recorded using standard zinc concentration i.e. 0.10% Zn applied through Zn Metalosate followed by FYM to influence the zinc levels in tomato crop (Table 11).

Table 11. Zn concentration (mg kg^{-1}) of edible parts of vegetable crops as influenced by different sources of Zn ($ZnSO_4$, Zn Metalosate and Zn-EDTA) at different locations in the second year of study

Treatment	Potato (*Kufri Jyoti*)	Okra	Tomato Polyhouse (GS 600)
Location	***Palampur***		***New Delhi***
1. NPK	19.83	28.67	27.3
2. NPK+ Soil Zn	31.83	35.88	41.3
3. NPK+FYM	25.41	38.33	49.3
4. NPK+0.050% through $ZnSO_4$	28.87	30.67	34.8
5. NPK+0.100% through $ZnSO_4$	32.15	33.35	40.2
6. NPK+ 0.150% through $ZnSO_4$	34.84	31.54	40.6
7. NPK+0.010% through Zn Metalosate	25.59	31.00	42.0
8. NPK+0.025% through Zn Metalosate	26.43	32.33	48.4
9. NPK+ 0.050% through Zn Metalosate	28.40	33.65	48.7
10. NPK+0.10% through Zn Metalosate	32.65	37.33	51.1
11. NPK+ 0.025% through Zn- EDTA	26.67	29.28	48.2
12. NPK+ 0.050% through Zn- EDTA	29.60	29.67	46.0
CD (P=0.05)	**6.28**	**5.56**	**8.68**

3. Fruit crops

During 2015-16 and 2016-17, the efficacy of Zn Metalosate was evaluated in grape, pomegranate and apple in terms of Zn concentrations in edible plant parts. Perusal of data in Table 12 revealed that application of Zn @ 0.1% through either of sources was equally effective. In general, the Zn concentration varied from 7.8 to 14.2 mg kg^{-1} in grape, 13.0 to 23.2 mg kg^{-1} in pomegranate and 55.0 to 92.0 mg kg^{-1} in apple fruits (Table 12). Basal application of Zn was not effective in enhancing Zn concentration in grape berries and pomegranate fruits. However, apple fruits Zn concentration increased significantly with basal application of Zn and was comparable with treatment received as standard dose of Zn through 3 foliar applications of $ZnSO_4$. The lower concentration of foliar Zn applied through Zn Metalosate i.e. 1/10 and ¼ could not influence Zn concentration in grape berries and pomegranate however, in apple these treatments were effective. Similar results were recorded in the second year of study (Table 13).

Table 12. Fruit Zn concentration (mg kg^{-1}) of fruit crops as influenced by different sources of Zinc ($ZnSO_4$, Zn Metalosate and Zn-EDTA) at different locations during 2015-16

Treatment	Grapes (Dilkush)	Pomegranate (Bhagwa)	Apple (Royal Delicious)
Location	*Bengaluru*		*Palampur*
1. NPK	7.8	13.0	55.0
2. NPK+ Soil Zn	8.8	14.2	82.5
3. NPK+FYM	8.0	13.2	77.8
4. NPK+0.050% through $ZnSO_4$	11.9	18.8	80.1
5. NPK+0.100% through $ZnSO_4$	12.2	20.0	84.5
6. NPK+ 0.150% through $ZnSO_4$	12.4	20.4	92.0
7. NPK+0.010% through Zn Metalosate	9.4	16.8	72.2
8. NPK+0.025% through Zn Metalosate	10.0	17.6	76.4
9. NPK+ 0.050% through Zn Metalosate	13.4	22.2	81.1
10. NPK+0.10% through Zn Metalosate	14.2	23.2	87.0
11. NPK+ 0.025% through Zn- EDTA	10.5	18.2	72.3
12. NPK+ 0.050% through Zn- EDTA	11.2	18.6	75.7
CD (P=0.05)	**5.2**	**7.7**	**4.6**

Table 13. Fruit Zn concentration (mg kg^{-1}) of fruit crops as influenced by different sources of Zinc ($ZnSO_4$, Zn Metalosate and Zn-EDTA) at different locations during 2016-17

Treatment	Grapes (Dilkush)	Pomegranate (Bhagwa)	Apple (Royal Delicious)
Location	*Bengaluru*		*Palampur*
1. NPK	8.39	13.50	70.67
2. NPK+ Soil Zn	9.38	14.48	110.33
3. NPK+FYM	8.85	13.85	103.39
4. NPK+0.050% through $ZnSO_4$	12.09	18.89	106.89
5. NPK+0.100% through $ZnSO_4$	12.26	20.02	112.00
6. NPK+ 0.150% through $ZnSO_4$	12.60	20.46	114.33
7. NPK+0.010% through Zn Metalosate	10.01	16.92	95.26
8. NPK+0.025% through Zn Metalosate	10.26	17.86	99.93
9. NPK+ 0.050% through Zn Metalosate	13.48	22.52	107.00
10. NPK+0.10% through Zn Metalosate	14.57	24.10	120.80
11. NPK+ 0.025% through Zn- EDTA	10.78	18.10	96.46
12. NPK+ 0.050% through Zn- EDTA	11.70	18.70	99.67
CD (P=0.05)	**2.24**	**6.20**	**7.15**

Periodical changes in Zn concentration in leaves

Effect of source and modes of Zn application on periodic changes in Zn content in leaves of tomato grown under polyhouse at different growth stages is presented in Table 14. First sampling of leaves was done before start of 1st foliar spray of Zn and subsequently after about a week of each foliar spray. Results indicated that there was no significant difference in Zn content in tomato leaves across the treatments, except soil application of Zn before first foliar spray. This is because of the fact that no other treatment has received Zn at this stage of crop growth.

Comparison of Zn content in tomato leaves after first spray, soil zinc and treatments like, 0.10% and 0.15% Zn through $ZnSO_4$, 0.050% and 0.10% Zn through Zn Metalosate and 0.050% Zn through Zn- EDTA were equally effective in enhancing leaf Zn content in tomato over no Zn-control. Other treatments, particularly related to foliar spray with lower concentration of Zn were inferior as far as Zn content in tomato leaves was concerned. However, application of lower concentration of Zn through metalosate (i.e. 0.025% Zn) was equally effective in maintaining the Zn concentration in tomato leaves as compared to that maintained by standard rate of Zn application (0.15% Zn) through conventional source i.e. zinc sulphate. This treatment was also at par with foliar spray of Zn through Zn-EDTA (0.025%, and 0.050% Zn). More or less similar trends in Zn content in tomato leaves under different treatments were recorded after second and third sprays as well.

In mango also, Zn supplements were applied starting from the fruit set at 15 days' intervals and leave samples taken after each spray were analyzed for Zn content. Results indicated that there was no significant difference in Zn content in mango leaves across the treatments before first spray, except in the treatment receiving soil application of Zn (Table 15). However, after first spray Zn concentration has increased significantly in all the treatments involving Zn supplements though the magnitude of increase was higher in treatments which received Zn through $ZnSO_4$. After second spray the leaf Zn content has reduced irrespective of the Zn treatment however, highest Zn content remained in leaves supplied with Zn through $ZnSO_4$ foliar feeding. The probable reason of decrease leaf Zn concentration after second spray could be attributed to enhanced translocation of Zn to other plant parts like fruits.

Treatment	Time of sampling			
	Before 1st spray	After 1st spray	After 2nd spray	After 3rd spray
1. NPK	36.21^{b}	23.71^{d}	21.30^{b}	26.45^{e}
2. NPK+ Soil Zn	61.92^{a}	56.42^{a}	39.64^{a}	38.24^{cde}
3. NPK+FYM	40.84^{b}	25.84^{d}	42.07^{a}	32.76^{de}
4. NPK+0.050% through $ZnSO_4$	35.17^{b}	31.17^{cd}	36.62^{ab}	40.34^{bcde}
5. NPK+0.100% through $ZnSO_4$	35.98^{b}	44.48^{abc}	43.33^{a}	46.61^{abcd}

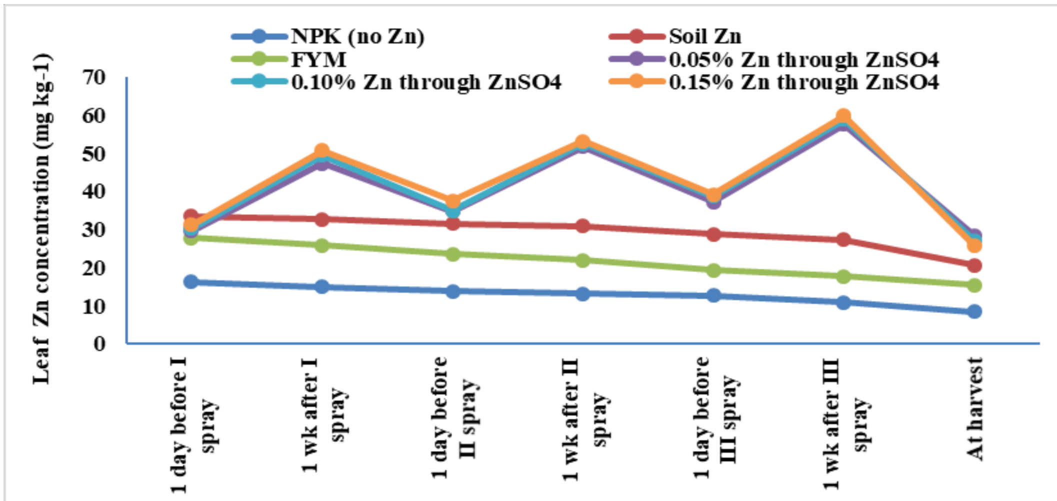
6. NPK+ 0.150% through $ZnSO_4$	40.08^{b}	51.58^{ab}	42.11^{a}	53.02^{abc}
7. NPK+0.010% through Zn Metalosate	36.74^{b}	31.74^{cd}	42.56^{a}	39.63^{bcde}
8. NPK+0.025% through Zn Metalosate	33.21^{b}	42.71^{bc}	41.87^{a}	51.45^{abcd}
9. NPK+ 0.050% through Zn Metalosate	33.60^{b}	47.10^{ab}	45.86^{a}	54.54^{abc}
10. NPK+0.10% through Zn Metalosate	35.00^{b}	55.00^{ab}	52.83^{a}	63.99^{a}
11. NPK+ 0.025% through Zn- EDTA	36.47^{b}	46.47^{ab}	42.02^{a}	51.73^{abc}
12. NPK+ 0.050% through Zn- EDTA	33.45^{b}	53.45^{ab}	46.92^{a}	57.50^{ab}

Cultivar: GS 600, Date of planting: 04-09-2015, Date of spray: 1st (20-1 0-2015), 2nd (05-12-2015 and 3rd (23-2-2016). Values in same column followed by the same letter are not significantly different at 5% probability levels.

Table 15. Periodical changes in leaf Zinc concentration (mg kg^{-1}) of mango as influenced by different sources of Zinc ($ZnSO_4$, Zn Metalosate and Zn-EDTA) at Lucknow

Treatment	Time of sampling		
	Before 1st spray	After 1st spray	After 2nd spray
1. NPK	17.0	23.0	21.0
2. NPK+ Soil Zn	24.0	46.0	37.0
3. NPK+FYM	20.0	35.0	31.0
4. NPK+0.050% through $ZnSO_4$	19.0	52.0	44.0
5. NPK+0.100% through $ZnSO_4$	21.0	53.0	38.0
6. NPK+ 0.150% through $ZnSO_4$	18.0	54.0	43.0
7. NPK+0.010% through Zn Metalosate	17.0	42.0	29.0
8. NPK+0.025% through Zn Metalosate	19.0	38.0	31.0
9. NPK+ 0.050% through Zn Metalosate	17.0	56.0	35.0
10. NPK+0.10% through Zn Metalosate	18.0	41.0	36.0
11. NPK+ 0.025% through Zn- EDTA	19.0	42.0	26.0
12. NPK+ 0.050% through Zn- EDTA	17.0	37.0	25.0
CD (P=0.05)	**5.2**	**9.3**	**9.3**

Similar to tomato and mango crops, the Zn concentration in grape petioles and pomegranate leaves also followed the same trend where incremental effect of Zn supplements through foliar feeding was observed. The comparative graphical representations are depicted in figures 7 and 8. As evident from the figures, the Zn concentration in grape petiole and pomegranate leaves was maintained higher irrespective of treatments over no Zn control. A consistent increase in Zn concentration in grape petiole and pomegranate leaves was observed before harvest stage however, it declined at harvest stage as some of the absorbed Zn might have translocated to berries and fruits.



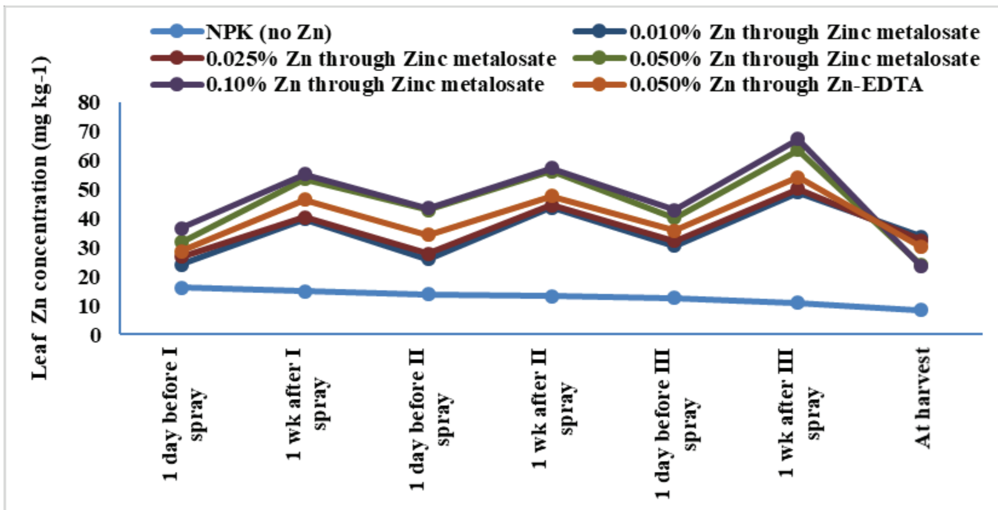
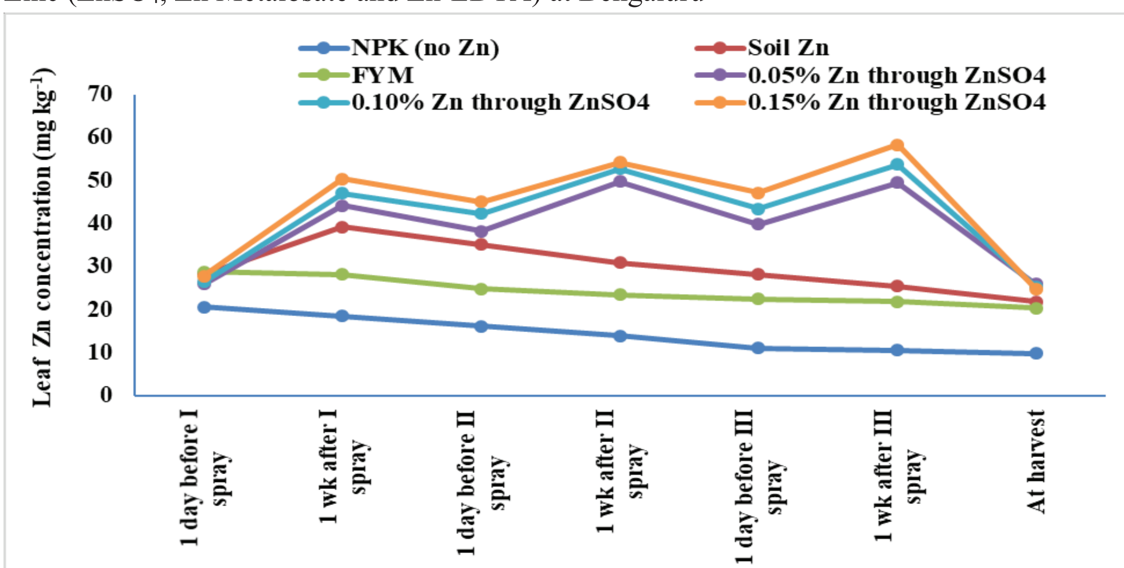


Figure 7. Zinc concentration (mg kg^{-1}) in grape petiole as influenced by different sources of Zinc ($ZnSO_4$, Zn Metalosate and Zn-EDTA) at Bengaluru



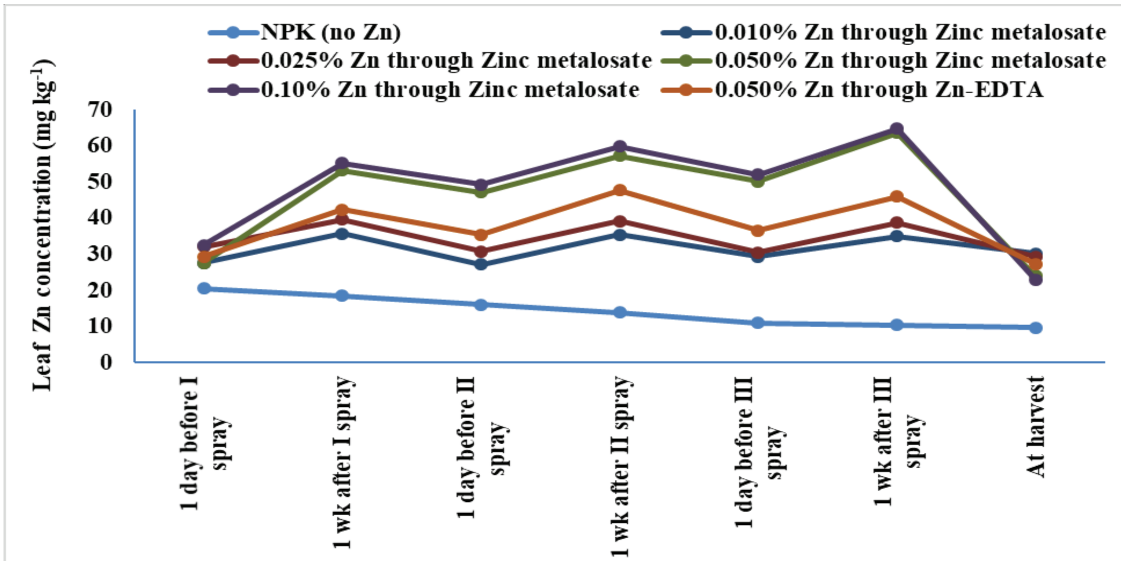


Figure 8. Zinc concentration (mg kg^{-1}) in pomegranate leaves as influenced by different sources of Zinc ($ZnSO_4$, Zn Metalosate and Zn-EDTA) at Bengaluru

Effect of source and modes of Zn application on Zn content in tomato leaves at different growth stages is presented in Table 16 for second year of study. Results indicated that, there was no significant difference in Zn content in tomato leaves across the treatments except soil application of Zn before starting of foliar spray. Zinc contents in tomato leaves improved on foliar spray of zinc and higher zinc content is noted in all treatments to more or less extents. However, there was no change in zinc concentration of leaves when the product Zn Metalosate was supplied at the $^{1}/_{10}$ times the standard zinc dose. But, foliar spray of standard Zn applied @ 0.10% through Zn Metalosate has maximized the zinc content in tomato from 37.8 to 58.7 mg kg^{-1}. The leaf zinc concentrations of capsicum leave after spray is indicated in Table 16.

Table 16. Periodical changes in leaf Zn concentration (mg kg^{-1}) of tomato and capsicum under polyhouse as influenced by different sources of Zn ($ZnSO_4$, Zn Metalosate and Zn-EDTA) at New Delhi

Treatment	Time of sampling		
	Tomato Polyhouse (GS 600)		Capsicum
	Before spray	After spray	After spray
1. NPK	37.2	30.0	157.0
2. NPK+ Soil Zn	44.7	52.2	182.3
3. NPK+FYM	39.9	36.0	129.0
4. NPK+0.050% through $ZnSO_4$	36.7	40.4	516.0
5. NPK+0.100% through $ZnSO_4$	37.3	44.4	611.0
6. NPK+ 0.150% through $ZnSO_4$	36.3	53.3	725.7
7. NPK+0.010% through Zn Metalosate	39.0	39.3	217.0
8. NPK+0.025% through Zn Metalosate	38.7	43.3	495.7
9. NPK+ 0.050% through Zn Metalosate	35.3	47.5	791.0

10. NPK+0.10% through Zn Metalosate	37.8	58.7	1321.3
11. NPK+ 0.025% through Zn- EDTA	36.8	46.9	722.3
12. NPK+ 0.050% through Zn- EDTA	35.0	49.9	696.7
CD (P=0.05)	**7.47**	**10.45**	**33.38**

In mango, Zn supplements were applied starting from the fruit set at 15 days' intervals and leaf samples taken after each spray were analysed for Zn content. Results indicated that there was a significant difference in Zn content in mango leaves across the treatments before first spray and a notably higher zinc content was recorded in the treatment of FYM, standard dose of Zn supplied through $ZnSO_4$ (Table 17). However, zinc supplied through Zn Metalosate @0.050% Zn was at par with Zn-EDTA @ 0.025 % concentration of zinc in improving mango leaf contents. After first spray, Zn concentration has increased significantly in all the treatments involving Zn supplements though the magnitude of increase was higher in treatments which received Zn through $ZnSO_4$. After second spray the leaf Zn content has improved irrespective of the Zn treatment except in control and ½ and standard dose of Zn applied through $ZnSO_4$.However, highest Zn content remained in leaves supplied with standard Zn supplied through $ZnSO_4$ as well as in half and standard Zn Metalosate foliar feeding. Increased leaf Zn concentration after second spray could be attributed by augmented assimilation of Zn after a couple of sprays.

Table 17. Periodical changes in leaf Zinc concentration (mg kg^{-1}) of mango as influenced by different sources of Zinc ($ZnSO_4$, Zn Metalosate and Zn-EDTA) at Lucknow

Treatment	**Time of sampling**		
	Before 1st spray	**After 1st spray**	**After 2nd spray**
1. NPK	23.0	27.0	24.0
2. NPK+ Soil Zn	19.0	24.0	28.0
3. NPK+FYM	26.0	35.0	23.0
4. NPK+0.050% through $ZnSO_4$	20.0	33.0	26.0
5. NPK+0.100% through $ZnSO_4$	27.0	38.0	48.0
6. NPK+ 0.150% through $ZnSO_4$	23.0	36.0	41.0
7. NPK+0.010% through Zn Metalosate	18.0	28.0	32.0
8. NPK+0.025% through Zn Metalosate	21.0	34.0	44.0
9. NPK+ 0.050% through Zn Metalosate	24.0	40.0	47.0
10. NPK+0.10% through Zn Metalosate	20.0	31.0	54.0
11. NPK+ 0.025% through Zn- EDTA	25.0	27.0	41.0
12. NPK+ 0.050% through Zn- EDTA	18.0	30.0	37.0
CD (P=0.05)	**5.2**	**6.2**	**7.3**

Zn concentration in grape petioles and pomegranate leaves also followed the same trend where incremental effect of Zn supplements through foliar feeding was observed. The comparative graphical representations are depicted in figures 9 and 10. As evident from the figures, the Zn concentration in grape petiole and pomegranate leaves was maintained higher irrespective of treatments over no Zn control. Slight decrease in zinc content is evident in between the time interval of the consecutive sprays. A consistent increase in Zn concentration in grape petiole and pomegranate leaves was observed before harvest stage. However, it declined at harvest stage as some of the absorbed Zn might have translocated to berries and fruits on maturation.

In particular, on application of foliar spray, zinc content in maize straw increased invariably till harvesting stage (Figure 11). FYM and soil zinc applied plots recorded higher in straw zinc contents prior to spray due to soil incorporated zinc. The higher zinc contents were recorded in the treatments with higher zinc doses although there was no initial supply of zinc. The zinc content in straw was in the order: *Before Spray <After Ist Spray≤ After IInd Spray > at Harvest*. Before spray, maximum zinc content in straw was registered with the application of standard zinc supplied through 0.10% through Zn Metalosate comparable to its half concentration supplied through Zn-EDTA. After first spray, a gradual increment in zinc doses and thereby in the zinc contents of straw were followed. On increasing zinc contents either through $ZnSO_4$, Zn Metalosate and Zn-EDTA, higher zinc has accumulated in the straw, however, the magnitude was greater using $ZnSO_4$ foliar feeding at standard and 1.5 times higher doses. Foliar feeding of $ZnSO_4$ and Zn-EDTA @0.05% Zn was at par with Zn Metalosate @0.10% Zn. After second spray, $ZnSO_4$@ 0.05 and 0.10% Zn concentration of Zn-EDTA was found better than the lower concentrations of Zn Metalosate, however, a better straw zinc was found with its half and standard concentration as well as $ZnSO_4$ @0.15 % Zn supply. At harvest, a decline in zinc concentration of straw is found due to translocation of zinc to the other plant parts.

In wheat var. HD2987, Zn supplements were applied starting from 30 DAS and straw samples taken after each spray was analyzed for Zn content. In general, a gradual increased zinc content of the wheat straw was recorded on applying 1st and 2nd spray of zinc either through $ZnSO_4$, Zn Metalosate or Zn-EDTA (Figure 12). After second spray of zinc, the succeeding plant parts might have got the supply of zinc from straw as the plant was blooming towards its grand growth stage, thereby lowering the zinc contents in the straw. At harvest stage, the zinc contents in the straw further declines comparably with that before the spray were applied. The spray of zinc through $ZnSO_4$, Zn Metalosate and Zn-EDTA improved the zinc uptake of straw as higher zinc content was recorded in these treatments.

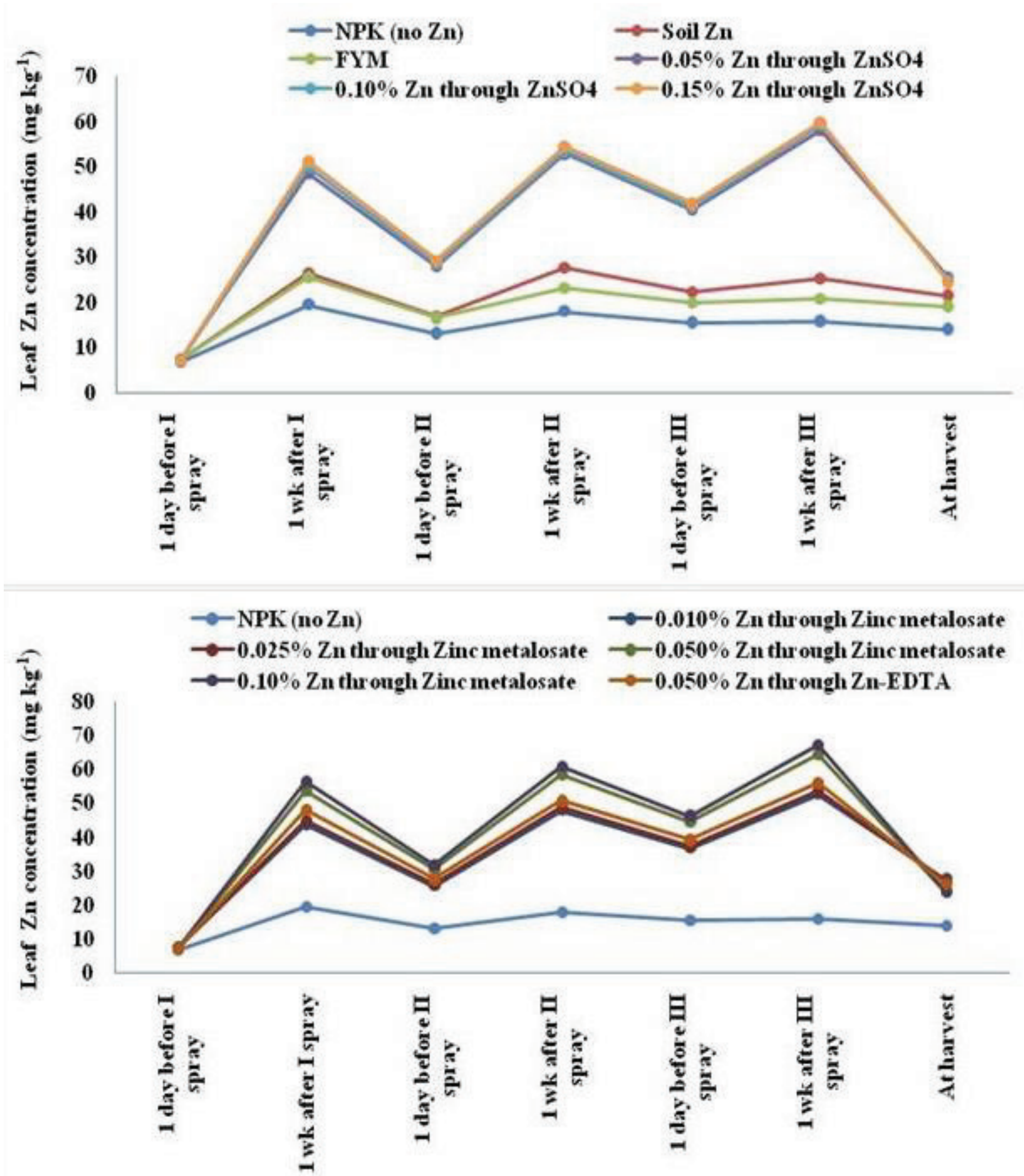
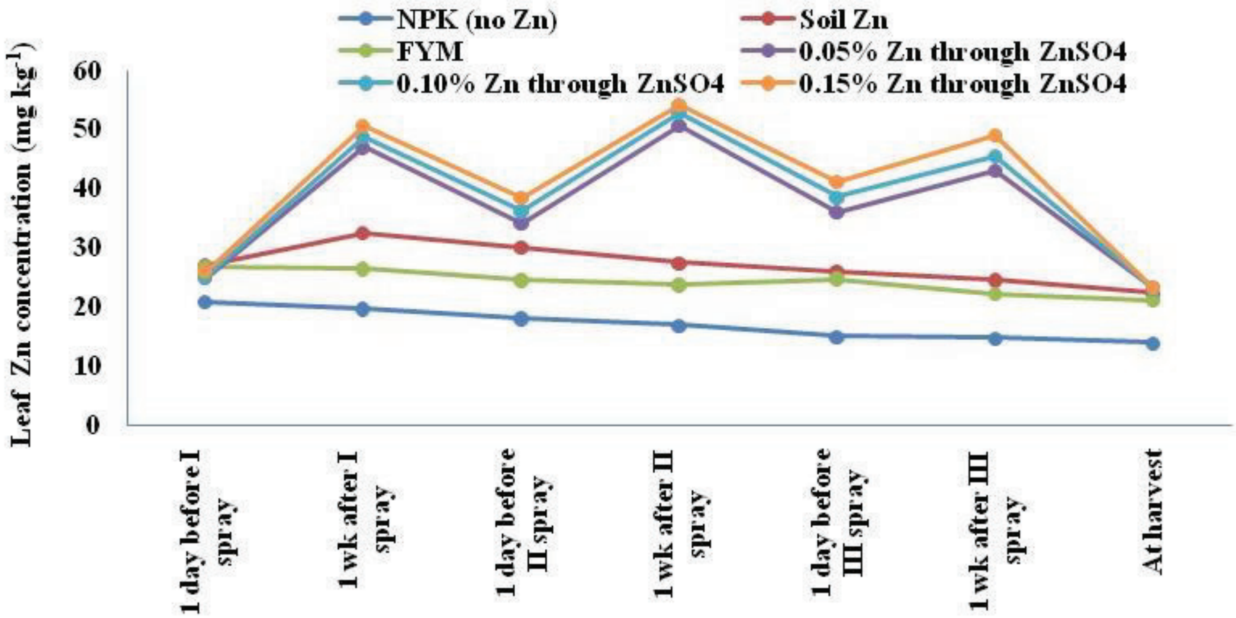


Figure 9. Zinc concentration (mg kg $^{-1}$) in grape petiole as influenced by different sources of Zinc ($ZnSO_4$, Zn Metalosate and Zn-EDTA) at Bengaluru



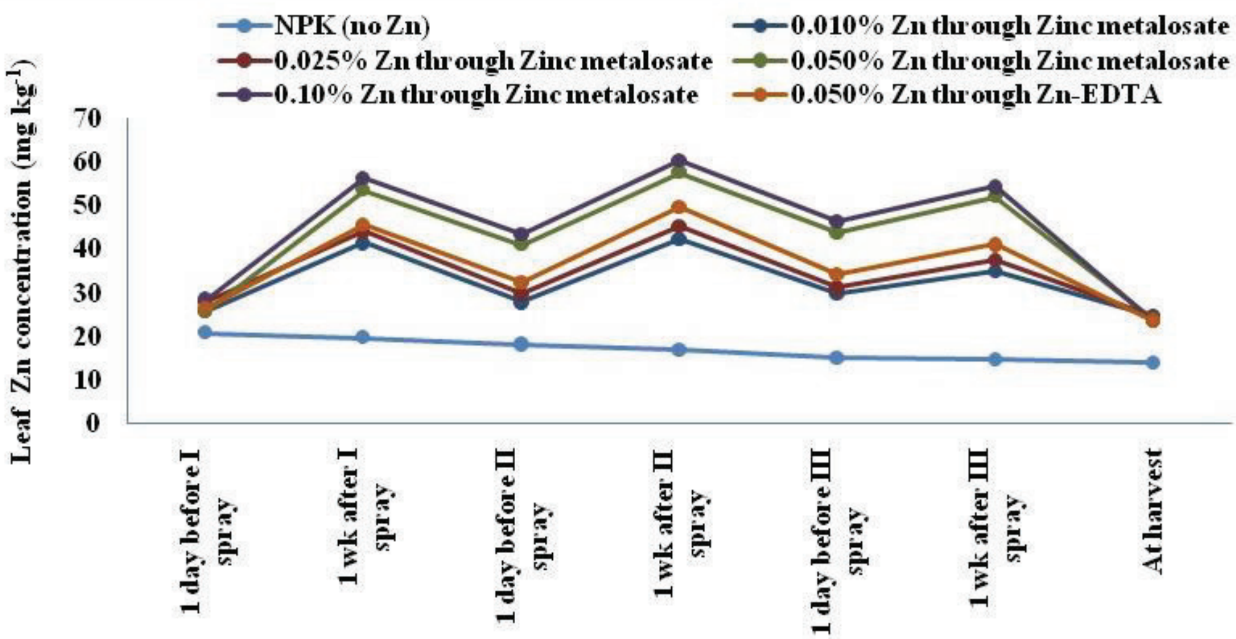
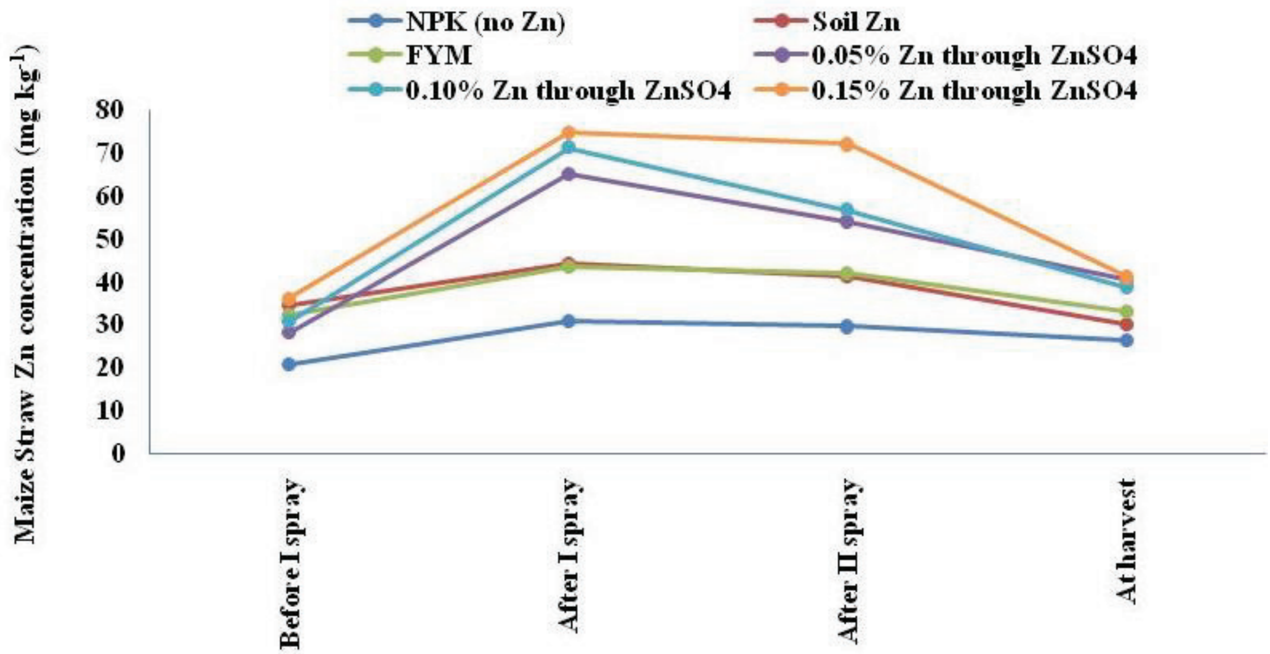


Figure 10. Zinc concentration (mg kg^{-1}) in pomegranate leaves as influenced by different sources of Zinc ($ZnSO_4$, Zn Metalosate and Zn-EDTA) at Bengaluru

The highest zinc content in wheat straw was registered with Zn supplied @ 0.1 and 0.15 % through $ZnSO_4$ after 2^{nd} and 3^{rd} spray in contrast to the highest straw content using Zn Metalosate @0.10% after 1^{st} spray. Decreased zinc content was noted in the wheat straw at harvest stage.



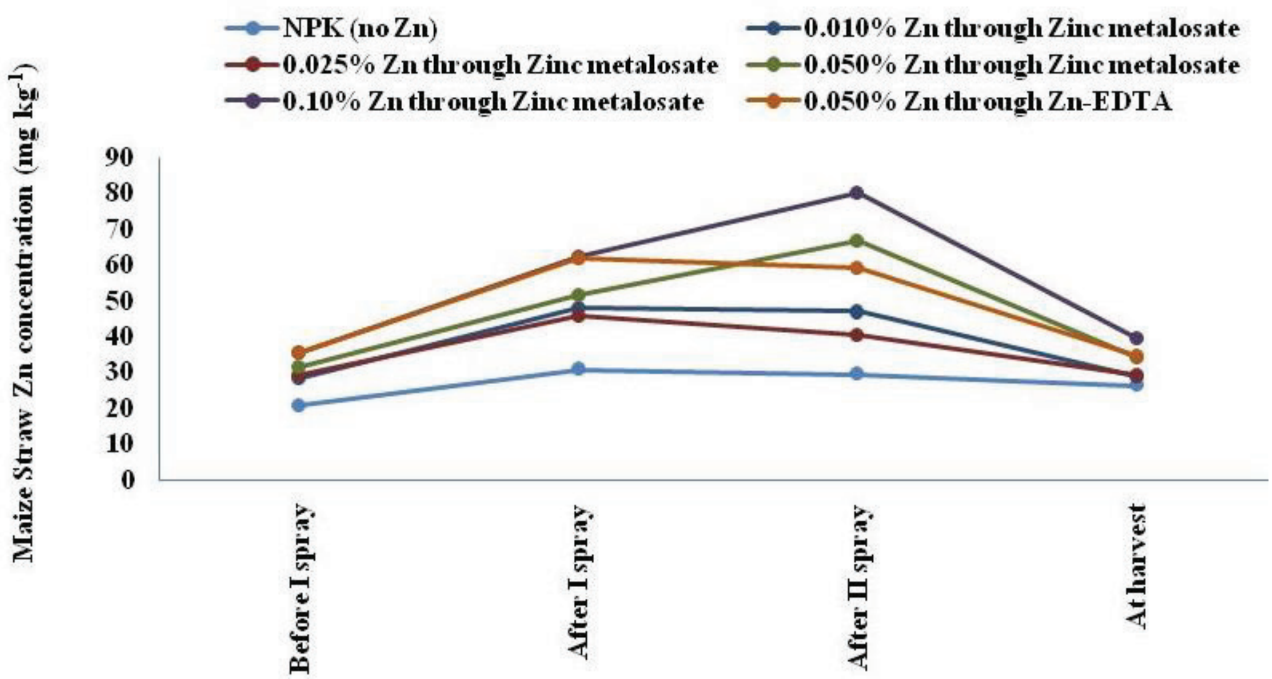
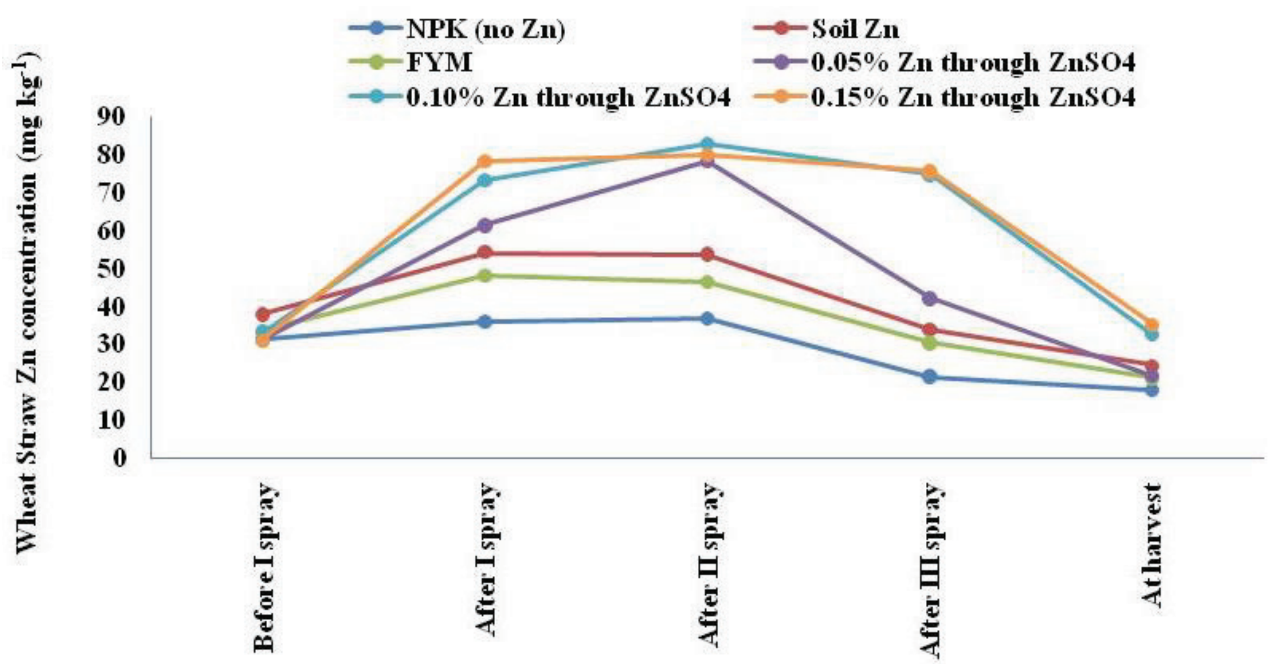


Figure 11. Zinc concentration (mg kg $^{-1}$) in maize straw as influenced by different sources of Zinc ($ZnSO_4$, Zn Metalosate and Zn-EDTA) at Bhopal



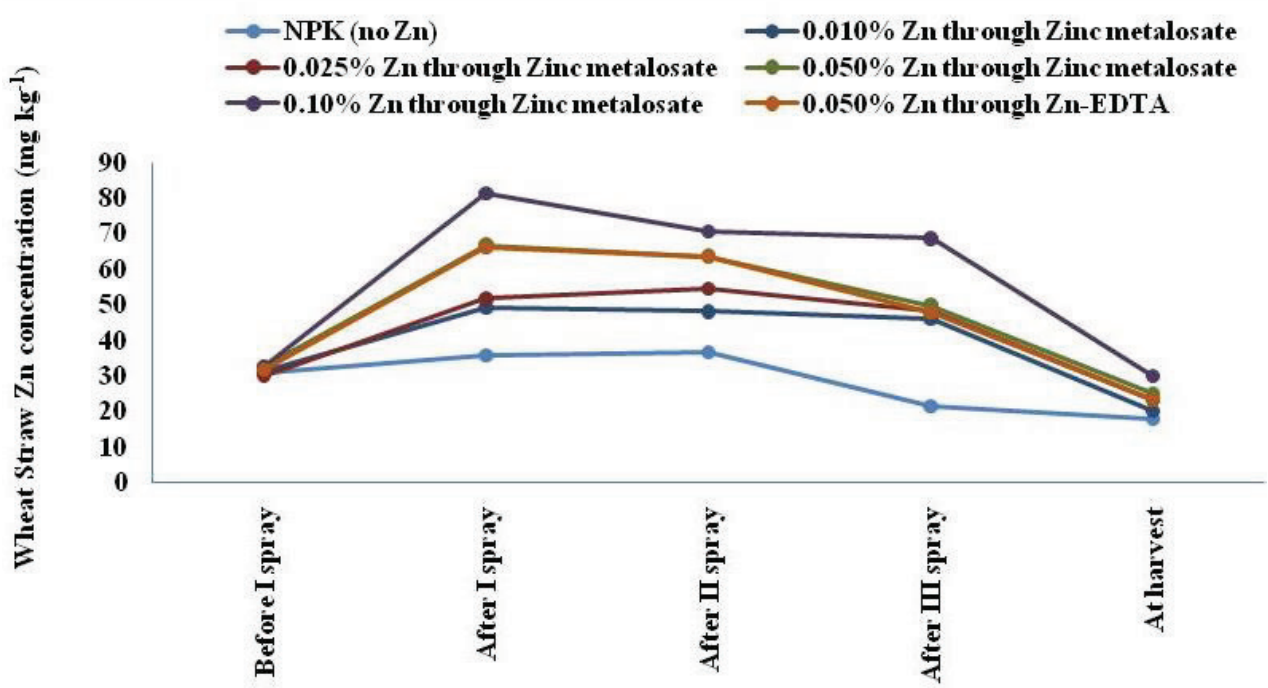


Figure 12. Zinc concentration (mg kg $^{-1}$) in wheat straw as influenced by different sources of Zinc ($ZnSO_4$, Zn Metalosate and Zn-EDTA) at Bhopal

Quality parameters

During both the years of study, fruit quality traits of some fruit crops like mango and grapes were analysed to measure the influence of Zn supplements on traits. Results presented in Table 18 indicated an increasing trend with respect to Total Soluble Solids (TSS), ascorbic acid, carotenoids and total sugar in mango fruits with the increasing concentrations of various zinc supplements. Most of these parameters showed significant increase over control. Quantitatively, TSS varied from 20.05 to 22.60 Brix, acidity from 0.06 to 0.12%, ascorbic acid from 20.16 to

46.75 mg/100g, carotenoids from 1.83 to 3.89 mg/100g and total sugar from 16.3 to 18.85% in different treatments. Application of graded doses of Zn Metalosate application has increased ascorbic acid and carotenoids content and decreased titrable acidity. As far as TSS and Total sugar is concerned, the effect of Zn was comparable irrespective of the sources.

Table 18. Quality parameters of mango as influenced by different sources of Zinc ($ZnSO_4$, Zn Metalosate and Zn-EDTA) at Lucknow

Treatment	TSS (Brix)	Acidity (%)	Ascorbic acid (mg/100g)	Carotenoids (mg/100g)	Total sugar (%)
1. NPK	20.05	0.12	27.49	1.83	16.30
2. NPK+ Soil Zn	22.15	0.09	31.16	2.31	17.82
3. NPK+FYM	20.35	0.08	29.33	1.89	16.45
4. NPK+0.050% through $ZnSO_4$	20.00	0.11	31.16	2.91	16.45
5. NPK+0.100% through $ZnSO_4$	22.20	0.11	32.08	3.62	16.70
6. NPK+ 0.150% through $ZnSO_4$	22.30	0.09	42.16	3.89	17.82
7. NPK+0.010% through Zn Metalosate	20.45	0.10	20.16	2.16	16.42
8. NPK+0.025% through Zn Metalosate	22.20	0.08	25.08	2.48	17.77
9. NPK+ 0.050% through Zn Metalosate	22.60	0.08	45.83	2.98	18.52
10. NPK+0.10% through Zn Metalosate	22.15	0.06	46.75	3.41	18.85
11. NPK+ 0.025% through Zn- EDTA	20.90	0.10	24.74	1.91	16.70
12. NPK+ 0.050% through Zn- EDTA	22.55	0.09	31.16	3.61	18.20
CD (P=0.05)	**1.50**	**0.07**	**4.20**	**0.30**	**1.46**

The results presented in Table 19 indicated that in grape berries also, significantly higher TSS (14.00 Brix) and total sugars (14.90%) were recorded in treatment which received 0.10% through Zn Metalosate followed by the immediately lower dose of Zn Metalosate (12.53 Brix and 13.28%, respectively). Significantly higher titrable acidity content was recorded in no Zn control (0.76 %) while titrable acidity percentage was recorded least in treatment which received 0.10% through Zn Metalosate (0.36%).

Table 19. Quality parameters of grape as influenced by different sources of Zinc ($ZnSO_4$, Zn Metalosate and Zn-EDTA) at Bengaluru

Treatment	TSS (Brix)	Total sugars (%)	Titrable Acidity (%)
1. NPK	10.87	11.51	0.76
2. NPK+ Soil Zn	12.27	12.99	0.56
3. NPK+FYM	12.00	12.94	0.65
4. NPK+0.050% through $ZnSO_4$	13.60	14.15	0.60
5. NPK+0.100% through $ZnSO_4$	13.53	14.30	0.58
6. NPK+ 0.150% through $ZnSO_4$	13.67	14.47	0.57
7. NPK+0.010% through Zn Metalosate	12.53	13.28	0.63

8. NPK+0.025% through Zn Metalosate	13.20	13.98	0.62
9. NPK+ 0.050% through Zn Metalosate	13.80	14.40	0.42
10. NPK+0.10% through Zn Metalosate	14.00	14.90	0.36
11. NPK+ 0.025% through Zn- EDTA	12.93	14.05	0.59
12. NPK+ 0.050% through Zn- EDTA	13.33	14.05	0.60
CD (P=0.05)	**0.35**	**0.49**	**0.08**

Ripe mango fruits were analyzed for enzymatic activities in response to Zn supplements are presented in Table 20. Enzyme activities and protein content increased significantly with application of Zn. Amylase activities were influenced most when Zn was supplied through Zn-EDTA followed by $ZnSO_4$ and Zn Metalosate. However, Invertase activities were noted the highest when Zn was supplied through basal application followed by treatment receiving 5 t FYM and 0.025% Zn-EDTA and 0.025 Zn Metalosate. The poly phenol oxidase activity was higher with ZnSO4 treatment as compared to Zn supplied through Zn Metalosate and Zn-EDTA. Similar to Invertase, SOD activities were better with treatment receiving standard dose of Zn through ZnSO4 followed by Zn Metalosate. Protein content did not show any pattern with application of Zn through either of the sources.

Table 20. Enzyme and protein activities in mango fruits as influenced by different sources of Zinc ($ZnSO_4$, Zn Metalosate and Zn-EDTA) at Lucknow

Treatment	Amylase	Invertase	PPO	SOD	Protein
1. NPK	0.36	40.19	0.002	2.96	0.85
2. NPK+ Soil Zn	1.07	65.16	0.008	2.73	0.80
3. NPK+FYM	1.30	58.10	0.018	2.05	0.65
4. NPK+0.050% through $ZnSO_4$	0.39	3.89	0.008	2.72	0.51
5. NPK+0.100% through $ZnSO_4$	1.51	39.14	0.004	2.87	0.56
6. NPK+ 0.150% through $ZnSO_4$	0.75	26.98	0.016	1.52	0.67
7. NPK+0.010% through Zn Metalosate	1.34	44.30	0.014	2.30	0.63
8. NPK+0.025% through Zn Metalosate	0.10	50.58	0.012	1.96	0.51
9. NPK+ 0.050% through Zn Metalosate	1.10	43.95	0.008	2.54	0.73
10. NPK+0.10% through Zn Metalosate	0.40	29.98	0.020	1.29	0.87
11. NPK+ 0.025% through Zn- EDTA	1.68	55.33	0.002	2.38	0.51
12. NPK+ 0.050% through Zn- EDTA	0.67	48.58	0.004	2.28	0.74
CD (P=0.05)	**0.28**	**0.36**	**0.008**	**0.17**	**0.03**

Amylase in mg starch hydrolyzed/mg protein; Invertase in µg sugar formed/mg protein; Polyphenol Oxidase (PPO) in ΔOD/ 100 mg fresh weight; Superoxide Dismutase (SOD) in EU/mg protein; Protein in mg/100 mg tissue.

During second year of study, Total Soluble Solids varied from 18.00 to 20.37 Brix, acidity from 0.14 to 0.26%, ascorbic acid from 9.16 to 22.91 mg/100g, carotenoids from 3.62 to 9.41 mg/100g and total sugar from 16.34 to 18.89% under different treatments (Table 21). Application of graded doses of Zn Metalosate application has increased ascorbic acid and carotenoids content and decreased titrable acidity. As far as TSS and Total sugar is concerned, the effect of Zn was comparable irrespective of the sources.

Table 21. Quality parameters of mango as influenced by different sources of Zinc ($ZnSO_4$, Zn Metalosate and Zn-EDTA) at Lucknow

Treatment	TSS (Brix)	Acidity (%)	Ascorbic acid (mg/100g)	Carote noids (mg/100g)	Total sugar (%)
1. NPK	18.00	0.18	9.16	3.62	16.34
2. NPK+ Soil Zn	18.00	0.16	11.91	4.27	16.43
3. NPK+FYM	19.27	0.23	13.74	4.30	18.10
4. NPK+0.050% through $ZnSO_4$	18.50	0.19	14.66	7.41	16.75
5. NPK+0.100% through $ZnSO_4$	19.75	0.24	15.58	3.72	17.75
6. NPK+ 0.150% through $ZnSO_4$	20.37	0.24	16.49	5.81	18.97
7. NPK+0.010% through Zn Metalosate	19.30	0.20	16.52	4.95	16.46
8. NPK+0.025% through Zn Metalosate	19.50	0.14	20.16	6.31	16.80
9. NPK+ 0.050% through Zn Metalosate	20.37	0.26	21.99	8.20	19.01
10. NPK+0.10% through Zn Metalosate	20.25	0.18	16.49	9.41	18.50
11. NPK+ 0.025% through Zn- EDTA	18.30	0.19	13.74	5.41	16.90
12. NPK+ 0.050% through Zn- EDTA	18.35	0.22	22.91	7.15	18.89
CD (P=0.05)	**1.80**	**0.06**	**4.10**	**0.29**	**1.60**

In grape berries also, significantly higher TSS (15.10 Brix) and total sugars (15.75%) were recorded in treatment which received 0.10% through Zn Metalosate followed by the immediately lower dose of Zn Metalosate (12.53 Brix and 13.28%, respectively) (Table 22). Significantly higher titrable acidity content was recorded in no Zn control (0.72 %) while titrable acidity percentage was recorded least in treatment which received 0.10% through Zn Metalosate (0.30%).

Table 22. Quality parameters of grape as influenced by different sources of Zinc ($ZnSO_4$, Zn Metalosate and Zn-EDTA) at Bengaluru

Treatment	TSS (◦ Brix)	Total sugars (%)	Titrable Acidity (%)
1. NPK	12.99	13.05	0.72
2. NPK+ Soil Zn	13.57	13.69	0.62
3. NPK+FYM	13.48	13.61	0.64
4. NPK+0.050% through $ZnSO_4$	13.95	14.39	0.49
5. NPK+0.100% through $ZnSO_4$	14.05	14.43	0.45
6. NPK+ 0.150% through $ZnSO_4$	14.12	14.52	0.49
7. NPK+0.010% through Zn Metalosate	13.62	13.82	0.60
8. NPK+0.025% through Zn Metalosate	13.79	14.13	0.54

9. NPK+ 0.050% through Zn Metalosate	14.60	15.09	0.40
10. NPK+0.10% through Zn Metalosate	15.10	15.75	0.30
11. NPK+ 0.025% through Zn- EDTA	13.68	14.00	0.57
12. NPK+ 0.050% through Zn- EDTA	13.89	14.21	0.52
CD (P=0.05)	0.50	0.55	0.09

Ripe mango fruits were analyzed for enzymatic activities in response to Zn supplements (Table 23). Enzyme activities and protein content increased significantly with application of Zn. Highest amylase enzyme concentration was noted using $ZnSO_4$ @0.10% followed by Zn Metalosate and $ZnSO_4$ at its half i.e. 0.050% concentration. The magnitude of increment in invertase contents was higher with all other treatments than application of Zn Metalosate at standard dose. However, Invertase activities were noted the highest when half dose of Zn was supplied through Zn Metalosate comparable to its ¼ dose. The poly phenol oxidase activity was higher with $ZnSO_4$ treatment as compared to Zn supplied through Zn Metalosate and Zn-EDTA. Increase in PPO suggests that there is higher phenol content of the of mango fruit in the concerned treatment. Although, Highest SOD activity was noted with no Zn applications i.e. control, $ZnSO_4$, Zn

Metalosate and Zn- EDTA were the potent enhancers of SOD contents. SOD activity was observed more with $ZnSO_4$ than Zn Metalosate at same applied doses. Protein content did not show any pattern with application of Zn through either of the sources.

Table 23. Enzyme and protein activities in mango fruits as influenced by different sources of Zinc ($ZnSO_4$, Zn Metalosate and Zn-EDTA) at Lucknow

Treatment	Amylase	Invertase	PPO	SOD	Protein
1. NPK	0.055	15.04	0.074	5.56	0.94
2. NPK+ Soil Zn	0.013	30.52	0.056	1.96	0.98
3. NPK+FYM	0.016	50.62	0.064	2.29	1.11
4. NPK+0.050% through $ZnSO_4$	0.073	66.14	0.053	1.66	0.79
5. NPK+0.100% through $ZnSO_4$	0.102	57.26	0.039	2.27	0.73
6. NPK+ 0.150% through $ZnSO_4$	0.048	66.30	0.052	1.96	0.72
7. NPK+0.010% through Zn Metalosate	0.037	80.56	0.023	1.76	0.67
8. NPK+0.025% through Zn Metalosate	0.020	96.33	0.038	1.38	0.82
9. NPK+ 0.050% through Zn Metalosate	0.092	95.62	0.045	1.74	0.72
10. NPK+0.10% through Zn Metalosate	0.054	32.71	0.052	2.38	0.78
11. NPK+ 0.025% through Zn- EDTA	0.017	39.38	0.027	1.45	0.64
12. NPK+ 0.050% through Zn- EDTA	0.015	43.81	0.048	1.88	0.78
CD (P=0.05)	**0.003**	**1.653**	**0.010**	**1.65**	**0.03**

Amylase in mg starch hydrolyzed/mg protein; Invertase in µg sugar formed/mg protein; Polyphenol Oxidase (PPO) in ΔOD/100 mg fresh weight; Superoxide Dismutase (SOD) in EU/mg protein; Protein in mg/100 mg tissue.

3.B. EVALUATION OF EFFICACY OF METALOSATE® BORON

The field experiments were conducted to evaluate the performance of boron metalosate against the standard sources of B (borax and boric acid) on fruit (grape, pomegranate, mango and apple), vegetable (cauliflower and tomato) and cereal (rice, wheat and maize) crops at GKVK, Bengaluru (Karnataka), ICAR-IARI, New Delhi, ICAR-CISH, Lucknow (UP), CSKHPKV, Palampur (HP), ICAR-NRRI, Cuttack (Odisha) and ICAR-IISS, Bhopal (MP) under the aegis of All India Coordinated Research Project on Micro-and Secondary Nutrients and Pollutant Elements in Soils and Plants during the year 2015-16 and 2016-17. The details of experimentation and results presented below.

Evaluation material

Boron metalosate was evaluated for different crops and cropping systems with respect to yield, and its use efficiency in comparison to standard B sources i.e. Borax and Boric acid. The Materials Specifications of Boron Metalosate are mentioned below:

Metalosate® Boron	**(5.0%B)**
Proprietary Blend of	Boron derived from disodium octaborate
Approx. % by WT	100%
Physical state	Liquid
Colour	Clear
Odour	Odourless
pH	8.0-9.0 (1% distilled water)
Melting point and Boiling point	Not available
Density	1.10 – 1.23 g/mL
Solubility in water	Water soluble
The above specifications are given on an indicative basis only.	

Experiments were conducted cereal crops (rice, wheat, maize), vegetable crops (tomato, potato) and fruit crops (mango, grapes, pomegranate) at six locations across the country. The details of crops and Cooperating centers are mentioned below.

Crop/ Cropping system	**Cooperating Centre**
1. Rice- Rice	ICAR-NRRI, Cuttack
2. Tomato, Capsicum	ICAR-IARI, New Delhi
3. Grapes, Pomegranate	GKVK, Bengaluru
4. Apple, Cauliflower	CSKHPKV, Palampur
5. Mango and Basic and biochemical studies	ICAR-CISH, Lucknow/ LU, Lucknow
6. Maize-Wheat	ICAR-IISS, Bhopal

Treatment Details

Evaluation material : **Boron Metalosate 5.0% B**

Experimental design : RBD

Replications : 3 (minimum)

Treatments : 12

Frequency of spray : 2

Treatments details : Same for both the crops except treatment no 2 & 3, where succeeding crops will be grown with NPK only

S. No.	Details	B added in each application (g)	Total B added (g)	Total product added (g)
T_1	NPK	0	0	-
T_2	NPK + Soil B through borax	1500	1500	15000
T_3	NPK + FYM	0	0	-
T_4	NPK + FS of 0.017% B through Boric acid	85	255	1500
T_5	NPK + FS of 0.034% B through Boric acid	170	510	3000
T_6	NPK + FS of 0.051% B through Boric acid	255	765	4500
T_7	NPK + FS of 0.0034% B through B Metalosate	17	51	1020
T_8	NPK + FS of 0.0085% B through B Metalosate	42.5	127.5	2550
T_9	NPK + FS of 0.017% B through B Metalosate	85	255	5100
T_{10}	NPK + FS of 0.034% B through B Metalosate	170	510	10200
T_{11}	T_8 + FS of 0.025% Zn through Zn Metalosate	42.5+ 125*	127.5	2550
T_{12}	T_9 + FS of 0.05% Zn through Zn Metalosate	85.0 + 250*	255	51100
FS= Foliar Spray; *quantity of Zn Metalosate				

Note:

- Spray volume for each hectare area is kept as 500 L. Any change in spray volume will have consequent bearing on the B supplied in each spray (g) and Requirement of product for each spray (g).
- T5 is the recommended practice i.e. 0.2% boric acid which supplies 0.034% B while T4 = ½ of T5 and T6 =1.5 times of T5.
- T10 is the equivalent dose of B adopted in T5 while T9 = ½ of T10; T8 = ¼ of T10; T7 = 1/10 of T10.
- Spray should be done at critical growth stages.

Observations taken:

i. Collection of representative surface soil (0-15 cm) samples before the application of fertilizers (treatments) and sowing of crops and post-harvest of crops from each plot (36 plots) of the experiment. Analysis of initial soil samples for pH, EC, $CaCO_3$, OC, available N, P, K, S, Zn, Cu, Fe, Mn, B and of the post-harvest soil samples for N, P, K, S, Zn and B.

ii. Initial concentration of Zn, B and other micronutrients of seed/ planting materials, if applicable.

iii. Chemical analysis for N, P, K, S, Zn, B, Cd, Pb and F of all input materials (evaluation materials i.e. B Metalosate, organic manure and irrigation water).

iv. Analysis of plant samples (tissue concentration analysis) one day before spray and one week after each spray as well as after harvest.

v. Yield attributing characteristics of crops and total above ground biomass and economic yield.

vi. Analysis of related quality parameters.

vii. Nutrient use efficiency of applied nutrients for all the treatments.

viii. Economics (additional profit or BC ratio).

Note: Some of the observations were taken during the experiments in first year however, some computational observations shall be performed at the end of the second year experiments.

Initial properties of soil at different centers

The initial soil samples from the fields where crops were grown, were processed and analysed for different fertility parameters, using standard analytical procedures as indicates below:

Parameters	**Method/ Reagents**
Soil pH and electrical conductivity	1:2.5 soil-water suspension
Soil organic carbon (SOC)	Wet-oxidation (Walkley and Black Carbon)
Available N	Alkaline $KMnO_4$ method
Available P	0.5 *M* $NaHCO_3$ (Olsen's)
Available K	Ammonium acetate method
Available S	0.15% $CaCl_2$-extractable
DTPA-extractable Fe , Zn , Cu, Mn	0.005*M* DTPA + 0.01*M* $CaCl_2.2H_2O$ + 0.1*M* TEA
Available B	Hot water/ $CaCl_2$-extractable

Analysis of initial soil samples collected at different experimental locations exhibited sandy loam to black clay loam texture of the soils at most of the locations except at Palampur where soils were silty clay loam in texture (Table 24). Soils at NRRI-Cuttack, IISS-Bhopal and CSKHPKV-Palampur centres had sandy clay loam, black clay, silty clay loam, respectively, while the texture of soil at IARI-New Delhi, GKVK-Bengaluru and CISH-Lucknow centre was sandy loam. In general, soil reaction of all the soils were acidic to neutral as pH varied from 5.0 at Palampur to 7.81 at New Delhi. In most of the experimental sites, soil organic carbon content was low to medium except at Palampur and Bajaura, Palampur where it was high (1.22, 1.30%). Electrical conductivity of soil ranged from 0.13 to 0.65 dS m^{-1}. At most of the sites, DTPA- extractable Zn content was below the critical limit and varied from 0.35 to 2.01 mg kg^{-1} however, soils of Palampur, Palampur-Bajaura and New Delhi experimental sites were having high Zn content. Similarly, B content at most of the experimental sites varied from 0.33 to 0.67 mg kg^{-1}. All the soils were adequate in available P and K content while low to medium in available S content. Quantitatively, available N ranged from 210 to 338.6 kg ha^{-1} while available P, K and S ranged from 26.50- 225.4 kg ha^{-1}, 259.4-560 kg ha^{-1} and 8.1-18.20 mg kg^{-1}, respectively. Likewise, Mn, Fe and Cu content was adequate in almost all the soils and ranged from 6.40-33.50, 8.04-45.60, 0.71-4.60 mg kg^{-1} across the locations.

Table 24. Initial properties of soil at different centers (B metalosate)

Parameters	**Cuttack**	**Bhopal**	**Palampur**		**New Delhi**	**Bengaluru**		**Lucknow**
Crop	**Rice**	**Maize-Wheat**	**Cauliflower**	**Apple**	**Tomato**	**Grape**	**Pomegranate**	**Mango**
Texture	***Sandy clay loam***	***Black clay soil***	***Silty clay loam***		***Sandy loam***	***Sandy loam***		***Sandy loam***
pH (1:2.5)	6.00	7.7	5.0	6.1	7.8	6.4	6.2	7.2
EC (1:2.5) dS/m	0.65	0.1	0.6	0.5	0.5	0.5	0.2	-
SOC (%)	0.61	0.6	1.2	1.3	0.6	0.2	0.6	0.37±0.04
Available N (kg ha^{-1})	225.4	325.0	235.2	235.2	210.0	288.8	338.6	-
Available P_2O_5 (kg ha^{-1})	28.7	26.5	73.2	225.4	114.0	58.4	57.4	26.9 ± 2.8
Available K_2O (kg ha^{-1})	301.0	415.0	274.1	263.2	560.0	354.8	355.6	259.4 ± 19.7
Available S (mg kg^{-1})	16.2	14.30	9.3	8.1	15.6	18.2	18.0	-
DTPA-Fe (mg kg^{-1})	45.6	36.50	26.8	15.6	15.5	18.6	17.2	8.0 ± 0.5
DTPA-Mn (mg kg^{-1})	16.4	12.6	33.5	24.8	8.6	15.3	12.0	6.4 ± 1.1
DTPA-Zn (mg kg^{-1})	0.7	0.5	2.0	1.8	1.0	0.6	0.5	0.3 ±0.2
DTPA-Cu (mg kg^{-1})	3.7	2.3	0.7	0.9	4.6	1.6	1.6	1.5 ± 0.4
HWS-B (mg kg^{-1})	0.5	0.5	0.4	0.3	0.7	0.4	0.5	-

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4. RESULTS

The field experiments were carried out as per technical programme at six centers *viz.*, CSKHPKV, Palampur (HP)/ Bajaura; IARI, New Delhi; CISH, Lucknow (UP); GKVK, Bengaluru (Karnataka); CRRI Cuttack (Odisha); and IISS, Bhopal (MP) under the aegis of All India Coordinated Research Project on Micro-and Secondary Nutrients and Pollutant Elements during the year 2015-16. Predominant cereal, fruit and vegetable crops of the region (Cuttack: rice-rice; Bhopal: maize-wheat; New Delhi: tomato & capsicum; Palampur: cauliflower, Bajaura: apple; Lucknow: mango; Bengaluru: grapes & pomegranate) were selected to evaluate the efficacy of B Metalosate fertilizers against the standard B sources. The results of the experiments are summarized below under appropriate subheads.

Crop yields

In general, application of B has magnificently increased the yields of cereals, vegetables as well as fruits crops.

1. Cereal crops

In the first year of experimentation, all the cereal crops responded to B application significantly irrespective of the sources (Table 25). In all cereals except maize, the highest yield was attained under the treatment which received three foliar spray of B @ 0.017% B through B Metalosate along with 0.05% Zn through Zn Metalosate (half of the recommended standard sources). In maize, application of FYM enhanced the corn yield maximum, which was statistically comparable to the treatment grown with three foliar spray of 0.051% B through Boric acid, 0.034% B through B Metalosate, 0.0085% B through B Metalosate + 0.025% Zn through Zn Metalosate, and 0.017% B through B Metalosate + 0.05% Zn through Zn Metalosate. Enhanced concentration of B (i.e. 0.051% B through Boric acid) did not show significant response over recommended B concentration (i.e. 0.034% B through Boric acid). At the same time, reducing concentration of B spray by half of the recommended rates did not affect the crop yield, rather both the treatment produced statistically comparable yield.

Response of *kharif* rice (Naveen), maize (Shaktiman 5), *durum* wheat (HD 2987) and *aestivum* wheat (Lok 1) to B supplements through Boric acid, B Metalosate is depicted in Figure 13. In general, a noteworthy response of foliar application of B to cereal crops was registered through any of the sources. Maximum response was obtained through the foliar application of the standard boron concentration i.e. 0.034% B through B Metalosate by maize and wheat crops at

Bhopal centre, while *kharif* rice crop shown maximum response towards half of the standard B application through B Metalosate over recommended NPK. Apparently, the lowest response of *kharif* rice and *durum* wheat (HD 2987) was registered under $^{1}/_{10}$ of standard B applied (i.e. 0.0034 % B) through B Metalosate in contrast the maize and *aestivum* wheat (Lok 1) by using ½ of the standard B applied through boric acid.

Table 25. Yields of cereal crops (t ha^{-1}) as influenced by different sources of boron (borax, boric acid and B metalosate) at different locations

Treatment	**Rice -Rice**		**Maize- wheat**		
	***Kharif* Rice (Naveen)**	***Rabi Rice* (Naveen)**	***Maize (Shaktiman 5)***	**Wheat (HD2987)**	**Wheat (Lok 1)**
Location	**Cuttack**		**Bhopal**		
1. NPK	4.30	4.48	5.03	3.21	3.91
2. NPK + Soil B through borax	4.60	4.83	6.12	3.86	4.96
3. NPK + FYM	4.70	4.74	6.70	4.06	5.25
4. NPK + 0.017% B through Boric acid	4.60	4.70	5.55	3.47	4.13
5. NPK + 0.034% B through Boric acid	4.70	4.90	5.61	3.63	4.30
6. NPK + 0.051% B through Boric acid	4.50	4.60	6.10	3.91	4.70
7. NPK + 0.0034% B through B Metalosate	4.40	4.70	5.60	3.36	4.24
8. NPK + 0.0085% B through B Metalosate	4.70	4.50	5.72	3.55	4.38
9. NPK + 0.017% B through B Metalosate	4.80	4.83	5.89	3.74	4.68
10.NPK + 0.034% B through B Metalosate	4.50	4.81	6.02	3.87	4.85
11.T_8 + 0.025% Zn through Zn Metalosate	4.70	4.64	6.07	3.94	5.04
12.T_9 + 0.05% Zn through Zn Metalosate	5.00	5.33	6.59	4.04	5.27
CD (P=0.05)	**0.30**	**0.27**	**0.68**	**0.37**	**0.50**

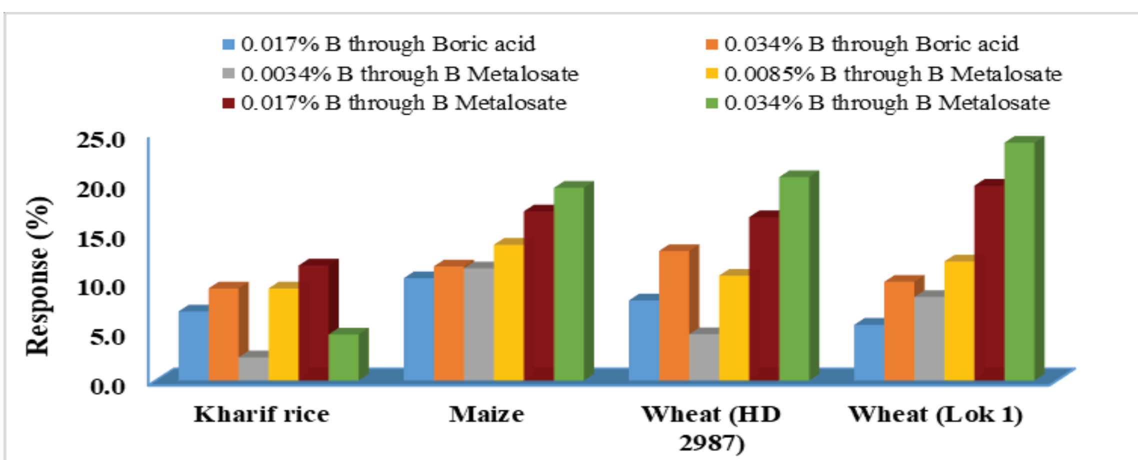


Figure 13. Response of different cereal crops to foliar supplementation of B through boric acid and B metalosate

In the second year of study, maximum grain yield of rice was recorded in the treatment receiving the application of 0.017% B through B Metalosate along with 0.05% Zn through Zn Metalosate at a significant level over other treatments (Table 26). B application through any of the sources yielded comparable rice yields. The highest yield of maize crop var. Shaktiman5, Wheat var. HD 2987 and Lok1 was attained under the treatment which received three foliar spray of B @ 0.017% B through B Metalosate along with 0.05% Zn through Zn Metalosate (half of the recommended standard sources) and it was comparable to yield obtained under FYM application. In maize, the highest yield was noted with application of FYM and the yield was comparable to yield obtained under foliar spray of recommended boron concentration @ 0.034% through boric acid. The application of 0.0085% B through B Metalosate+0.025% Zn through Zn Metalosate, and 0.0085% B through B Metalosate+0.050% Zn through Zn Metalosate also enhanced the yields. Enhanced concentration of B (i.e. 0.051% B through Boric acid) did not show significant response over recommended B concentration (i.e. 0.034% B through Boric acid). At the same time, reducing concentration of B spray through Boric acid by half of the recommended rates improved the crop yield of maize. For other crops, both treatments produced statistically at par yield.

Table 26. Yields of cereal crops (t ha^{-1}) as influenced by different sources of boron (borax, boric acid and B metalosate) at different locations

Treatment	Rice - Rice		Maize - wheat			
	***Kharif* Rice (Naveen)**	***Rabi* Rice (Naveen)**	**Maize (Shaktiman 5)**	**Maize (Nath Samrat 1144)**	**Wheat (HD2987)**	**Wheat (Lok 1)**
Location	**Cuttack**			**Bhopal**		
1. NPK	4.27	4.10	4.82	4.16	3.94	4.64
2. NPK + Soil B through borax	4.68	5.07	5.67	4.78	4.51	5.49
3. NPK + FYM	4.83	5.17	6.12	5.58	4.70	6.08
4. NPK + 0.017% B through Boric acid	4.88	4.84	5.40	4.33	4.24	5.34
5. NPK + 0.034% B through Boric acid	4.91	4.97	5.70	5.50	4.31	5.74
6. NPK + 0.051% B through Boric acid	4.51	4.57	6.27	5.46	4.41	5.91
7. NPK+0.0034%B through B Metalosate	4.46	4.63	5.24	4.35	4.07	5.39
8. NPK +0.0085% B through B Metalosate	4.63	4.64	5.37	4.40	4.31	5.70
9. NPK + 0.017% B through B Metalosate	5.01	4.91	5.71	4.85	4.47	6.13
10. NPK + 0.034% B through B Metalosate	4.72	4.86	5.59	5.22	4.65	5.96

11. T8 + 0.025% Zn through Zn Metalosate	4.83	4.71	5.79	5.11	4.41	5.58
12. T9 + 0.05% Zn through Zn Metalosate	5.24	5.39	6.57	5.41	4.73	6.42
CD (P=0.05)	**0.50**	**0.59**	**0.69**	**0.54**	**0.39**	**0.45**

Response of *kharif* and *rabi* rice (Naveen), maize (Shaktiman 5 and Nath Samrat 1144), *durum* wheat (HD 2987) and *aestivum* wheat (Lok 1), during second year of study, to B supplements through Boric acid, B Metalosate is depicted in Figure 14. In general, a peculiar response of foliar application of B to cereal crops was registered through any of the sources. Maximum response was obtained through the foliar application of the boron concentration i.e. 0.0085% B through B Metalosate+0.025% Zn through Zn Metalosate by maize var. shaktiman 5 and wheat crops at Bhopal centre. While *kharif* rice crop has shown maximum response towards half of the standard B application through B Metalosate over recommended NPK. Apparently, the lowest response of maize and *durum* wheat was registered using $^{1}/_{10}$ of standard B applied (i.e. 0.0034 % B) through B Metalosate in contrast the maize and *aestivum* wheat (Lok 1) by using ½ of the standard B applied through boric acid.

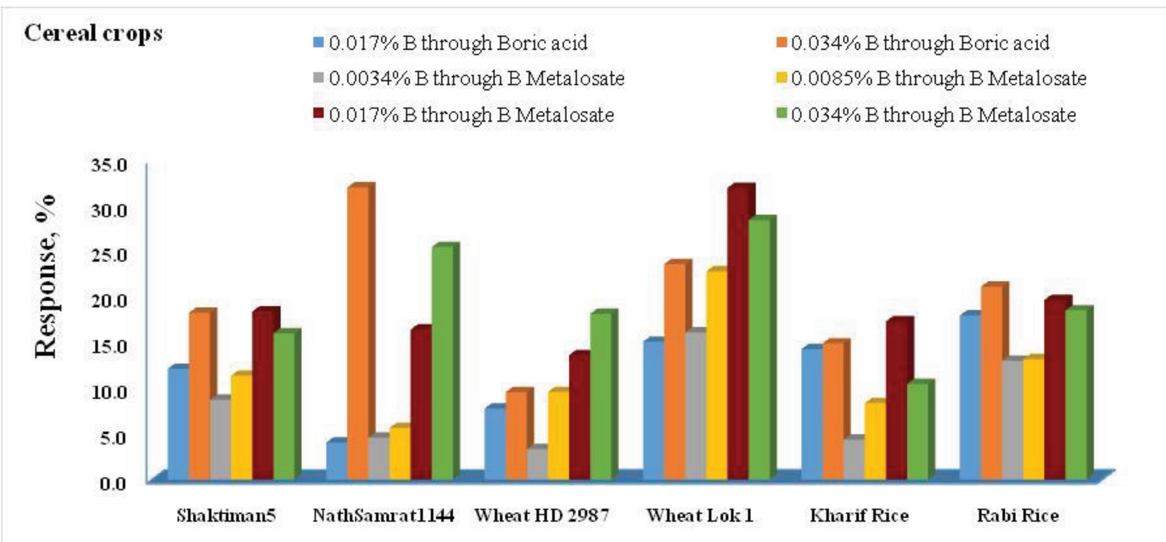


Figure 14. Response of different cereal crops to foliar supplementation of B through boric acid and B Metalosate

2. Vegetable Crops

During both the year of experimentations, B Metalosate product was evaluated against standard sources of B on cauliflower and tomato grown at Palampur and New Delhi, respectively. In the first year, the curd yield of cauliflower varied from 9.32 to 12.84 t ha^{-1} (Table 27). The application of FYM showed best result followed by basal application of @ 1.5 kg B ha^{-1} through borax, 3 foliar spray of B @ 0.034% B through Boric acid and B Metalosate, respectively. The effect of B supply at equal rates of application through either of the sources gave similar curd yield of cauliflower. Under open field conditions, highest tomato yield was recorded under the treatment receiving full dose of B through B Metalosate which was at par when ½ dose of B supplied through B Metalosate along with ½ dose of Zn through Zn Metalosate. On average, tomato yield varied from 48.1 to 53.4 t ha^{-1} (Table 27). In general, B supplied through B Metalosate was more effective in enhancing fruit yield than that supplied through boric acid. Boron supplied through borax gave significantly higher fruit yield over no B control but it was proved much inferior to boric acid and B Metalosate.

Table 27. Yields of vegetable crops (t ha^{-1}) as influenced by different sources of boron (borax, boric acid and B metalosate) at different locations

Treatment	Cauliflower *(Pusa Snowball K1)*	Tomato (Narendra)
Location	***Palampur***	***New Delhi***
1. NPK	9.32	48.10^{g}
2. NPK + Soil B through borax	11.14	49.05^{ef}
3. NPK + FYM	12.84	48.70^{fg}
4. NPK + 0.017% B through Boric acid	10.27	48.65^{fg}
5. NPK + 0.034% B through Boric acid	10.85	49.60^{de}
6. NPK + 0.051% B through Boric acid	10.62	50.05^{cd}
7. NPK + 0.0034% B through B Metalosate	10.15	50.80^{c}
8. NPK + 0.0085% B through B Metalosate	10.41	52.30^{b}
9. NPK + 0.017% B through B Metalosate	11.27	52.90^{ab}
10. NPK + 0.034% B through B Metalosate	11.53	53.35^{a}
11. T_8 + 0.025% Zn through Zn Metalosate	10.65	52.85^{ab}
12. T_9 + 0.05% Zn through Zn Metalosate	11.30	53.35^{a}
CD (P=0.05)	**0.53**	**-**

The response of vegetable crops to B application varied with crop and level and sources of B application (Figure 15). Response to B application was much higher in cauliflower as compared to tomato crop however, the highest response was observed with application of B @ 0.034% B through B Metalosate in both the crops. The crop response decreased with reducing the level of B application in both the crops. On average, response of boric acid was much inferior in tomato than in cauliflower.

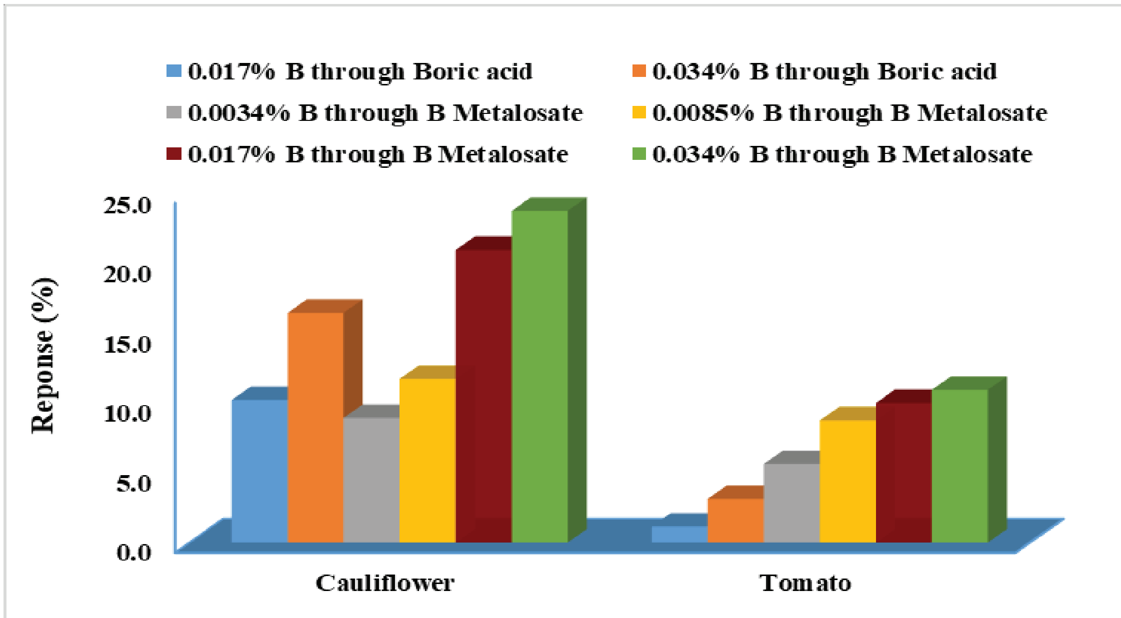


Figure 15. Response of different vegetable crops to foliar supplementation of B through boric acid and B Metalosate

During the second year, the curd yield of cauliflower varied from 10.2 to 13.5 t ha^{-1} (Table 28). The application of FYM resulted in best yield followed by 3 foliar spray of B @ 0.034% B through B Metalosate, basal application of @ 1.5 kg B ha^{-1} through borax and 3 foliar spray of B @ 0.034% B through Boric acid. The effect of B supply at equal rates of application through either of sources gave similar curd yield of cauliflower. B Metalosate and its combination with Zn Metalosate are proved to be promising in magnifying the yields of tomato crop under polyhouse conditions. Soil zinc application as well as foliar application of boric acid was also good in mounting up the tomato yield in an insignificant manner over control and each other. Under open field conditions, there has been no significant change in the yields of tomato crop on any of the soil and foliar zinc supplements. The yield of capsicum ranged from 9.5 to 14.7 t ha^{-1}. The maximum yield of capsicum was registered with the application of B @0.017% through B Metalosate along with 0.05% Zn supplied through Zn Metalosate.

Table 28. Yields of vegetable crops (t ha^{-1}) as influenced by different sources of boron (borax, boric acid and B metalosate) at different locations

Treatment	Cauliflower *(Pusa Snowball K1)*	Tomato (Narendra)		Capsicum
		Polyhouse	Open field	Polyhouse
Location	***Palampur***	***New Delhi***		
1. NPK	10.24	45.8	27.8	9.5
2. NPK + Soil B through borax	11.88	47.1	29.0	12.2
3. NPK + FYM	13.55	47.4	28.1	11.1
4. NPK + 0.017% B through Boric acid	11.31	48.7	29.1	12.4
5. NPK + 0.034% B through Boric acid	11.62	48.3	29.3	12.7
6. NPK + 0.051% B through Boric acid	11.43	48.5	29.4	12.8
7. NPK + 0.0034% B through B Metalosate	10.74	59.2	30.7	13.5
8. NPK + 0.0085% B through B Metalosate	11.00	60.1	30.9	13.7
9. NPK + 0.017% B through B Metalosate	11.48	60.4	31.0	13.8
10. NPK + 0.034% B through B Metalosate	12.17	57.6	31.1	14.0
11. T_8 + 0.025% Zn through Zn Metalosate	10.76	59.4	31.3	14.3
12. T_9 + 0.05% Zn through Zn Metalosate	10.52	58.8	31.2	14.7
CD (P=0.05)	**0.87**	**9.51**	**5.43**	**1.67**

The response of vegetable crops to B application varied with crop and level and sources of B application (Figure 16). Among the foliar applications, the highest response was observed with application of B @ 0.034% B through B Metalosate in cauliflower. The crop response decreased with reducing the level of B application. On average, response of boric acid was much inferior in cauliflower.

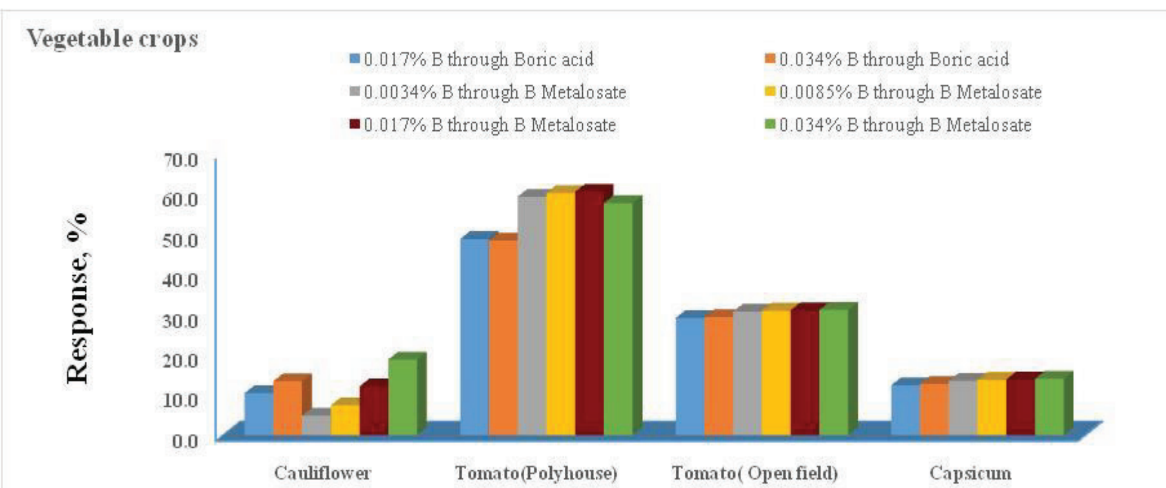


Figure 16. Response of different vegetable crops to foliar supplementation of B through boric acid and B Metalosate

3. Fruit crops

Similar to Zn application, supplementation of B through various sources at various rates also influenced the fruit crop yields significantly. During first year of study, the fruit yields of grape (cv. Dilkush) and pomegranate (cv. Bhagwa) grown at Bengaluru ranged from 18.3 to 42.1 kg/plant and 15.41 to 50.34 kg/plant. (Table 29). The application of boric acid @ standard dose was inferior to standard dose of B supplied through B Metalosate. Application of ½ rate of standard dose of B and Zn through Metalosate gave highest yield in both the crops. Although reduction in B concentration supplied through B Metalosate resulted in reduction of fruit yields of both the crops but yield obtained even @ ¼ of B Metalosate concentration was superior to standard supply of B through boric acid.

Mango (cv. Mallika) grown at Lucknow gave similar yields with B applied at equal concentration through either of the sources. Similar to grape and Pomegranate, the highest mango and apple yield was obtained with the combined application of ½ doses each of B and Zn through Metalosate. In 7 years old apple plantation at Bajaura, Palampur, B application has significantly improved the fruit yield irrespective of the sources. The fruit yield varied from 19.6 to 38.80 kg/plant. Application of B @ standard dose of B through B Metalosate had given significantly higher yield than that obtained with same rate of application through boric acid. Application of lower dose of B lower dose of B i.e. ¼ gave at par fruit yield with that supplied through boric acid. Although the application of B through borax gave significantly higher fruit yield of apple but it proved inferior to other sources.

Table 29. Yields of fruit crops (kg/plant) as influenced by different sources of boron (borax, boric acid and B metalosate) at different locations

Treatment	Grapes (Dilkush)	Pomegranate (Bhagwa)	Mango (Mallika)	Apple (Royal Delicious)
Location	***Bengaluru***		***Lucknow***	***Palampur***
1. NPK	18.29	15.41	31.46	19.60
2. NPK + Soil B through borax	22.67	17.63	34.35	24.00
3. NPK + FYM	21.94	16.30	37.59	28.60
4. NPK + 0.017% B through Boric acid	23.48	23.84	38.02	27.50
5. NPK + 0.034% B through Boric acid	24.51	30.74	44.32	32.00
6. NPK + 0.051% B through Boric acid	27.24	36.89	44.77	32.43
7. NPK + 0.0034% B through B Metalosate	22.95	20.27	36.76	26.67
8. NPK + 0.0085% B through B Metalosate	23.56	27.96	37.29	28.67
9. NPK + 0.017% B through B Metalosate	30.22	38.93	44.17	38.27

10. NPK + 0.034% B through B Metalosate	32.92	43.97	43.66	38.80
11. T_8 + 0.025% Zn through Zn Metalosate	39.15	46.13	47.16	34.63
12. T_9 + 0.05% Zn through Zn Metalosate	42.11	50.34	50.46	36.93
CD (P=0.05)	**4.14**	**3.51**	**9.40**	**4.14**

In most of the fruit crops response of B application through B Metalosate was maximum. On average, application of standard dose of B through B Metalosate resulted in 38.8, 80.0, 98.0 and 185.0% increase in the fruit yields of mango, grapes, apple and pomegranate, respectively (Figure 17). The crop response at lower doses of both the B sources was comparable in grapes and mango.

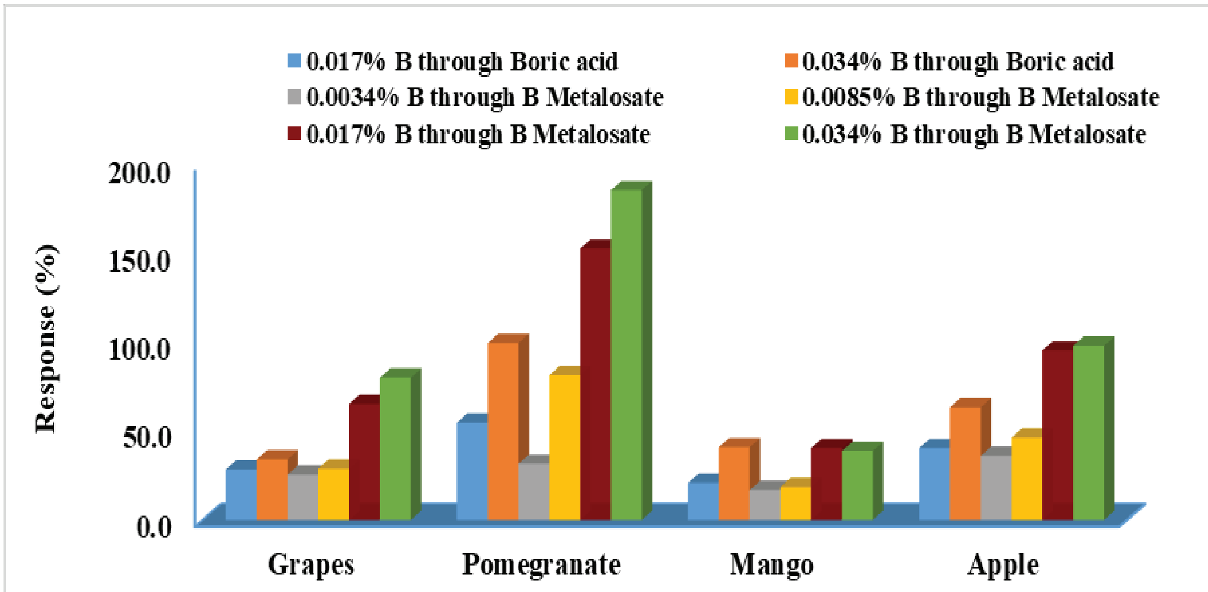
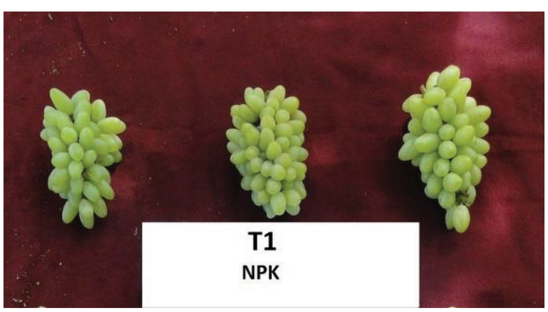
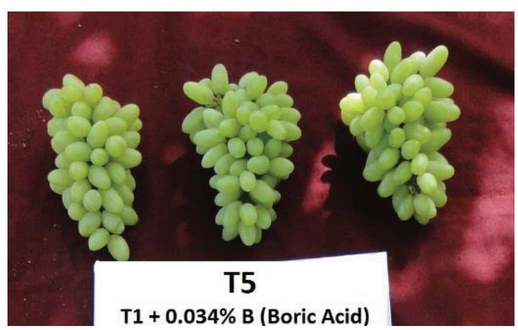
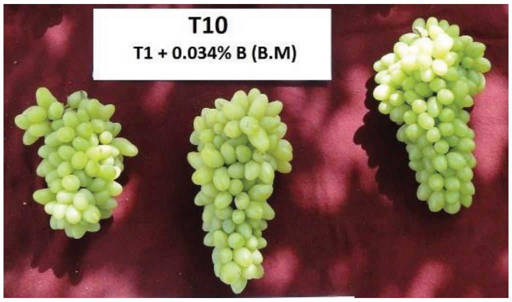


Figure 17. Response of different fruit crops to foliar supplementation of B through boric acid and B metalosate







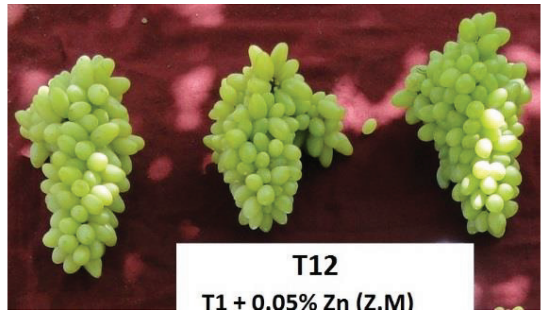
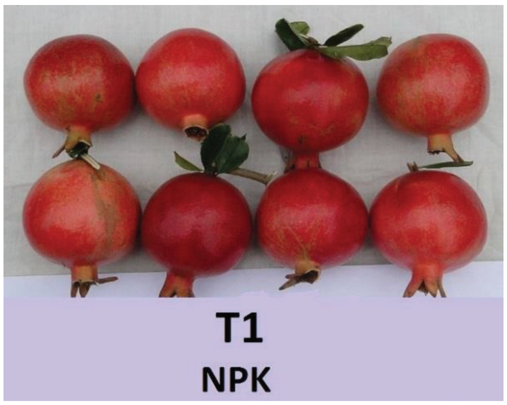
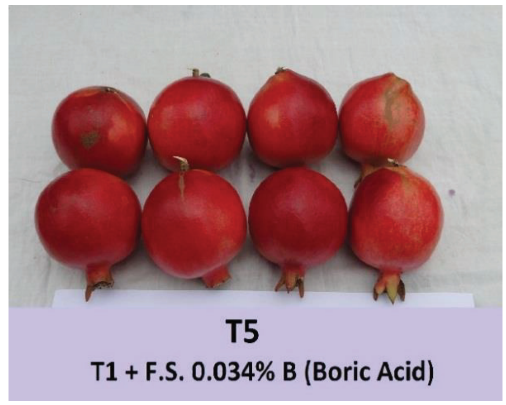
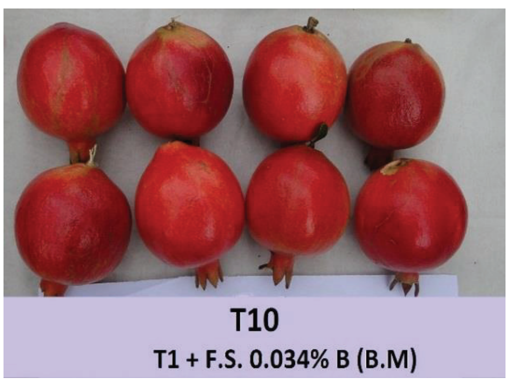


Plate 8. Effect of sources of B on grapes







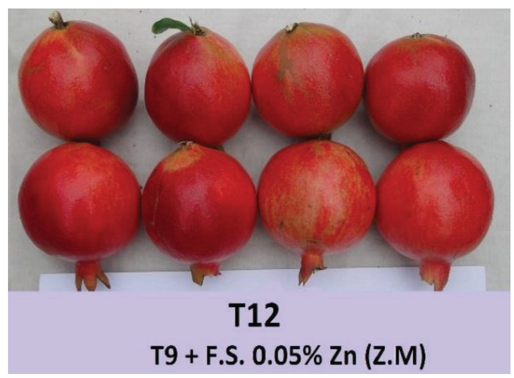
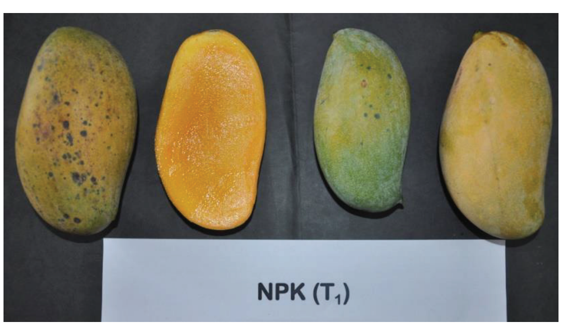
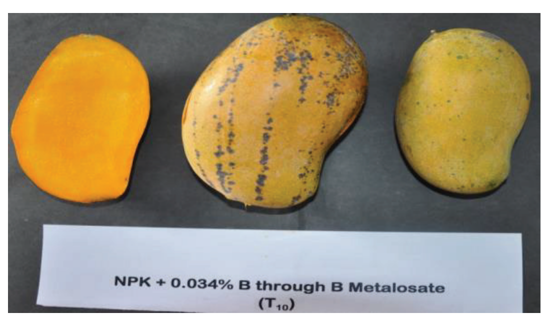


Plate 9. Effect of sources of B on pomegranate





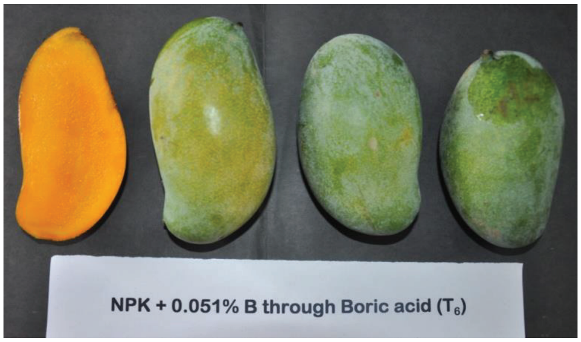


Plate 10. Effect of sources of B on mango

During second year, fruit yield of grape (cv. Dilkush) and pomegranate (cv. Bhagwa) grown at Bengaluru ranged from 21.8 to 42.3 kg/ plant and 26.8 to 53.2 kg/plant (Table 30). The application of boric acid @ standard and half the standard dose was inferior to that by through B Metalosate respectively. Application of ½ rate of standard dose of B and Zn through Metalosate gave highest yield in both the crops. Although reduction in B concentration supplied through B Metalosate resulted in reduction of fruit yields of both the crops but yield obtained even @ ¼ and $^{1}/_{10}$ of B Metalosate concentration was equivalent to standard supply of B through boric acid. A significant increase in the yield of Pomegranate was noted with the enhancement of the standard supply B by 1.5 times through Boric acid. The increased doses of boron than those in standard apparently improved the yield of mango var. Mallika grown at Lucknow. The fruit yield of apple was significantly affected by different treatments in comparison to control. The fruit yield varied from minimum of 25.8 kg $tree^{-1}$ in control to maximum of 39.7 kg $tree^{-1}$ on application of standard dose of B through B Metalosate. The soil application of boron significantly increased in the fruit yield by 4.6% over the control. Application of half dose of B i.e. 0.017% B through B Metalosate with and without 0.05% Zn applied through Zn Metalosate. Among the two sources of foliar application of boron, the application of B metalosate was found superior to the application of boric acid at same level of boron application. Irrespective to the source of foliar spray, the increase in the concentration of foliar application of boron was followed by an increase in the fruit yield of apple. This might be due to the fact that adequate boron increases the pollination and fruit set, as it is responsible for pollen germination and pollen tube formation. Whereas, a poor supply of boron causes poor flowering, low fruit set and hence low yield.

Table 30. Yields of fruit crops (kg/plant) as influenced by different sources of boron (borax, boric acid and B metalosate) at different locations

Treatment	Grapes (Dilkush)	Pomegranate (Bhagwa)	Mango (Mallika)	Apple (Royal Delicious)
Location	***Bengaluru***		***Lucknow***	***Palampur***
1. NPK	21.88	26.80	39.42	25.8
2. NPK + Soil B through borax	24.92	30.28	41.37	27.0
3. NPK + FYM	24.11	27.90	47.51	30.7
4. NPK + 0.017% B through Boric acid	25.67	33.79	48.00	29.6
5. NPK + 0.034% B through Boric acid	27.21	37.85	53.31	34.1
6. NPK + 0.051% B through Boric acid	29.76	41.30	52.78	34.5
7. NPK + 0.0034% B through B Metalosate	25.35	31.76	44.82	28.8
8. NPK + 0.0085% B through B Metalosate	26.51	36.15	48.34	30.8
9. NPK + 0.017% B through B Metalosate	32.52	42.96	53.18	39.7
10. NPK + 0.034% B through B Metalosate	36.72	46.46	53.57	39.9
11. T_8 + 0.025% Zn through Zn Metalosate	42.27	48.61	58.58	36.1
12. T_9 + 0.05% Zn through Zn Metalosate	45.64	53.18	57.30	38.0
CD (P=0.05)	**2.58**	**3.08**	**4.12**	**3.5**

In all the fruit crops except apple, response of B application through @ 0.034% B through B Metalosate with 0.05% Zn through Zn Metalosate was maximum (Figure 18). There was a response of 108, 98 and 45% to fruit yields of mango, grapes, and pomegranate, respectively. Apple fruit responded best both with the half and standard boron doses through B Metalosate and a 53.8 and 54.6 % improvement in fruit yield was noted. The other boric acid and Metalosate foliar spray also helped in raising the yield responses by the fruit crops. The B application standard rate through foliar spray of Metalosate is quite beneficial.

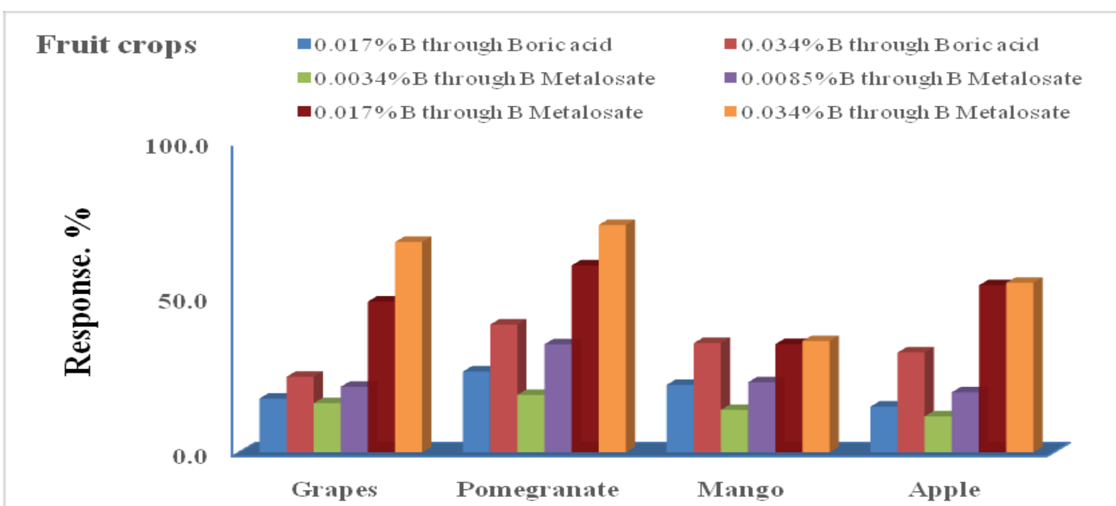


Figure 18. Response of different fruit crops to foliar supplementation of B through boric acid and B metalosate

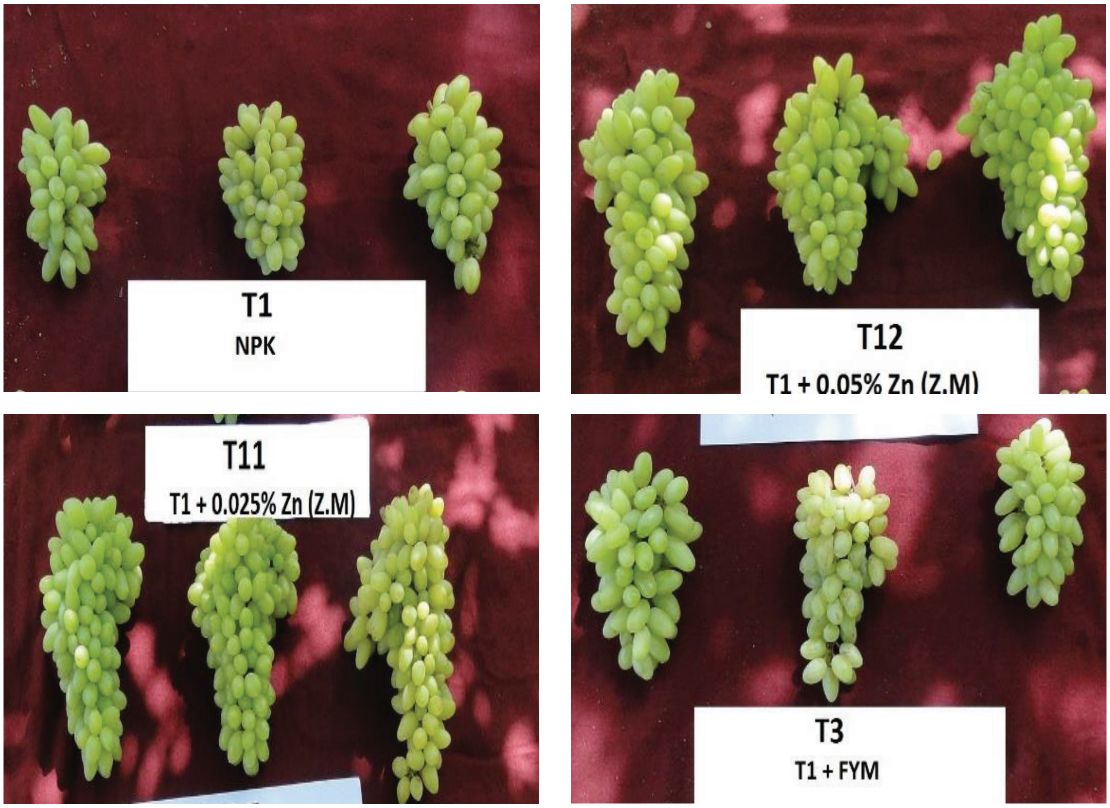


Plate 11. Effect of sources of B on grapes

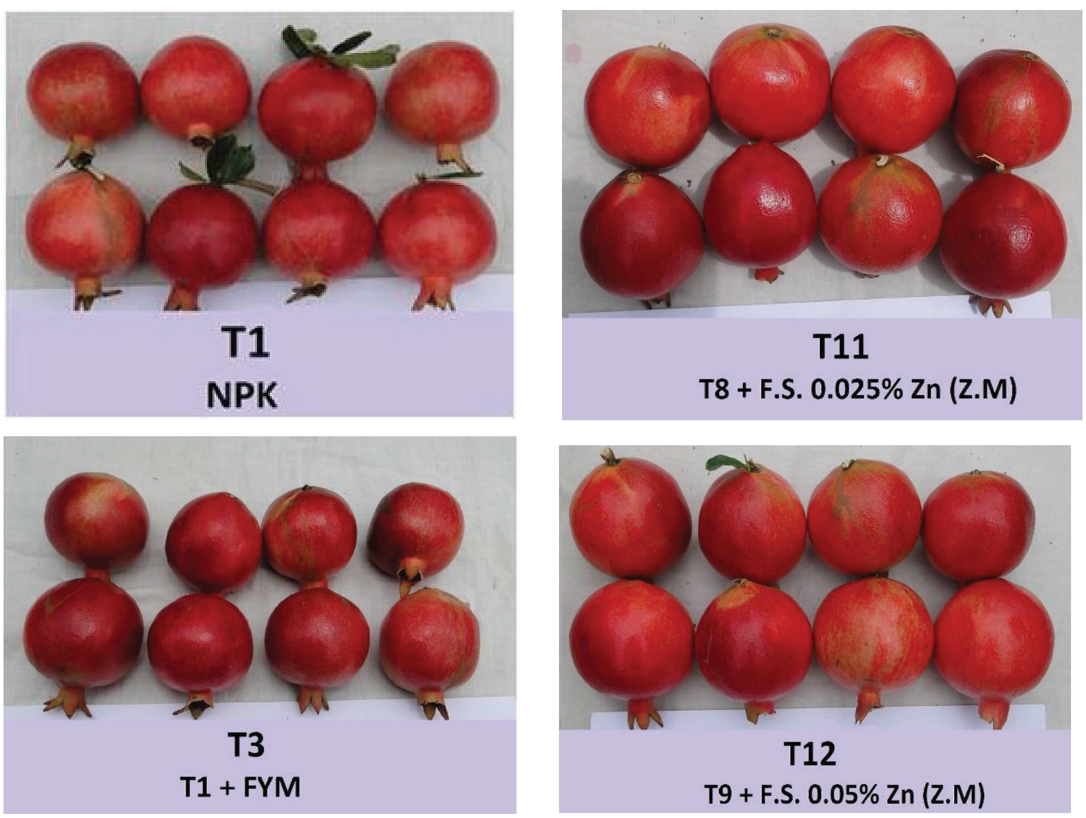


Plate 12. Effect of sources of B on pomegranate

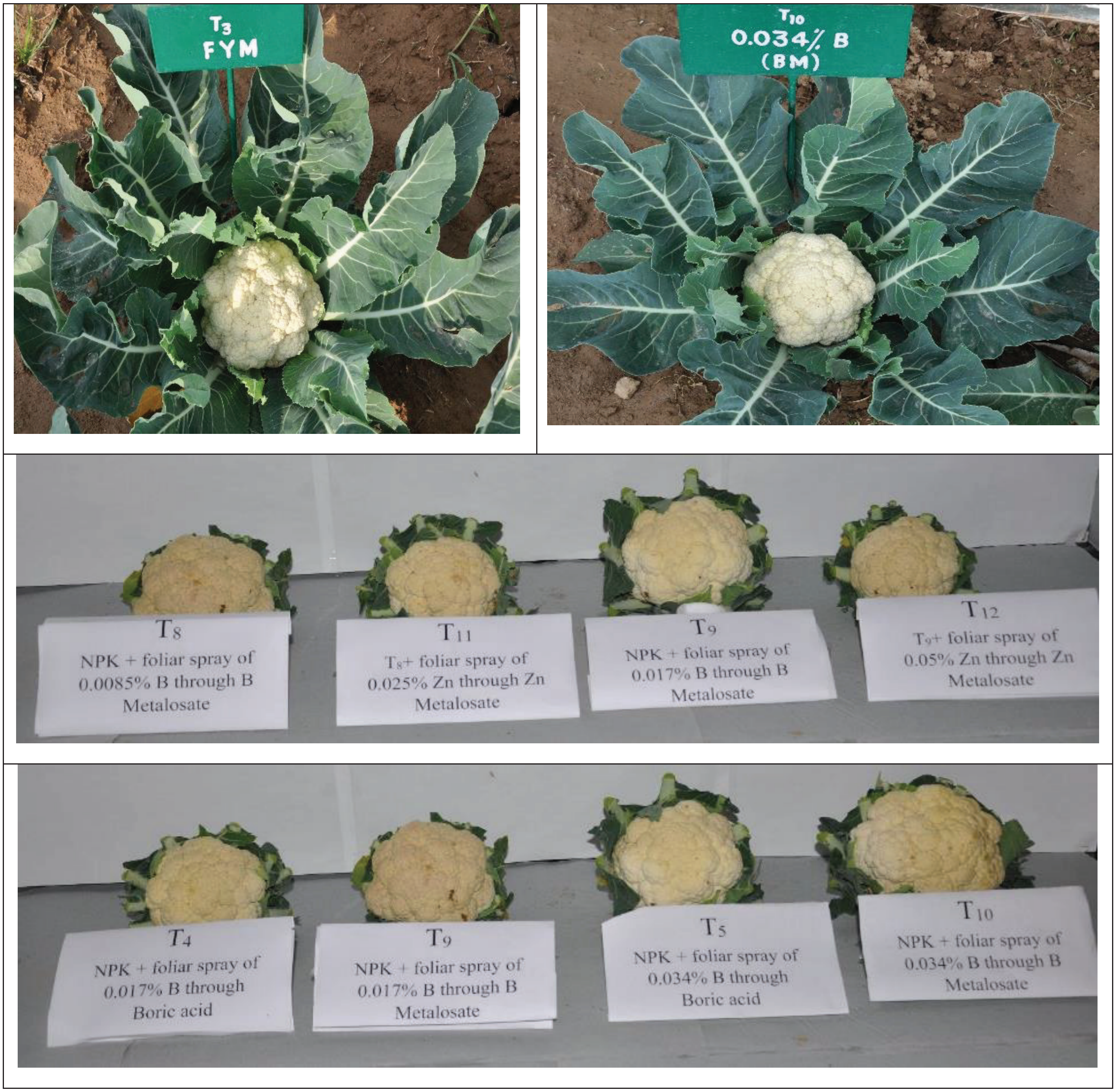


Plate 13. Effect of sources of B on cauliflower

T_5 = NPK + foliar spray of 0.034% B through Boric acid

T_{10} = NPK + foliar spray of 0.034% B through B Metalosate

T_{12} = T_9+ foliar spray of 0.05% Zn through Zn Metalosate

Plate 14. Effect of sources of B on apple

Boron concentration in edible pant parts

1. **Cereal crops**

Application of B through different sources and concentration has also influenced B concentration in edible plant parts. Among the three cereal crops evaluated under different sources of B during first year of study, rice crop grown in *kharif* did not show any effect on grain B concentration irrespective of the treatment (Table 31). However, rice crop grown in *rabi* season exhibited highest B concentration in the treatment receiving 0.017% B through B Metalosate which was comparable with its immediate lower and higher concentration as well as B supplied through foliar spray of 0.034% B through boric acid.

In maize, highest B concentration was recorded when 1.5 kg B was applied through borax followed by the treatment receiving ½ of the standard concentration along with the 0.05% Zn through Zn Metalosate and 0.051% B through boric acid. In wheat, the highest concentration was registered when standard dose i.e. 0.034% B supplied through B Metalosate. It is noteworthy that concentration of B in wheat grain was comparable under the treatment receiving B through borax or B supplied through standard as well ½ concentration of B foliar sprayed to the crop through B Metalosate. Similar results were obtained in second year of study (Table 32).

Table 31. Grain B concentration of cereal crops as influenced by different sources of boron (borax, boric acid and B metalosate) at different locations (mg kg^{-1})

Treatment	Rice -Rice		Maize- wheat		
	Kharif Rice (Naveen)	*Rabi* Rice (Naveen)	Maize (Shaktiman 5)	Wheat (HD2987)	Wheat (Lok 1)
Location	*Cuttack*		*Bhopal*		
1. NPK	4.90	4.70	1.40	0.87	1.03
2. NPK + Soil B through borax	4.90	5.50	1.75	1.15	1.27
3. NPK + FYM	5.00	5.60	1.69	1.00	1.12
4. NPK + 0.017% B through Boric acid	5.30	5.90	1.58	0.99	1.16
5. NPK + 0.034% B through Boric acid	5.30	6.80	1.82	1.05	1.25
6. NPK + 0.051% B through Boric acid	4.70	6.10	1.90	1.21	1.32
7. NPK + 0.0034% B through B Metalosate	4.60	6.40	1.56	1.28	1.21
8. NPK + 0.0085% B through B Metalosate	5.20	7.10	1.82	1.42	1.35
9. NPK + 0.017% B through B Metalosate	5.10	7.10	1.89	1.60	1.43
10. NPK + 0.034% B through B Metalosate	4.80	6.50	2.00	1.65	1.55
11. T_8 + 0.025% Zn through Zn Metalosate	5.10	5.70	1.53	1.32	1.11
12. T_9 + 0.05% Zn through Zn Metalosate	6.30	6.00	1.72	1.39	1.25
CD (P=0.05)	**NS**	**0.60**	**0.10**	0.19	**0.15**

Table 32. Grain B concentration (mg kg^{-1}) of cereal crops as influenced by different sources of boron (borax, boric acid and B metalosate) at different locations

Treatment	Rice -Rice		Maize- wheat		
	Kharif Rice (Naveen)	*Rabi* Rice (Naveen)	Maize (Shaktiman 5)	Wheat (HD2987)	Wheat (Lok 1)
Location	***Cuttack***		***Bhopal***		
1. NPK	4.21	4.56	1.34	0.84	0.99
2. NPK + Soil B through borax	5.00	4.96	1.68	1.10	1.23
3. NPK + FYM	4.90	5.12	1.63	0.96	1.09
4. NPK + 0.017% B through Boric acid	5.21	5.44	1.53	0.93	1.12
5. NPK + 0.034% B through Boric acid	5.31	6.55	1.74	1.01	1.20
6. NPK + 0.051% B through Boric acid	5.50	6.92	1.78	1.16	1.29
7. NPK + 0.0034% B through B Metalosate	4.70	6.30	1.51	1.23	1.17
8. NPK + 0.0085% B through B Metalosate	4.79	6.61	1.78	1.37	1.32
9. NPK + 0.017% B through B Metalosate	5.07	6.91	1.84	1.55	1.39
10. NPK + 0.034% B through B Metalosate	4.69	7.02	1.93	1.63	1.52
11. T_8 + 0.025% Zn through Zn Metalosate	4.73	6.47	1.49	1.27	1.06
12. T_9 + 0.05% Zn through Zn Metalosate	5.59	6.73	1.69	1.35	1.22
CD (P=0.05)	**0.25**	**0.51**	**0.09**	**0.15**	**0.12**

2. Vegetable Crops

The concentration of B in vegetable crops got influenced with application of B irrespective of the sources, however, it varied with level of concentration and sources of B used in the experiments at different locations during both the year of study (Table 33). During first year, B concentration ranged from 13.3 to 25.7 mg kg^{-1} and 15.4 to 46.6 mg kg^{-1} in cauliflower and tomato, respectively. Similar to the maize crop, the highest B concentration in cauliflower curd was observed when 1.5 kg B was applied through borax. In tomato, the highest B concentration was obtained when standard dose of B i.e. 0.034% B was applied through B Metalosate. Interestingly, B supply by boric enhanced tomato fruit B concentration.

Table 33. Fruit B concentration (mg kg^{-1}) of vegetable crops as influenced by different sources of B (borax, boric acid and B metalosate) at different locations

Treatment	Cauliflower (*Pusa Snowball K1*)	Tomato (Narender)
Location	***Palampur***	***New Delhi***
1. NPK	13.3	15.4
2. NPK + Soil B through borax	25.7	25.1
3. NPK + FYM	20.3	21.7
4. NPK + 0.017% B through Boric acid	21.1	26.3

5. NPK + 0.034% B through Boric acid	22.2	30.2
6. NPK + 0.051% B through Boric acid	22.5	33.8
7. NPK + 0.0034% B through B Metalosate	18.7	37.6
8. NPK + 0.0085% B through B Metalosate	20.1	41.3
9. NPK + 0.017% B through B Metalosate	21.4	42.3
10. NPK + 0.034% B through B Metalosate	21.8	46.6
11. T_8 + 0.025% Zn through Zn Metalosate	19.0	41.5
12. T_9 + 0.05% Zn through Zn Metalosate	19.7	44.0
CD (P=0.05)	**1.9**	**3.0**

During second year, the concentration of B in tomato varied from 25.1 to 40.1 mg kg-1 under different treatments at New Delhi (Table 34). B concentration in Cauliflower (*Pusa Snowball KI*) ranged from 13.1 to 26.3 mg kg^{-1} at Palampur location (Table 34). B concentration in cauliflower curd got improved on adding any of the sources of boron; however, it was found highest on applying B in soil through Borax. The foliar application through boric acid and B Metalosate were equally effective. Increasing or decreasing B content by 1.5 times and ½ times through boric acid could not induce any increment in fruit Boron concentrations anyways. Similarly, the standard and $^{1}/_{10}$ th, ¼th and half the doses of standard boron applied through B metalosate were at par with each other.

Table 34. Fruit B concentration (mg kg^{-1}) of vegetable crops as influenced by different sources of B (borax, boric acid and B metalosate) at different locations

Treatment	Cauliflower	Tomato
	(*Pusa Snowball K1*)	(Narender)
Location	***Palampur***	***New Delhi***
1. NPK	13.07	25.1
2. NPK + Soil B through borax	26.28	28.1
3. NPK + FYM	21.17	27.7
4. NPK + 0.017% B through Boric acid	21.43	29.3
5. NPK + 0.034% B through Boric acid	23.27	32.8
6. NPK + 0.051% B through Boric acid	22.77	34.8
7. NPK + 0.0034% B through B Metalosate	19.37	29.5
8. NPK + 0.0085% B through B Metalosate	21.53	35.1
9. NPK + 0.017% B through B Metalosate	21.75	36.8
10. NPK + 0.034% B through B Metalosate	22.22	38.6
11. T8 + 0.025% Zn through Zn Metalosate	20.37	38.4
12. T9 + 0.05% Zn through Zn Metalosate	20.13	40.1
CD (P=0.05)	**3.49**	**4.50**

3. Fruit Crops

Similar to vegetable crops, fruit crops particularly grapes and pomegranate exhibited very high concentration of B in edible plant parts. The application B has further increased fruit B concentration in all the three fruit crops evaluated in the project. During 2015-16, B concentration varied from 22.0 to 53.6, 20.0 to 49.8 and 8.4 to 15.4 mg kg^{-1} in grapes, pomegranate and apple, respectively (Table 35). In grapes and pomegranate, B supplied through B Metalosate had shown significantly higher concentration than the treatment receiving B through boric acid. However, in apple, both boric acid and B Metalosate had equally improved B concentration.

Table 35. Fruit B concentration (mg kg^{-1}) of fruit crops as influenced by different sources of boron (borax, boric acid and B metalosate) at different locations

Treatment	Grapes (Dilkush)	Pomegranate (Bhagwa)	Apple (Royal Delicious)
Location	***Bengaluru***		***Palampur***
1. NPK	22.0	20.0	8.4
2. NPK + Soil B through borax	26.9	24.4	13.5
3. NPK + FYM	23.8	21.6	14.1
4. NPK + FS 0.017% B through Boric acid	29.5	28.5	14.5
5. NPK + FS 0.034% B through Boric acid	34.2	33.8	15.0
6. NPK + FS 0.051% B through Boric acid	37.7	35.5	15.4
7. NPK + FS 0.0034% B through B Metalosate	28.1	26.3	10.9
8. NPK + FS 0.0085% B through B Metalosate	33.0	31.0	11.6
9. NPK + FS 0.017% B through B Metalosate	40.9	39.3	14.7
10. NPK + FS 0.034% B through B Metalosate	43.2	42.0	15.3
11. T_8 + FS 0.025% Zn through Zn Metalosate	49.7	47.0	11.4
12. T_9 + FS 0.05% Zn through Zn Metalosate	53.6	49.8	14.2
CD (P=0.05)	**4.8**	**6.5**	**1.9**

During 2016-17, B concentration varied from 23.3 to 53.9, 21.9 to 49.9 and 9.2 to 15.7 mg kg^{-1} in grapes, pomegranate and apple, respectively (Table 36). In grapes and pomegranate, B supplied through B Metalosate had shown significantly higher concentration than the treatment receiving B through boric acid. The treatments in which zinc Metalosate was supplied with B Metalosate at ¼ and ½ concentrations were significantly better in influencing B contents. However, in apple both boric acid and B Metalosate had equally improved B concentration.

Table 36. Fruit B concentration (mg kg^{-1}) of fruit crops as influenced by different sources of boron (borax, boric acid and B metalosate) at different locations

Treatment	Grapes (Dilkush)	Pomegranate (Bhagwa)	Apple Royal Delicious)
Location	***Bengaluru***		***Palampur***
1. NPK	23.25	21.87	9.23
2. NPK + Soil B through borax	27.82	24.75	11.66
3. NPK + FYM	25.45	22.91	14.20
4. NPK + FS 0.017% B through Boric acid	32.14	28.75	14.68
5. NPK + FS 0.034% B through Boric acid	35.69	34.30	15.19
6. NPK + FS 0.051% B through Boric acid	38.51	35.84	15.71
7. NPK + FS 0.0034% B through B Metalosate	29.80	27.12	11.02
8. NPK + FS 0.0085% B through B Metalosate	34.00	31.60	11.68
9. NPK + FS 0.017% B through B Metalosate	41.77	39.99	14.87
10. NPK + FS 0.034% B through B Metalosate	45.05	42.91	15.36
11. T8 + FS 0.025% Zn through Zn Metalosate	50.03	48.47	11.59
12. T_9 + FS 0.05% Zn through Zn Metalosate	53.91	49.99	14.42
CD (P=0.05)	**5.41**	**5.26**	**1.26**

Periodical changes in B concentration in leaves

During first year of study, application of B through foliar spray using B metalosate was more effective in enhancing the B concentration in tomato leaves after second foliar spray as compared to boric acid (Table 37). Combined application of Zn and B through metalosate could not improve the B content in leaves further. Moreover, soil application of B through borax could not maintain the level of B as obtained with foliar spray (Table 37). In mango, huge variation in leaf B content was recorded even before B spray however, after first spray after first spray leaf B concentration has increased dramatically with application of B through B Metalosate (Table 38). B applied through boric acid was also effective in enhancing the leaf B concentration. However, the magnitude of increase was bit less. Similar trend was exhibited by application of various B supplements after second spray also.

Table 37. Periodical changes in leaf B concentration (mg kg^{-1}) of tomato as influenced by different sources of B (borax, boric acid and B metalosate) at New Delhi

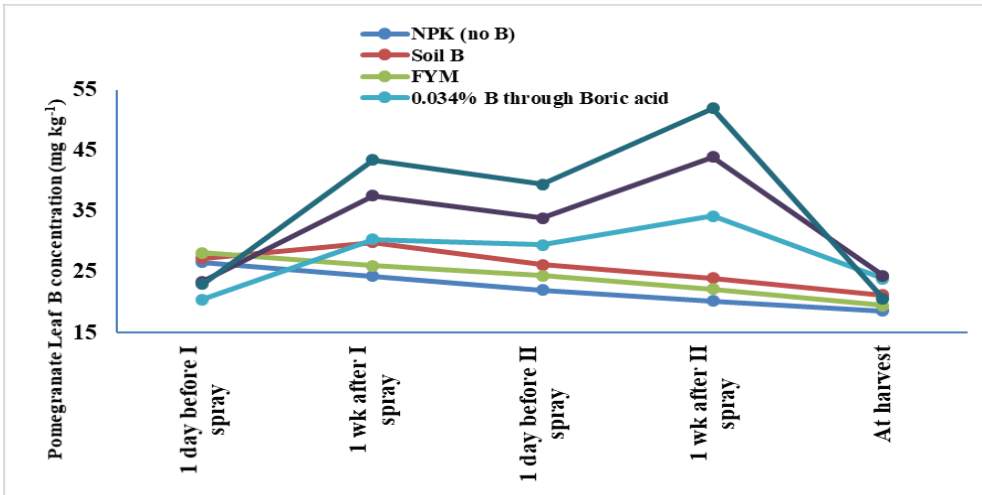
Treatment	Time of sampling	
	After 1st spray	After 2nd spray
1. NPK	22.15^{h}	19.40^{g}
2. NPK + Soil B through borax	26.44^{fg}	26.95^{ef}
3. NPK + FYM	24.05^{gh}	24.26^{f}
4. NPK + FS 0.017% B through Boric acid	27.98^{ef}	29.53^{e}

5.	NPK + FS 0.034% B through Boric acid	30.59[cde]	33.29[d]
6.	NPK + FS 0.051% B through Boric acid	32.46[bc]	37.24[c]
7.	NPK + FS 0.0034% B through B Metalosate	28.35[def]	39.70[c]
8.	NPK + FS 0.0085% B through B Metalosate	32.92[bc]	43.03[b]
9.	NPK + FS 0.017% B through B Metalosate	36.04[ab]	45.06[ab]
10.	NPK + FS 0.034% B through B Metalosate	38.81[a]	46.13[a]
11.	T_8 + FS 0.025% Zn through Zn Metalosate	30.25[cde]	44.74[ab]
12.	T_9 + FS 0.05% Zn through Zn Metalosate	31.71[cd]	45.63[ab]

Table 38. Periodical changes in leaf B concentration (mg kg^{-1}) of mango as influenced by different sources of B (borax, boric acid and B metalosate) at Lucknow

Treatment	Before 1st spray	After 1st spray	After 2nd spray
1. NPK	24.1	19.6	23.4
2. NPK + Soil B through borax	21.9	25.0	25.0
3. NPK + FYM	19.8	25.0	23.6
4. NPK + FS 0.017% B through Boric acid	20.7	26.4	22.0
5. NPK + FS 0.034% B through Boric acid	21.3	31.8	26.6
6. NPK + FS 0.051% B through Boric acid	18.9	34.6	29.9
7. NPK + FS 0.0034% B through B Metalosate	19.6	27.0	24.0
8. NPK + FS 0.0085% B through B Metalosate	22.3	37.6	27.9
9. NPK + FS 0.017% B through B Metalosate	21.6	38.1	31.0
10. NPK + FS 0.034% B through B Metalosate	15.3	35.5	32.6
11. T8 + FS 0.025% Zn through Zn Metalosate	24.1	36.6	29.4
12. T9 + FS 0.05% Zn through Zn Metalosate	18.0	38.3	22.0
CD (P=0.05)	**4.2**	**7.5**	**5.3**

Periodical changes in B concentration of pomegranate leaves and grape petioles as influenced by different sources of B is depicted in Figure 19. As expected, B concentration has increased with application of B however, the magnitude of increase varied with level of concentration and source of B. Among the various treatments, leaf B and petiole B concentration were more influenced when B was supplied at full dose of B either through B Metalosate or boric acid. Further, the highest B concentration in leaves and petiole after 1st and 2nd spray was recorded in treatment supplied with ½ of recommended B and Zn concentration through Metalosates. Similar to Zn, a consistent increase in B concentration in grape petiole and pomegranate leaves was observed before harvest stage however, it declined at harvest stage as some of the absorbed B might have translocated to berries and fruits.



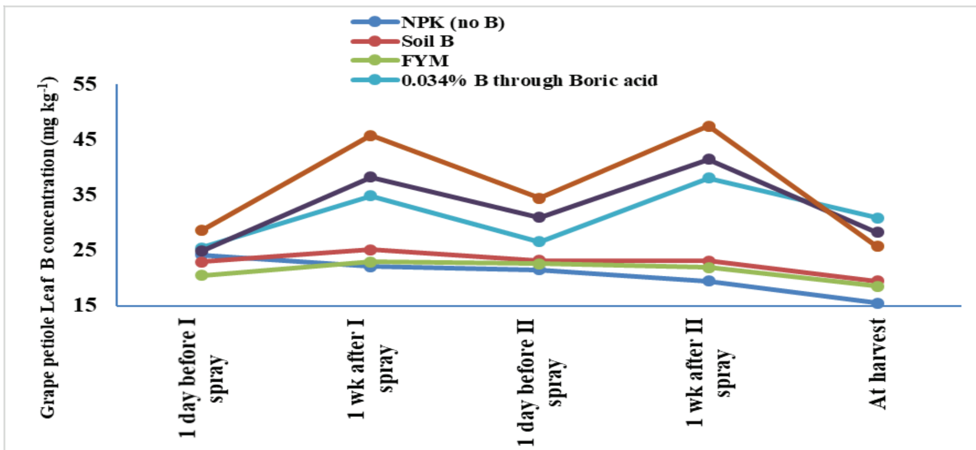


Figure 19. Periodical changes in B concentration (mg kg^{-1}) of pomegranate leaves and grape petiole as influenced by different sources of B (borax, boric acid and B metalosate) at Bengaluru

During second year of study, concentration of B in tomato leaf in the second year of study followed the trend as recorded in first year (Table 39). a huge variation in B content was recorded even before B spray in mango fruit leaves at Lucknow. However, leaf B concentration increased substantially after first spray of B through B Metalosate (Table 40). B applied through boric acid was also effective in enhancing the leaf B concentration however, at a similar extent after 1st spray. The higher concentration spray of B @ 0.051 % through boric acid was somewhat better. Similar trend was exhibited by application of various B supplements after second spray also.

Among the various treatments, leaf B and petiole B concentration were more influenced when B was supplied at full dose of B either through B Metalosate or full and higher dose through boric acid.

Table 39. Periodical changes in leaf B concentration (mg kg^{-1}) of tomato as influenced by different sources of B (borax, boric acid and B metalosate) at New Delhi

Treatment	Time of sampling	
	After 1st spray	After 2nd spray
1. NPK	22.1	21.4
2. NPK + Soil B through borax	29.1	27.1
3. NPK + FYM	24.6	25.0
4. NPK + FS 0.017% B through Boric acid	26.2	25.2
5. NPK + FS 0.034% B through Boric acid	33.7	31.1
6. NPK + FS 0.051% B through Boric acid	35.9	33.5
7. NPK + FS 0.0034% B through B Metalosate	27.7	25.3
8. NPK + FS 0.0085% B through B Metalosate	35.4	33.7
9. NPK + FS 0.017% B through B Metalosate	38.8	36.1
10. NPK + FS 0.034% B through B Metalosate	40.5	39.5
11. T_8 + FS 0.025% Zn through Zn Metalosate	38.7	35.0
12. T_9 + FS 0.05% Zn through Zn Metalosate	40.0	37.7
CD (P=0.05)	**4.66**	**4.84**

Table 40. Periodical changes in leaf B concentration (mg kg^{-1}) of mango as influenced by different sources of B (borax, boric acid and B metalosate) at Lucknow

Treatment	Before 1st spray	After 1st spray	After 2nd spray
1. NPK	24.90	21.20	19.50
2. NPK + Soil B through borax	22.20	28.30	21.90
3. NPK + FYM	20.00	25.00	23.50
4. NPK + FS 0.017% B through Boric acid	20.80	30.20	28.90
5. NPK + FS 0.034% B through Boric acid	24.90	32.90	32.00
6. NPK + FS 0.051% B through Boric acid	26.30	36.10	39.30
7. NPK + FS 0.0034% B through B Metalosate	22.90	27.20	31.90
8. NPK + FS 0.0085% B through B Metalosate	27.20	28.90	34.30
9. NPK + FS 0.017% B through B Metalosate	19.00	28.20	28.80
10. NPK + FS 0.034% B through B Metalosate	21.90	32.80	25.90
11. T8 + FS 0.025% Zn through Zn Metalosate	23.40	29.50	26.50
12. T9 + FS 0.05% Zn through Zn Metalosate	24.70	28.10	25.20
CD (P=0.05)	**4.20**	**5.48**	**4.87**

Further, the highest B concentration in leaves and petiole after 1st and 2nd spray was recorded in treatment supplied with ½ of recommended B and Zn concentration through Metalosate. Similar to Zn, a consistent increase in B concentration in grape petiole and pomegranate leaves was observed before harvest stage however, it declined at harvest stage as some of the absorbed B might have translocated to berries and fruits.

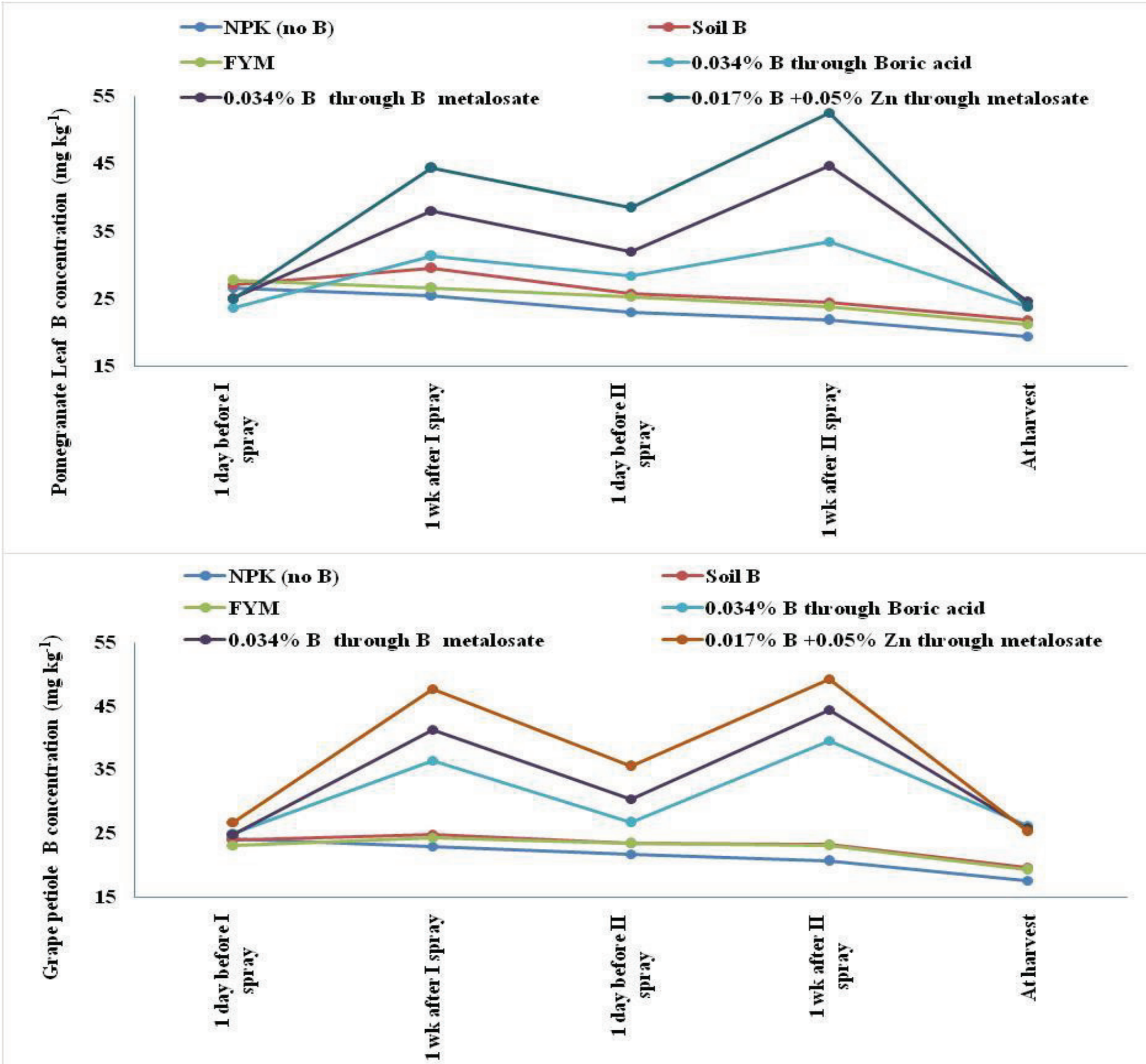


Figure 20. Periodical changes in B concentration of pomegranate leaves and grape petiole as influenced by different sources of B (borax, boric acid and B metalosate) at Bengaluru

Quality parameters

In both the year of study, application of various B supplements such as borax, boric acid and B Metalosate influenced fruit quality parameters of mango cv. Mallika significantly. During first year, Total Soluble Solids ranged from 18.3 to 22.5 Brix, acidity from 0.080 to 0.162%, ascorbic acid from 24.74 to 34.83 mg/100g, carotenoids from 2.29 to 3.79 mg/100g and total sugar from 15.17 to 18.95% under different treatments (Table 41). There was increasing trend of TSS, ascorbic acid, carotenoids and total sugar with increase in concentrations of various B supplements as well as combined use of Zn and B metalosate while acidity reduced correspondingly.

Table 41. Quality parameters of Mango as influenced by different sources of boron (borax, boric acid and B metalosate) at Lucknow

Treatment	TSS (Brix)	Acidity (%)	Ascorbic acid (mg/100g)	Carotenoids (mg/100g)	Total sugar (%)
1. NPK	18.30	0.108	24.74	2.29	15.17
2. NPK + Soil B through borax	20.73	0.094	29.33	2.77	17.42
3. NPK + FYM	19.30	0.135	31.16	2.63	16.02
4. NPK + 0.017% B through Boric acid	20.55	0.108	28.08	2.69	18.67
5. NPK + 0.034% B through Boric acid	20.75	0.107	30.53	2.78	17.05
6. NPK + 0.051% B through Boric acid	21.95	0.094	33.00	3.57	17.17
7. NPK + 0.0034% B through B Metalosate	20.15	0.162	26.58	2.75	16.72
8. NPK + 0.0085% B through B Metalosate	20.30	0.121	29.33	3.22	16.45
9. NPK + 0.017% B through B Metalosate	21.00	0.108	29.99	3.63	15.47
10. NPK + 0.034% B through B Metalosate	20.80	0.108	33.91	3.65	16.85
11. T8 + 0.025% Zn through Zn Metalosate	19.70	0.094	32.66	3.27	16.70
12. T9 + 0.05% Zn through Zn Metalosate	22.55	0.080	34.83	3.79	18.95
CD (P=0.05)	**1.51**	**0.091**	**8.47**	**0.34**	**1.61**

Application of B had also influenced various enzyme activities and protein content in mango fruit pulp (Table 42). In general, amylase activities increased in all the treatments irrespective of the level and source of the B. However, greater improvement was recorded in treatment receiving 5 t FYM ha^{-1} or 1.5kg B through borax. Thus the inference may be drawn that supply of B is effective in converting starch into sugar when applied at higher doses. Lower doses of B Metalosate and boric acid were more effective in enhancing the Invertase activity in fruit pulp. Lower doses of B Metalosate were also effective in enhancing the SOD activities in mango fruit. Reduction in SOD level with increasing level of B Metalosate application indicated that B Metalosate did not induce any oxidative stress in mango. With increase in B metalosate supply, protein content increased linearly at most places.

Table 42. Enzyme and protein activities in mango fruits as influenced by different sources of boron (borax, boric acid and B metalosate) at Lucknow

Treatment	Amylase	Invertase	PPO	SOD	Protein
1. NPK	0.34	26.98	0.028	1.36	0.59
2. NPK + Soil B through borax	1.37	21.27	0.004	1.53	0.66
3. NPK + FYM	1.64	28.08	0.002	0.47	0.64
4. NPK + 0.017% B through Boric acid	0.66	76.01	0.002	0.78	0.76

5. NPK + 0.034% B through Boric acid	0.33	46.51	0.002	1.14	0.60
6. NPK + 0.051% B through Boric acid	1.24	52.71	0.014	1.01	0.65
7. NPK + 0.0034% B through B Metalosate	0.60	74.83	0.002	3.91	0.59
8. NPK + 0.0085% B through B Metalosate	0.64	68.79	0.028	2.32	0.79
9. NPK + 0.017% B through B Metalosate	0.32	66.67	0.002	1.44	0.78
10. NPK + 0.034% B through B Metalosate	0.59	46.84	0.002	0.48	0.85
11. T8 + 0.025% Zn through Zn Metalosate	0.69	46.22	0.022	0.99	0.65
12. T9 + 0.05% Zn through Zn Metalosate	0.51	48.16	0.014	0.61	0.79
CD (P=0.05)	**0.08**	**0.42**	**0.11**	**0.23**	**0.03**

Amylase in mg starch hydrolyzed/mg protein; Invertase in µg sugar formed/mg protein; Polyphenol Oxidase (PPO) in ΔOD/ 100 mg fresh weight; Superoxide Dismutase (SOD) in EU/mg protein; Protein in mg/100 mg tissue.

During second year of study, Total Soluble Solids in mango cv. Mallika ranged from 18.8 to 22.4 Brix, acidity from 0.16 to 0.24%, ascorbic acid from 11.9 to 22.9 mg/100g, carotenoids from 1.3 to 8.4 mg/100g and total sugar from 16.2 to 19.2 % recorded in different treatments (Table 43). There was increasing trend with respect to TSS, ascorbic acid, carotenoids and total sugar with the increasing concentrations of various B supplements as well as combined use of Zn and B metalosate while acidity reduced correspondingly.

Table 43. Quality parameters of mango as influenced by different sources of boron (borax, boric acid and B metalosate) at Lucknow

Treatment	TSS (Brix)	Acidity (%)	Ascorbic acid (mg/100g)	Carotenoids (mg/100g)	Total sugar (%)
1. NPK	18.88	0.23	16.50	2.73	16.24
2. NPK + Soil B through borax	19.60	0.24	12.83	4.85	16.32
3. NPK + FYM	20.05	0.23	11.91	3.50	17.00
4. NPK + 0.017% B through Boric acid	20.70	0.22	16.50	1.49	16.22
5. NPK + 0.034% B through Boric acid	20.60	0.20	20.16	5.27	17.70
6. NPK + 0.051% B through Boric acid	20.25	0.19	13.75	3.50	16.10
7. NPK + 0.0034% B through B Metalosate	19.65	0.18	12.83	1.29	16.16
8. NPK + 0.0085% B through B Metalosate	20.25	0.16	14.66	4.43	17.82
9. NPK + 0.017% B through B Metalosate	21.23	0.22	15.58	3.32	17.01
10. NPK + 0.034% B through B Metalosate	21.50	0.20	13.75	8.35	18.90
11. T8 + 0.025% Zn through Zn Metalosate	22.43	0.19	22.91	3.64	19.20
12. T9 + 0.05% Zn through Zn Metalosate	20.83	0.19	12.83	3.53	18.83
CD (P=0.05)	**1.51**	**0.09**	**4.39**	**0.34**	**1.52**

Application of B has influenced various enzyme activities and protein content in mango fruit pulp (Table 44). In general, Amylase activities increased in all the treatments irrespective of the level and source of the B. However, greater improvement was recorded in treatment receiving 1.5kg B through borax followed by NPK. Lower doses of B Metalosate and boric acid were more effective in enhancing the Invertase activity in fruit pulp and SOD activities in mango fruit. Highest PPO content was recorded with the application of foliar spray of B @0.034% dose through boric acid. With increase in B metalosate application, SOD levels dropped.

Table 44. Enzyme and protein activities in mango fruits as influenced by different sources of boron (borax, boric acid and B metalosate) at Lucknow

Treatment	Amylase	Invertase	PPO	SOD	Protein
1. NPK	0.083	60.75	0.060	2.575	0.937
2. NPK + Soil B through borax	0.093	33.32	0.035	2.419	0.767
3. NPK + FYM	0.003	53.30	0.065	2.260	0.858
4. NPK + 0.017% B through Boric acid	0.041	33.53	0.058	2.149	0.793
5. NPK + 0.034% B through Boric acid	0.059	65.27	0.145	6.358	0.793
6. NPK + 0.051% B through Boric acid	0.067	33.79	0.049	4.849	0.683
7. NPK + 0.0034% B through B Metalosate	0.021	72.52	0.054	3.66	0.793
8. NPK + 0.0085% B through B Metalosate	0.061	111.44	0.054	5.816	0.823
9. NPK + 0.017% B through B Metalosate	0.035	24.55	0.039	4.076	0.974
10. NPK + 0.034% B through B Metalosate	0.059	50.99	0.013	4.239	0.857
11. T_8 + 0.025% Zn through Zn Metalosate	0.051	50.75	0.068	4.738	0.975
12. T_9 + 0.05% Zn through Zn Metalosate	0.044	87.95	0.055	2.846	0.746
CD (P=0.05)	0.003	1.471	0.005	0.091	0.013

Amylase in mg starch hydrolyzed/mg protein; Invertase in µg sugar formed/mg protein; Polyphenol Oxidase (PPO) in ΔOD/ 100 mg fresh weight; Superoxide Dismutase (SOD) in EU/mg protein; Protein in mg/100 mg tissue.

CONCLUSION

In geographical areas of low phytoavailability, essential mineral nutrients are supplied to crops as fertilizers to achieve greater yields. In addition, fertilizers containing essential mineral elements are occasionally supplied to crops to increase their concentrations in edible portions for the benefit of human health. In order to explore the suitability of new Zn and B based products/ carriers for supplementation, the field experiments were conducted to evaluate the performance of Zinc Metalosate and Boron Metalosate against the standard sources of Zn and B on fruits (like grape, pomegranate, mango and apple), vegetables (cauliflower, tomato, capsicum and potato) and cereal (rice, wheat and maize) crops. The products were evaluated at GKVK, Bengaluru (Karnataka), ICAR-IARI, New Delhi, ICAR-CISH, Lucknow (UP), CSKHPKV, Palampur (HP), ICAR-NRRI, Cuttack (Odisha) and ICAR-IISS, Bhopal under the aegis of All India Coordinated Research Project on Micro and Secondary Nutrients and Pollutant Elements in Soils and Plants during the year 2015-16 and 2016-17.

On the basis of two-years experimentation and demonstration trial on farmers' field, the performance (yield, agronomic efficiency, Zn/B concentration and crop quality) of Zn and B M etalosate liquid formulations has been rated either at par and/or superior to standard sources of Zn (zinc sulphate, Zn-EDTA) and B (Borax and Boric acid) commonly used in India. The yield and quality of fruit and vegetable crops obtained under ½ to ¼ dose of Metalosate liquid formulations were at par with the that recorded under recommended doses of standard sources of Zn and B fertilizer. Thus, the products could be recommended for mitigating Zn and B deficiency in crops at farmers' field and also for enhancing Zn and B loading in edible plant parts.

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