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Effect of Zinc Biofortification in Sweet Corn (*Zea mays* L. *saccharata*)

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ABSTRACT

A field experiment was carried out at the Student's Research Farm, Khalsa College, Amritsar during *Kharif* season of 2022. The experiment consisted of ten treatments *viz,* T_1: Control, T_2: Seed inoculation (*Bacillus subtilis*), T_3: Seed treatment with $ZnSO_4$@0.5%, T_4: Foliar application of $ZnSO_4$@0.5%, T_5:Seed treatment with $ZnSO_4$@0.5% + foliar application of $ZnSO_4$@0.5%, T_6: Seed treatment with $ZnSO_4$@1%, T_7: Foliar application of $ZnSO_4$@1%, T_8: Seed treatment with $ZnSO_4$@1% + foliar application of $ZnSO_4$@1%, T_9: Seed inoculation (*Bacillus subtilis*) + seed treatment with $ZnSO_4$@0.5% + foliar application of $ZnSO_4$@0.5%, T_{10}: Seed inoculation (*Bacillus subtilis*) + seed treatment with $ZnSO_4$@1% + foliar application of $ZnSO_4$@1% with four replications in RBD design.The results revealed that treatment (T_{10}) *i.e.* Seed inoculation (*Bacillus subtilis*)+ seed treatment with $ZnSO_4$@1% + foliar application of $ZnSO_4$@1% recorded higher grain yield (37.6 q/ha), stover yield (70.5 q/ha), harvest index (34.7%), zinc content in grains (40.7 mg/kg), zinc uptake by grains (153.0 g/ha), zinc content in stover (53.1 mg/kg), zinc uptake by stover (374.3 g/ha) than control and treatments where zinc was applied as seed treatment and foliar application. All these parameters were followed by T_9, T_8, T_5, T_7, T_4, T_6, T_3, T_2, T_1.

Key Words: Zinc biofortification, Solubilizer, Sweet corn, Zinc.

INTRODUCTION

Maize (*Zea mays* L.) is an important cereal crop of the world (Tollennar and Lee, 2002) also called Queen of Cereals because of its high productive potential as compared with any other cereal crop. In Punjab, during 2022, maize occupied an area of 105.2 thousand hectares, with a production of 413.4 thousand tonnes (Anonymous, 2022a). Sweet corn (*Zea mays* L. *saccharata*) is very popular in consumers for its unique taste, pleasant flavour and sweetness (Bodhare, 2023). Sweet corn differs from maize due to its genetic mutations that confer a sugary endosperm (Fritz *et al,* 2010). Sweet corn (*Zea mays* L. *saccharata)* also known as Sugar Corn is a hybridized variety of maize (*Zea mays* L.) specifically bred to increase sugar content. Total sugar content in sweet corn at milky stage ranges 25 to 30 per cent as compared with 2 to 5 per cent of normal corn. Modern sweet corn varieties are classified as normal sugary (Su), sugary enhanced (Se) and shrunken (Sh_2) which are also called as super sweet.These differ in sweetness and ratio of conversion of sugar to starch (Singh *et al,* 2014). Sweet corn has highly nutritional value, according to a study per 100g of sweet corn contains 19.02g carbohydrates, 2.70g dietary fiber, 1.18g fat and 3.2g protein. Zinc activates enzymes responsible for the synthesis of certain proteins. It is helpful in the formation of chlorophyll and some carbohydrates. Zinc is essential in the formation of auxins, which help in growth regulation. Zinc deficiency not only retards the growth and yield of plants but also affects human beings (Ayalew, 2016) with malnutrition, neuronal disorders of susceptibility to various infectious diseases (Hafeez *et al*, 2013). More than two billion people around the world are victims of hidden hunger (Garg *et al*, 2018).

Bio-fortification is an evolving techniques to overcome micro-nutrient malnutrition (Ngozi, 2013). It is attained by applying micro-nutrients to soil or directly to foliage of crop (Valenca *et al*, 2017). The unavailable zinc compounds can be

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converted back to available form through bio-augmentation of plant growth promoting *Rhizobacteria* (PGPR) inoculants having the ability to solubilize zinc compounds, may be called as Zn solubilizing bacteria (ZSB). Several ZSB strains have been documented for their ability to solubilize unavailable forms of Zn thus improving plant growth, yield and grain quality. Among several ZSB strains, Zn solubilizing *Bacillus* strains solubilize unavailable Zn compounds through production of chelating ligands, secretion of organic acids, amino acid, phytohormones. They are beneficial for plants as they increase the root functions, decrease disease impact, increase plant growth and development (Rana *et al*, 2012; Ramesh *et al,* 2014; Abaid-Ullah *et al*, 2015). Zn solubilizing *Bacillus* strains have the ability to increase uptake and translocation of Zn. Zinc fertilizers are widely used to enhance the yield and Zn contents and quality of edible grains of different crops. Seed priming with Zn sulphate solution speed up the emergence of crop and finally increased grain yield (Aboutalebian *et al,* 2012). Foliar Zn application is more effective as compared with soil applied Zn to increase grain Zn contents of cereals, whole grain Zn concentration including endosperm could be increased by foliar application (Cakmak *et al,* 2010).Therefore, this field experiment was designed to evaluate the effects of different methods of Zn application on yield and quality characteristics of sweet corn.

MATERIALS AND METHODS

The field experiment entitled Effect of Zinc Biofortification in Sweet Corn (*Zea mays* L. *saccharata*) was conducted at Student's Research Farm, Khalsa College, Amritsar during *Kharif* season of 2022.The weekly mean meteorological data recorded during crop season (July to November, 2022) at Amritsar is located at 30-38' N latitude, 74-52' E longitude and altitude of 236 m above sea level.This tract is characterized by semi humid climate. During the research period, the maximum wind speed was observed 5.20 Km/hr and minimum was 1.58 km/hr. The maximum relative humidity was 82.29 per cent and minimum was 13.07 per cent. The monsoon generally start in the second week of July. The soil in the experimental field was sandy loam.The experiment was laid out in Randomized Block Design (RBD) with four replications and ten treatments comprising T_1:Control, T_2: Seed inoculation (*Bacillus subtilis*), T_3: Seed treatment with $ZnSO_4$@0.5%, T_4: Foliar application of $ZnSO_4$@0.5%, T_5: Seed treatment with $ZnSO_4$@0.5%+ foliar application of $ZnSO_4$@0.5%, T_6:Seed treatment with $ZnSO_4$@1%, T_7: Foliar application of $ZnSO_4$@1%, T_8: Seed treatment with $ZnSO_4$@1%+ foliar application of $ZnSO_4$@1%, T_9: Seed inoculation (*Bacillus subtilis*)+ seed treatment with $ZnSO_4$@0.5%+ foliar application of $ZnSO_4$@0.5%, T_{10}: Seed inoculation (*Bacillus subtilis*)+seed treatment with $ZnSO_4$@1%+ foliar application of $ZnSO_4$@1%. Sowing was done as per treatment. Sweet corn variety Sugar-75 was sown by dibbling two seeds per hill keeping row to row spacing of 60 cm and plant to plant spacing of 20 cm. Generally irrigations was applied during the pre-tasselling, silking and grain filling stage. Fertilizer nitrogen was applied at 125 kg/ha and and zinc sulphate (monohydrate) at 15 kg/ha. For plant protection measures, Coragen 20 SC (Chlorantranilliprole) @ 200 ml/ha in 150 litres of water was applied at 25 and 36 days after sowing of crop. Sweet corn was harvested when endosperm inside the kernels was still liquid. Observations on different parameters such as grain yield, stover yield, harvest index, Zn content and uptake by grains and stover were recorded and further analysis. Data recorded were subjected to analysis of variance (ANOVA) using EDA software developed by Department of Mathematices and Statistics, PAU, Ludhiana.

RESULTS AND DISCUSSION

Effect of Zinc Biofortification on grain yield, stover yield and harvest index in sweet corn (*Zea mays* L. *saccharata*).

Grain yield (q/ha)

The grain yield varied significantly with different zinc application methods (Table 2).The data showed that higher grain yield (37.6 q/ha) was observed in T_{10} when zinc was integrated through 3 methods which was also at par with T_9 having grain yield of (36.1 q/ha) and T_8 having grain yield of (35.3 q/ha) as compared with all other treatments where one or two methods of zinc was applied. T_5 produced grain yield of (34.1 q/ha) which was significantly better as compared with T_1 (28.2 q/ha) and T_2 (29.1 q/ha) and remained at par with T_7, T_4, T_6, T_3. Per cent increase in grain yield in T_{10}(33.3%), T_9 (28.0%), T_8 (25.1%), T_5(20.9%), T_7(17.7%), T_4(13.8%), T_6(10.9%), T_3(6.73%), T_2(3.19%) was recorded as compared with control. Seed treatment with Zinc sulphate showed increase in grain yield (Harris *et al,* 2007). Zinc solubilizing *Bacillus* strains solubilize unavailable Zn compounds through production of chelating ligands, secretion of organic acids, phytohormones and thus improving plant growth, yield and grain quality. Higher grain yield recorded might be due to fulfillment of source (leaves) to sink (grain), through supply of required nutrients by 3 methods, Zn application showed beneficial effect on physiological process, plant metabolism, growth thereby leading to higher grain yield. Zn application also enhanced the carbohydrates supply to kernels, increasing yield components like cob length, number of grains per cob which was due to better vegetative growth of crop plant, which have direct influence on grain yield. Similar results were given by Naik *et al* (2019), Shivay and Prasad (2014), Mumtaz *et al* (2018).

Stover Yield (q/ha)

Stover yield is an important parameter of the biological yield to evaluate its productivity index for judging the ultimate performance of a crop.The data showed that higher stover yield of (70.5 q/ha) was observed in T_{10} which was at par with T_9 having stover yield of (69.6 q/ha) and T_8 having stover yield of (68.3 q/ha). T_5 gave statistically higher stover yield of (67.8 q/ha) as compared with T_1(61.8 q/ha), T_2(62.2 q/ha) and remained at par with T_7, T_4, T_6, T_3. Per cent increase in stover yield in T_{10}(14.0%), T_9 (12.6%), T_8 (10.5%), T_5(9.70%), T_7(7.11%), T_4(6.47%), T_6(4.20%),T_3(3.07%), T_2(0.71%) was recorded as compared with control.This might be due to more vegetative growth. These results were in line with Preetha and Stalin (2014).

Harvest index (%)

The harvest index signifies the yield of the plant parts of economic interest, as per cent of total biological yield in terms of dry matter.The data indicated that harvest index was not significantly influenced by different zinc applications methods. However, highest harvest index (34.7%) was recorded in T_{10} and the lowest harvest index (31.3%) was recorded in T_1. Per cent increase in harvest index in T_{10}(10.8%),T_9(9.26%),T_8(8.62%), T_5(6.90%), T_7(6.70%), T_4(4.47%), T_6(4.46%), T_3(2.23), T_2(1.59%) was recorded as compared with control. Similar results were given by Azab *et al* (2015).

Effect of Zinc Biofortification on Zn content and Zn uptake by grains and stover in sweet corn (*Zea mays* L. *saccharata*).

Zn content in grains (mg/kg)

Zn content in grains is an indication of potential yield response to applied zinc solubilizers, seed and foliar application. It was evident that Zn content in grains was influenced by different zinc application methods. Higher Zn content (40.7 mg/kg) in grains was recorded in T_{10} which was significantly higher as compared with T_1, T_2, T_3, T_6 and was at par with rest of treatments and the lowest Zn content (31.1 mg/kg) in grains was found in control. Per cent increase in Zn content in grains in T_{10}(30.8%), T_9(27.0%), T_8(19.9%), T_5(19.2%), T_7(17.0%), T_4(13.5%),T_6(9.96%), T_3(6.43%), T_2(2.89%) was recorded as compared with control. Zn solubilizing *Bacillus* strains has the ability to increase uptake and translocation of Zn. Whole grain Zn concentration including endosperm could be increased by foliar application of Zn (Cakmak *et al,* 2010). Higher zinc content in grains might be due to Zn function to improve metabolic reactions, activation of enzymes that leads to improvement in quality parameters like Zn content.Similar results were reported by Kumar (2011) and Mumtaz *et al* (2018).

Zn uptake by grains (g/ha)

Zn application also influenced the Zn uptake by grains. It was noted that Zn uptake by grains (153.0 g/ ha) was the highest in T_{10} and it was statistically higher than all treatments except T_9 and the lowest Zn uptake by grains (87.7 g/ha) was recorded in control. Per cent increase in Zn

Table 1. Weekly mean meteorological data recorded during the crop season (July-November, 2022).

Date	Standard meteorological week	Wind speed (Km/hr)	Relative humid ity (%)	Total rainfall (mm)	T max. (^{o}C)	T min. (^{o}C)
July	21	5.20	31.14	9.08	39.51	25.80
	22	2.80	23.26	5.28	43.48	28.71
August	23	3.37	13.07	0	46.29	30.21
	24	3.53	24.08	20.96	44.44	31.82
	25	3.15	48.27	43.01	36.32	25.84
	26	3.04	42.05	28.05	40.71	29.41
	27	2.39	57.13	24.83	38.36	29.49
	28	3.21	62.03	90.6	37.03	28.65
September	29	2.28	70.81	101.28	35.67	27.46
	30	2.29	80.08	56.92	32.87	26.34
	31	1.86	82.29	68.27	32.98	26.48
	32	2.40	81.47	70.42	33.14	25.90
October	33	3.14	80.52	47.61	32.70	25.54
	34	2.83	79.64	45.88	32.89	25.72
	35	1.58	79.17	4.38	33.45	25.04
November	36	1.82	74.49	22.00	33.36	24.78
	37	1.87	74.65	23.74	33.43	24.82
	38	2.02	73.31	25.00	33.48	24.40
	39	2.28	75.09	43.87	31.72	22.54

uptake by grains in T_{10}(74.4%), T_9(62.4%), T_8(50.0%), T_5(44.2%), T_7(37.7%), T_4(29.1%), T_6(22.0%), T_3(13.5%), T_2(6.84%) was recorded as compared with control.The improvement in uptake of nutrients may be due to stimulation of root proliferation by effects of bacterial strains and Zn play an important role in biosynthesis of enzymes and resulted in favourable effects of Zn on metabolic reaction within plants which provide more uptake of nutrients for plants.This might be also due to slow release of these micro-nutrients into soil solution which facilitate more Zn uptake by grains. Similar results were given by Dwivedi *et al* (2002).

Zn content in stover (mg/kg)

Zn content in stover is an indication of Zn applied to the crop and uptake by the plant. Zinc content in stover was influenced by different zinc application methods. Higher Zn content (53.1mg/kg) in stover was recorded in T_{10} and the lowest Zn content in stover (42.1 mg/kg) was found in T_1. Per cent increase in Zn content in stover in T_{10} (26.3%), T_9 (26.1%), T_8(20.4%),T_5(16.6%), T_7(14.0%),T_4(13.3%), T_6(9.97%), T_3(9.0%), T_2(2.61%) was recorded as compared with control. Increase in zinc content in stover might be due to bacterial strains provide Zn by symbiosis to corn roots and seed and foliar application also enhances Zn absorption in stover.Similar results were given by Mumtaz *et al* (2018).

Zn uptake by stover (g /ha)

Zn application also influenced the Zn uptake by stover. Higher Zn uptake by stover (374.3 g/ ha) was recorded in T_{10} which was statistically higher from all other treatments except T_9 and the lowest Zn uptake by stover (260.1 g/ha) was found in control. Per cent increase in Zn uptake by stover in T_{10}(43.9%), T_9(41.2%), T_8(33.1%), T_5 (27.9%), T_7(22.6%), T_4 (20.6%), T_6 (14.5%), T_3(12.5%), T_2(3.30%) was recorded as compared with control. This might be due to colonization of ZSB that facilitate solubilization of tightly bound fraction of nutrients. Plant absorb and accumulate more Zn in stover as compared with grain. Similar results were given by Tariq *et al* (2014).

Table 2. Effect of Zinc Biofortification on grain yield, stover yield and harvest index in sweet corn (*Zea mays* L. *saccharata*).

Symbol	Treatment	Grain Yield (q/ha)	Stover Yield (q/ha)	Harvest index (%)
T_1	Control	28.2	61.8	31.3
T_2	Seed inoculation (*Bacillus subtilis*)	29.1	62.2	31.8
T_3	Seed treatment with $ZnSO_4$@0.5%	30.1	63.7	32.0
T_4	Foliar application of $ZnSO_4$@0.5%	32.1	65.8	32.7
T_5	Seed treatment with $ZnSO_4$@0.5% + foliar application of $ZnSO_4$@0.5%	34.1	67.8	33.5
T_6	Seed treatment with $ZnSO_4$@1%	31.3	64.4	32.6
T_7	Foliar application of $ZnSO_4$@1%	33.2	66.2	33.4
T_8	Seed treatment with $ZnSO_4$@1%+ foliar application of $ZnSO_4$@1%	35.3	68.3	34.0
T_9	Seed inoculation (*Bacillus subtilis*)+ seed treatment with $ZnSO_4$@0.5%+ foliar application of $ZnSO_4$@0.5%	36.1	69.6	34.2
T_{10}	Seed inoculation (*Bacillus subtilis*)+ seed treatment with $ZnSO_4$@1%+ foliar application of $ZnSO_4$@1%	37.6	70.5	34.7
CD (p=0.05)		3.27	5.06	NS

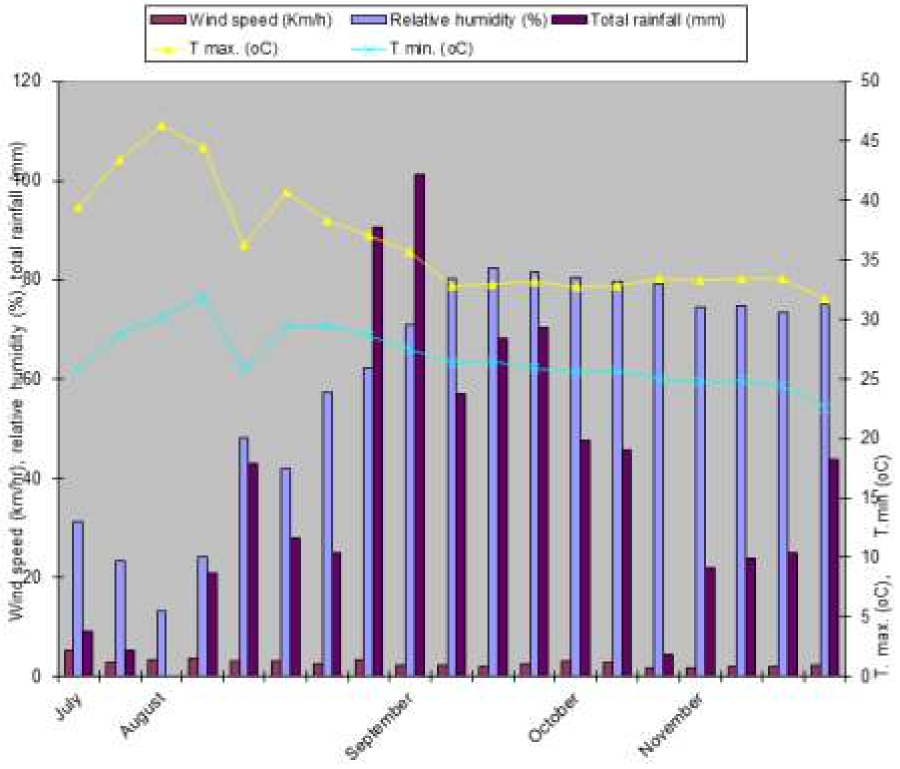

Figure1 Weekly mean meteorological data recorded during the crop season (July-November, 2022).

Table 3. Effect of Zinc Biofortification on Zn content and uptake by grains and stover in sweet corn (*Zea mays* L. *saccharata*).

Symbol	Treatment	Zn content in grains (mg/kg)	Zn uptake by grains (g/ha)	Zn content in stover (mg/kg)	Zn uptake by stover (g/ha)
T_1	Control	31.1	87.7	42.1	260.1
T_2	Seed inoculation (*Bacillus subtilis*)	32.2	93.7	43.2	268.7
T_3	Seed treatment with $ZnSO_4$@0.5%	33.1	99.6	45.9	292.3
T_4	Foliar application of $ZnSO_4$@0.5%	35.3	113.3	47.7	313.8
T_5	Seed treatment with $ZnSO_4$@0.5%+ foliar application of $ZnSO_4$@0.5%	37.1	126.5	49.1	332.8
T_6	Seed treatment with $ZnSO_4$@1%	34.2	107.0	46.3	298.1
T_7	Foliar application of $ZnSO_4$@1%	36.4	120.8	48.2	319.0
T_8	Seed treatment with $ZnSO_4$@1%+ foliar application of $ZnSO_4$@1%	37.3	131.6	50.7	346.2
T_9	Seed inoculation (*Bacillus subtilis*)+ seed treatment with $ZnSO_4$@0.5%+ foliar application of $ZnSO_4$@0.5%	39.5	142.5	52.8	367.4
T_{10}	Seed inoculation (*Bacillus subtilis*)+ seed treatment with $ZnSO_4$@1%+ foliar application of $ZnSO_4$@ %	40.7	153.0	53.1	374.3
CD(p=0.05)		6.20	20.8	7.60	26.1

CONCLUSION

Keeping in view the results obtained after experimental period, it may be concluded that seed inoculation (*Bacillus subtilis*) + seed treatment with $ZnSO_4$@1% + foliar application of $ZnSO_4$@1% (T_{10}) significantly produced higher grain yield, stover yield, harvest index and higher quality characteristics such as Zn content and uptake by grains and stover and this is contributing to human nutrition (biofortification).

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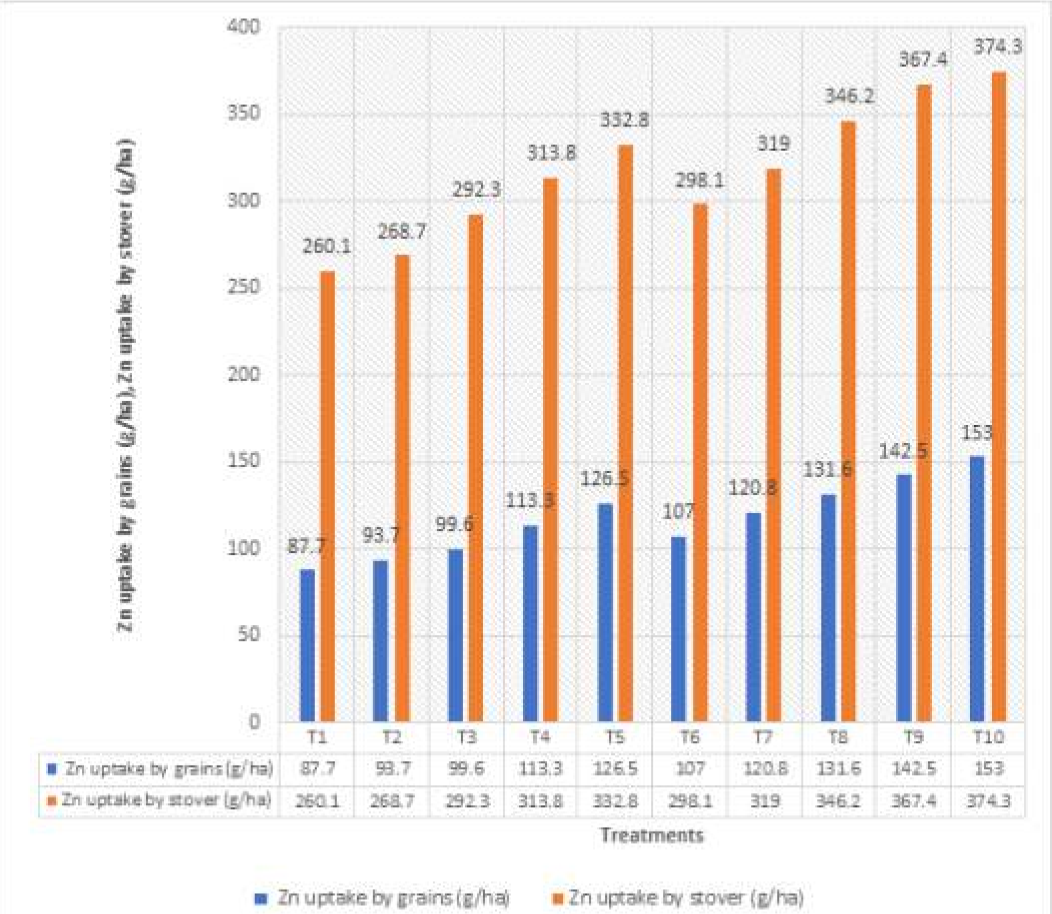

Figure 2 Effect of Zinc Biofortification on Zn uptake by grains and Zn uptake by stover in sweet corn (*Zea mays* L. *saccharata*).

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