

Response of Capsicum Hybrids to Zinc (Zn) Fertilization under Protected Cultivation

Abstract

Micronutrients, particularly Zinc (Zn), play a vital role in the growth and development of plants due to its catalytic effect on many metabolic processes. However, the varietal responses to growth and yield vary significantly. A screening experiment was conducted to know the growth and yield response of six capsicum hybrids viz., Indra, Priyanka, Inspiration, Massilia, Bachata and Local green with two levels of ZnSO₄ (with and without ZnSO₄) as basal soil application. The growth and yield attributes at harvest stage was recorded. The dry matter production (DMP) and fresh fruit yield was also noted for all the six hybrids. Results revealed that, Zn fertilisation significantly improved the plant height, root growth, fruit development as well as fresh fruits yield. Higher plant height (83 cm), root length (37 cm), root volume (13 cc), fruit numbers, fruit weight (15 and 133g), fruit length, girth, pericarp thickness (9.17, 8.25 and 0.67 cm), DMP (65.0 g pot⁻¹) as well as fresh fruit yield (4.70 kg pot⁻¹) were observed with Indra followed by Inspiration and Bachata. Lesser response for the Zn application was noticed with the local green hybrid for various growth and yield traits. Indra was found to be highly responsive to Zn fertilisation while Inspiration, Bachata, Massilia, and Priyanka were medium responsive and local green hybrid was observed to be less responsive to Zn fertilisation.

Keywords: Capsicum hybrids, Zn fertilization, growth attributes, root traits, yield, DMP

1. INTRODUCTION

Greenhouse vegetable production is a lucrative industry and capsicum has become one of the most popular vegetable commercially grown under protected cultivation because of its adaptability to various situations. It is grown on large scale as an off season vegetable crop and its consumption in India is increasing day by day due to the hike in demand by urban consumers [1, 2]. Plants grown in greenhouse and open field conditions vary in their growth periods and responses to fertilizer nutrients and growing climate very significantly. Due to constant microclimate, crops grown under greenhouse were shown to have high photosynthetic ability and higher yield [3] thus having exhaustive effect on soil fertility which needs to be addressed adequately. Monitoring the nutrients in soil and removal by crops is an important tool in fertilizer management of crops. Capsicum responds well to fertilizer applications and is reported to have high demand for major nutrients (NPK). Fontes *et al.*, [4] evaluated the nutrient accumulation in capsicum under greenhouse condition and reported that nitrogen (N) content in shoot and fruits increased to the maximum of 11.562 and 4.679 mg plant⁻¹, respectively, 224 days after transplantation, where 40.5% was retained by fruits. For potassium (K), there was an accumulation of 250 kg ha⁻¹, and 40% was accumulated in the fruit. The calcium (Ca) and sulfur (S) accumulation was 114 kg ha⁻¹ and 23 kg ha⁻¹, respectively. Next to major nutrients, micronutrients are usually required in lesser quantities and equally essential for various plant metabolic activities. Particularly Zn deficiency in Indian soils is likely to increase from 49 to 63% by 2025 makes it essential for crops with scheduled fertilization [5].

The Zn also plays a fundamental role in basic biochemical processes such as enzyme catalysis or activation, protein synthesis, carbohydrate and auxin metabolism, chlorophyll production, pollen formation, cytochrome and nucleotide synthesis, maintenance of membrane integrity, and energy dissipation [6]. In plants, 90.5% of the total Zn required moves towards the roots by diffusion. It is also transported in the xylem tissues from roots to shoots [7]. However maximum Zn content has been detected in the phloem tissues indicating Zn remobilization towards the fruit during ripening [8]. Deficiency of Zn results in various abnormalities in the development of plants which becomes visible as deficiency symptoms such as reduction in flowering and fruit development with prolonged growth periods which resulted in delayed maturity and decreases yield and quality. Hence, results in sub-optimal nutrient-use efficiency, reduction in photosynthesis and nitrogen metabolism [9]. Zinc deficiency occurs predominantly in arid and semi-arid, calcareous, sandy, peat soils, and high phosphorus-containing soils [10]. Zinc fertilization to deficient soils could increase the yield of crops [11] and also increases the plant height, number of side branches, and leaf area [12]. Foliar spraying of Zn and salicylic acid increased the fruit yield and quality as well as Nitrogen (N), Phosphorus (P), Potassium (K) intake [13] and water use efficiency [14]. The role of Zn in various plant metabolic processes was studied by several authors [15], [16],[17] who reported that, application of micronutrients as foliar spray caused an enhancement in plant growth, fruit yield and its physical and chemical properties of fruits. In the same way, authors studied the effect of foliar application of micronutrients and reported significant improvement in yield [18], which might be attributed to increased photosynthetic activity and increased the production and accumulation of carbohydrates. Also, the effect of soil application of micronutrients on the yield and quality of capsicum was studied [19] and noticed higher fruit weight and yield. Perusal of the literature showed differential responses of plants' physiology for different levels of Zn which vary with cultivars. Hence the present investigation was carried out to understand the differential responses of capsicum hybrids to Zn fertilisation in terms of growth and development of crop as well as fruit yield.

2. MATERIALS AND METHODS

2.1 Experimental details

A screening experiment was conducted to know the growth attributes, root traits and yield attributes of six capsicum hybrids to zinc fertilization grown in grow bags under protected cultivation in the farmer's field (110 48' 15.8" N 770 59' 25.3" E) at Thalavadi, Erode district. The experiment consists of two treatments viz., control (No Zn), and 37.5 kg ZnSO₄ application ha⁻¹ which were tested with six capsicum hybrids viz., Indra, Priyanka, Inspiration, Massilia, Bachata, and local green. The experiment was laid out in a Randomised Block Design with three replications. Recommended fertilizer nutrients such as Nitrogen, Phosphorus, and Potassium were applied as per soil test recommendation. About 45 days old seedlings of all the capsicum hybrids were transplanted in each grow bag, and the treatments were imposed. Necessary plant protection measures were carried out as and when needed. The growth attributes viz., plant height, leaf length, breadth, root length, root volume as well as yield and dry matter production with the application of zinc were determined and reported.



Plate 1. Overview of the experiment

2.2 Soil processing and analysis

Soil collected from the farmer field was shade dried, sieved and used for analysis. Soil pH and electrical conductivity were determined using 1:25 soil water suspension [20] and Organic carbon was estimated using wet digestion method [21]. Phosphorous was estimated colorimetrically [22], Potassium by neutral normal ammonium acetate using flame photometry [23], Nitrogen by kjeldahl distillation method [24] and DTPA extractable Fe, Zn, Mn and Cu as per the standard method given by Lindsay and Norwell [25] using atomic absorption spectrophotometry (GBC Avanta model).

2.3 Measurement of Growth and Root Traits

The plant height was measured randomly in five plants by measuring the length of plant from collar region of the shoot to meristem and it was expressed in centimetre. Leaf length and leaf breadth was also measured for each treatment in plants.

Root length was determined by measuring the length of root from the base of the stem to the tip of the lengthiest root and expressed in centimetre. The root volume was observed by immersing the washed root in a measuring cylinder filled with known quantity of water. The increase in volume of the water was measured and expressed in cubic centimetre [26].

2.3 Dry matter production

The plants from each grow bag was uprooted, washed with water to remove the soil particles, shade dried and oven dried at 70°C for 24 hours or until obtaining constant weight and the dry weight was reported as gram per grow bag.

2.4 Fruit Yield and yield attributes

In each pot, capsicum fruits at marketable stage were harvested weekly and the total yield as an average was computed by using the fruit yield (kg plant^{-1}) from each plot. The average fruit length in cm was determined after measuring the length of ten fruits at random. Furthermore, the fruit diameter and pericarp thickness in cm was determined with a “vernier caliper” for ten fruits selected at random. Weight of the single fruit was measured using digital weighing balance and fruit yield per plant was calculated and expressed as grams.

2.5 Statistical analysis

The data obtained from the study were subjected to the analysis of variance to find out the significance [27] using SPSS software. Principal component analysis and hierarchical clustering were plotted using R studio software [28].

3. RESULTS AND DISCUSSION

3.1 Physico-chemical properties of the experimental soil

The experimental soil was sandy loam in texture with neutral pH (7.42) and lesser electrical conductivity (0.33 dS m^{-1}). The organic carbon content of the soil was low (0.40%) and non-calcareous in nature (2.50% free CaCO_3). The soil had low available nitrogen (157 kg ha^{-1}), medium available phosphorus (12.0 kg ha^{-1}) and available potassium (280 kg ha^{-1}) status. Regarding the available micronutrients, zinc was deficient (0.68 mg g^{-1}) while other micronutrients were sufficient (6.50, 3.48 1.00, and 0.52 mg kg^{-1} for iron, manganese, copper, and boron, respectively) in the soil.

3.2 Growth attributes

Plant height (cm) represents the growth rate of capsicum as it is one of the main growth contributing factors and presented in Fig 1(a), which denoted significant differences among all capsicum hybrids. It was observed that, basal soil application of soil test based NPK + $37.5 \text{ kg ZnSO}_4 \text{ ha}^{-1}$ increased the plant height up to 83 cm in Indra followed by Inspiration (77 cm), Bachata (73.5cm), Massilia (76.1 cm), Priyanka (73.07 cm) and local green (66.1 cm). Lesser plant height (76.83, 73.6, 71.03, 68.57, 66.6 and 64.0 cm respectively) of all the genotypes was observed with control. There was a great variation between the treatments in terms of plant height (cm) which would be very beneficial for capsicum growers. In capsicum crop more plant height produces more flowers, thus ultimately producing more yields per plant. The favourable effect of Zn in improving plant height might be due to its role in enhancement of photosynthetic and chlorophyll structure formation, augmenting cell elongation and division which lead to an increase in plant metabolism resulting in increased plant growth parameters over the no Zn control [29]. Moreover, research findings also reported an increase in plant height with the application of zinc fertilizers [30] and foliar application of Zinc and Boron @ 1g/L for capsicum increased the plant height and number of leaves per plant [31].

Maximum leaf length and breadth of 18.7 and 9.23 cm was recorded with hybrid Indra [Fig1 (a& b)] by the addition of soil test based NPK + $37.5 \text{ kg ZnSO}_4 \text{ ha}^{-1}$ followed by Inspiration (15.1, 8.73 cm), Bachata (13.3, 8.20 cm), Priyanka (12.1, 6.97 cm), Masilia (12.3, 7.50 cm) and Local green (11.1, 6.03 cm). Leaf length and breadth are important yield contributing parameters in capsicum. Comparatively lesser leaf length and breadth was noticed in control (no Zn) irrespective of capsicum hybrids and minimum leaf length and breadth was found in Local green hybrid. An increase in the above growth parameters due to the application of zinc may be attributed to the improvement in plant growth and enhancement in the photosynthetic and other metabolic activities which led to increase in various plant metabolites responsible for cell division and cell elongation due to the optimum supply of

zinc and also increased the growth of internodal portion with higher synthesis of growth hormones like indole acetic acid (IAA) and metabolizing gibberlic acid [32,33,34].

3.3 Root traits

The root traits such as root length and root volume of the capsicum hybrids were recorded and given in Fig.2. The results envisaged that, application of soil test based NPK + 37.5 kg ZnSO₄ ha⁻¹ had a positive influence on root length and root volume of capsicum hybrids and it ranges from 18.8 cm to 37 cm and 5.50 to 13 cc respectively. The higher mean root length and root volume of 25.5 cm and 8.50 cc was recorded with the addition of 37.5 kg ZnSO₄ ha⁻¹. Among the hybrids, higher root length (37.0 cm) and root volume (13.0 cc) was observed with Indra hybrid followed by Inspiration (29.5 cm and 9.1 cc), Bachata (25.5 cm and 8.5 cc), Masilia (22.5 cm and 7.5 cc), Priyanka (19.5 cm and 7.3 cc) and local green (18.8 cm and 5.5 cc). Lesser root length (14.3 cm) and root volume (4.8 cc) was observed in local green variety in no Zn applied control. This could be attributed to the significant influence of Zn on building up of the natural auxin level (IAA) and consequently activating the cell division, enlargement and thereby enhancing the plant height. Similar increase in plant height due to higher soil Zn availability was reported by [35] and [36]. Increase in root length and volume was due to better Zn nutrition at early growth stages [37].

3.4 Yield attributes

Significant variation in yield attributes was recorded by the application of Zn (Fig. 3). Application soil test based NPK + 37.5 kg ZnSO₄ ha⁻¹ recorded the highest mean yield attributes like number of fruits (12 plant⁻¹), pericarp thickness (0.59 cm), fruit length (7.61 cm), fruit girth (6.55 cm) and fruit weight (104.8 g). Similar to growth attributes, the lowest yield attributes were recorded in control (no Zn). Among the genotypes, Indra recorded the highest pericarp thickness, fruit length, fruit girth and fruit weight (0.67 cm, 9.17 cm, 8.16 cm and 133 g) respectively. As regards the no. of fruits per plant, Indra recorded the highest no. of fruits per plant (15 nos.) followed by Bachat (13 nos.), Inspiration (12 nos.). Minimum numbers of fruits, pericarp thickness, fruit length, girth and weight of 7.00, 0.31 cm, 5.37 cm, 4.85 cm and 78.7 g respectively was observed with Local green hybrid in control pots (no Zn). This might be due to the improved production of phyto-hormones prompted by Zn fertilisation, which in turn increased the fruit development and production [38]. The most important effect of including Zn applications to capsicum is that it can improve yield and yield components and growth characteristics [16] as its application increases endogenous hormones like auxins, gibberellins, and melatonin which will benefit growth, development and fruit production [39]. It was reported that, the average fruit weight and fruit girth could be directly increased by the Zn applications [40]. It was also reported that application of Zn in tomatoes increased the fruit weight and fruit number and positively affected the fruit yield [41]. Literatures suggested that Zn application in different forms can increase fruit weight, number of fruits, polar and equatorial diameter as well as yield of crops [38, 42,43,44,45].

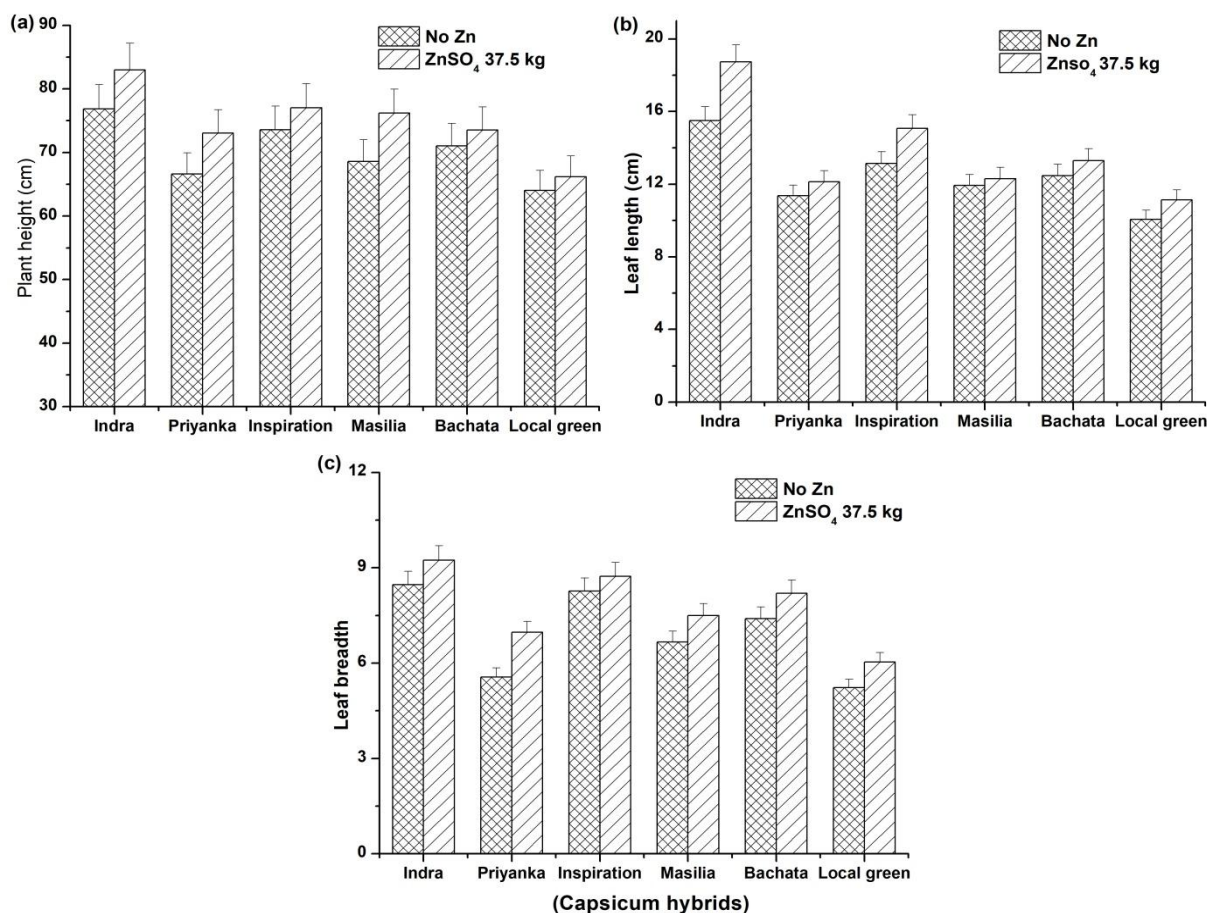


Fig.1 Changes in growth attributes (a) plant height, (b) leaf length and (c) leaf breadth due to Zn fertilization at harvest.

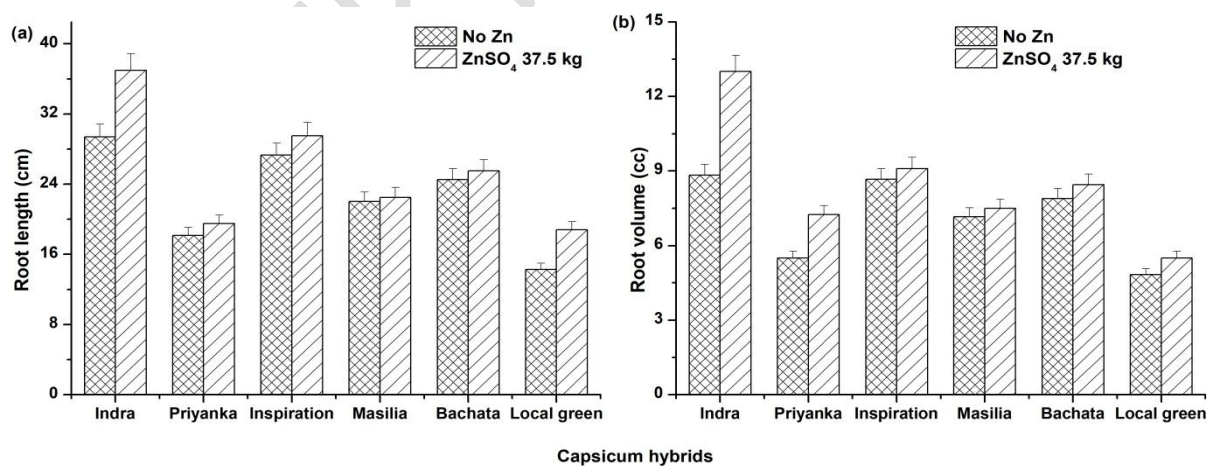


Fig.2 Changes in root traits (a) root length and (b) root volume due to Zn fertilization

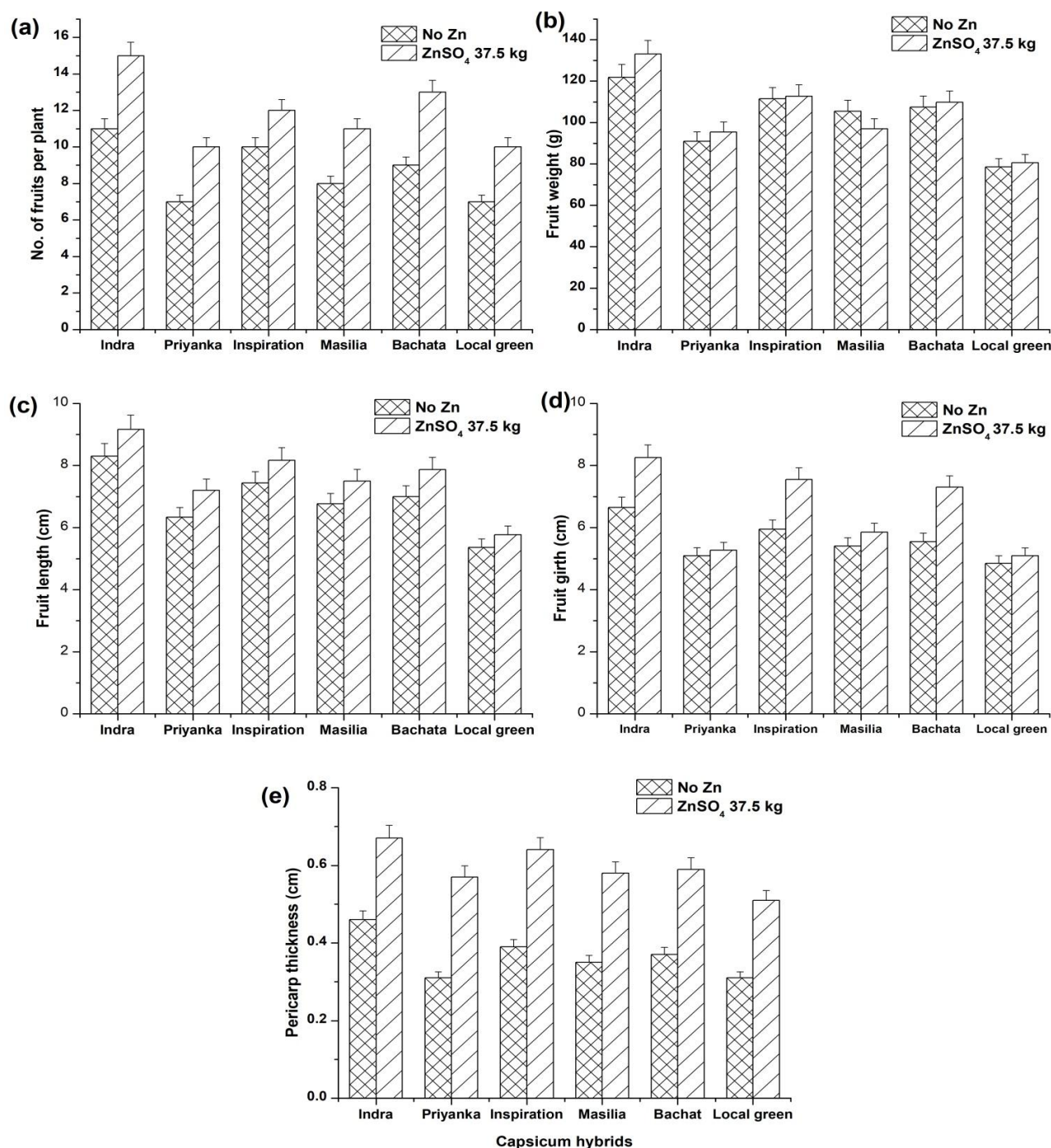


Fig.3 Changes in yield attributes (a) No. of fruits (b) fruit weight (c) fruit length (d) fruit girth and (e) pericarp thickness due to Zn fertilization

3.5 Yield and Dry matter production

The fresh fruit yield of capsicum showed significant variation with the application of soil test based NPK + 37.5 kg ZnSO₄ ha⁻¹ (Fig.4). The application of 37.5 kg ZnSO₄ ha⁻¹ recorded higher mean fresh fruit yield (4.23 kg) with the yield increase of 13 to 25%. The hybrid Indra recorded the highest fruit yield of 4.70 kg followed by Inspiration (4.41 kg), Bachata (4.26 kg), Priyanka (4.11 kg) and Masilia (3.99 kg). Lesser fruit yield was noticed with Local green hybrid (3.43 kg) in control (no Zn). It has been shown that, there is a positive relationship between Zn application and fruit yield in other

cultivated plants such as tomato [46], pea [47], soybean [48] and corn [49,50]. Similarly, Zn application increased the yield significantly in capsicum also [54,52]. The application of Zn increases endogenous hormones (auxins, gibberellins, and melatonin) and improves the activities of aquaporin and the antioxidant system, which in turn supports photosynthetic efficiency, thus increased the fruit yields and yield related attributes [38,39,42].

Next to yield, dry matter production also followed the same trend (Fig. 5) with the application of NPK+ 37.5 kg ZnSO₄ ha⁻¹ by registering the highest DMP of 57.6 g followed by control (no Zn) with a DMP of 48.9 g. Among the six genotypes, Indra recorded the highest DMP of 65.0 g followed by Inspiration (59.6 g), Bachat (58.8 g), Masilia (56.0 g) and local green (50.7 g). The lowest yield and DMP was noted in control (no Zn). Similar positive effect of added Zn fertilizers in increasing the DMP was reported by [53] and [54].

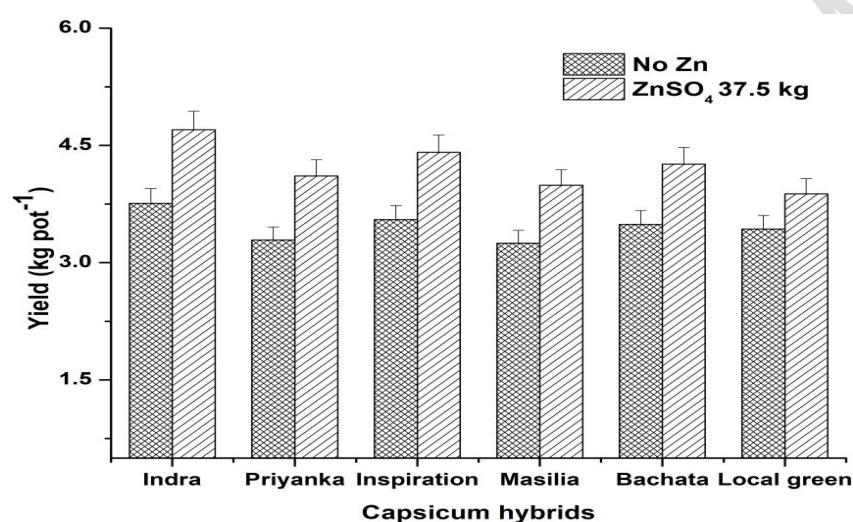


Fig.4 Changes in fresh fruit yield due to Zn fertilization

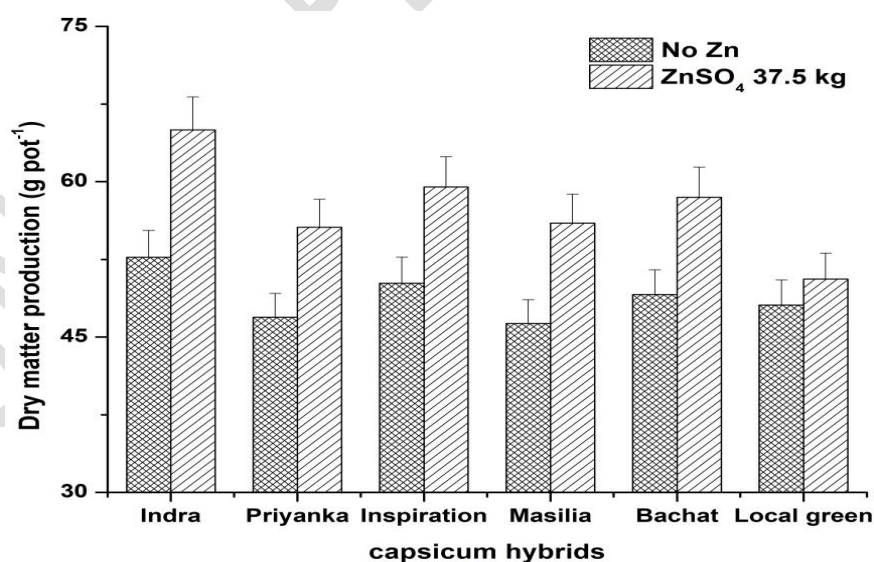


Fig. 5 Changes in dry matter production (DMP) due to Zn fertilization

4. CONCLUSION

It can be concluded from the study that, basal application of soil test based NPK + 37.5 kg ZnSO₄ ha⁻¹ to capsicum hybrids increased the growth and yield attributes as well as yield. Out of the six capsicum hybrids, higher plant height (83 cm), root length (37 cm), root volume (13 cc), fruit numbers and weight (15 and 133 g), fruit length, girth and pericarp thickness (9.17, 8.25 and 0.67 cm), DMP (65 g) as well as fresh fruit yield (4.70 kg) were observed with Indra followed by Inspiration and Bachata. Lesser improvement in growth and yield traits due to Zn application was noticed with local green hybrid. Hence, capsicum hybrid Indra was found to be highly responsive to Zn fertilisation while Inspiration, Bachata, Massilia, and Priyanka as medium responsive to Zn fertilisation.

DISCLAIMER

The products used for this research are commonly and predominantly used in our area of study and country. There is no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for litigation but knowledge advancement. Also, the research was not funded by the producing company rather; it was financed by the personal efforts of the authors.

REFERENCES

1. Sreedhara D.S, Kerutagi M.G, Basavaraja H, Kunnal L.B, Dodamani M.T. Economics of capsicum production under protected conditions in Northern Karnataka. *Karnataka J. Agric. Sci.* 2013; 26 (2): 217-219.
2. Kumar P, Chauhan R.S, Grover R.K. Economic analysis of capsicum cultivation under polyhouse and open field conditions in Haryana. *Int. J. Farm Sci.* 2016; 6(1):96-100.
3. Patricia M, Xiao-Ping Li, Krishna K. Niyogi, Non-Photochemical quenching, A response to excess light energy. *Plant Physiol.* 2001; 125 (4):1558-1566.
4. Fontes P.C.R, Dias E.N, Graça R.N. Acúmulo de nutrientes e método para estimar doses de nitrogênio e de potássio na fertirrigação do pimentão. *Horticultura Brasileira.* 2005; 23: 275-280.
5. Radhika K, Meena S. Effect of zinc on growth, yield, nutrient uptake and quality of groundnut: A review. *J. Pharm. Innov.* 2021; 10(2): 541-546
6. Alloway B.J. Soil factors associated with zinc deficiency in crops and human. *Environ. Geochem. Health.* 2009; 31: 537-548
7. Cakmak I, Kalayci M, Kaya Y, Torun A.A, Aydin N, Wang Y, Arisoy Z, Erdem H, Yzici A, Gokmen O, Ozturk L, Horst W.J. Biofortification and localization of zinc in wheat grain, *J. Agric. Food Chem.* 2010; 58:9092-9102
8. Palmgren M.G, Clemens S, Williams L.E, Krämer U, Borg S, Schjørring J.K, Sanders D. Zinc biofortification of cereals: problems and solutions. *Trends Plant Sci.* 2008; 13(9), 464–473.
9. Das S, Green A. Importance of zinc in crops and human health. *J SAT Agric Res.* 2013; 11: 1-7.
10. Hafeez B, Khanif Y.M, Saleem M. Role of zinc in plant nutrition-A review. *Am. J. Exp. Agric.* 2013; 3 (2):374–91.

11. Suganya A, Saravanan A, Manivannan N. Role of zinc nutrition for increasing zinc availability, uptake, yield, and quality of maize (*Zea mays* L.) grains: An overview. *Commun. Soil Sci. Plant Anal*, 2020; 51(15): 2001-2021.
12. Pahlavan-Rad M.R, Pessarakli M. Response of wheat plants to zinc, iron, and manganese applications and uptake and concentration of zinc, iron, and manganese in wheat grains. *Commun. Soil Sci. Plant Anal*. 2009; 40(7-8): 1322-1332.
13. Abou El-Yazied A. Effect of foliar application of salicylic acid and chelated zinc on growth and productivity of sweet pepper (*Capsicum annum* L.) under Autumn planting. *Res. J. of Agric. and Biol. Sci.* 2011; 7(6): 423–433.
14. Yadav D, Shivay Y.S, Singh Y.V, Sharma V.K, Bhatia A. Enhancing nutrient translocation, yields and water productivity of wheat under rice–wheat cropping system through zinc nutrition and residual effect of green manuring. *J. Plant Nutr.* 2020; 43(19): 2845-2856.
15. Tamilselvi P, Vijayakumar R.M, Nainar P. Studies on the effect of foliar application of micronutrients on growth and yield of tomato (*Lycopersicon esculentum* Mill). Cv. PKM-1. *South Ind. Hort.* 2002; 53(1-6): 46-51.
16. Hatwar G.P, Gondane S.U, Urkude S.M, Gahukar O.V. Effect of micronutrients on growth and yield of chilli. *J. Soils and Crops*. 2003; 13(1): 123-125.
17. Shahean A.M, Fatma A.R, Singer S.M. Growing onion plants without chemical fertilization. *Research J. of Agri. And Biolo. Sci.* 2007; 3(2): 95-104.
18. Bhatt L, Srivastava B.K, Singh M.P. Studies on the effect of foliar application of micronutrients on growth, yield and economics of tomato. *Prog. Hort.* 2004; 36(2): 331-334.
19. Malawadi M.N, Shashidhara G.B, Palled Y.B. Effect of secondary and micronutrients on yield, nutrient uptake and quality of chilli. *Karnataka J. Agric. Sci.* 2004; 17(3): 553-556.
20. Jackson M.L. Soil chemical analysis. 2nd ed. Prentice Hall Pvt. & Ltd. New Delhi, India: 1973.
21. Walkley A, Black C.A. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science*. 1934; 37: 29-38.
22. Olsen S.R, Sommers L.E. Phosphorus. In *Methods of Soil Analysis Part 2*. Inc, Publisher Madison, American Society of Agronomy, Soil Science Society of America. 1982; 403-430.
23. Black C.A. *Methods of Soil Analysis, Part-2*, Inc, Publisher, Madison, Wisconsin, USA: American Society of Agronomy, Soil Society of America. 1965.
24. Bremner J, Mulvaney C. Nitrogen-Total. In *Methods of Soil Analysis*, Inc, Publisher, Madison, Wisconsin, USA: American Society of Agronomy, Soil Society of America, 1982; 594-624.
25. Lindsay W.L, Norwell W.A. Development of a DTPA soil test for zinc, iron, manganese, and copper. *Soil Sci. Soc. Am. J.* 1978; 42(3):421-428.
26. Hossne A.J, Jesús Méndez N, Leonett F.A, Meneses J.E, Gil J.A. Maize root growth under regular water content, subjected to compaction, irrigation frequencies, and shear stress. *Rev. Fac. Nac. Agron. Medellin*. 2016; 69(1):7867-7880.

27. Panse V.C, Sukhatme P.V. Statistical methods for Agricultural workers. 3rd ed.ICAR, New Delhi; 1978
28. Kassambara A. Practical guide to cluster analysis in R: Unsupervised machine learning. vol. 1. Sthda; 2017.
29. Baloch Q.B, Chachar Q.I, Tareen M.N. Effect of foliar application of macro and micro nutrients on production of green chilies (*Capsicum annuum* L.). J. Agric.Tech. 2008; 4(2):177-184.
30. Rukmani, Prabhakaran, Thiyageshwari, Banumathy, Senthil. Synthesis and formulation of micronutrient chelate and evaluation of its efficiency on rice crop. Master of Science, Tamil Nadu Agricultural University, 2018.
31. El-Mohsen ABD, El-Bassiony, ZakariaFawzy, Maged El-Nemr, SamyShehata. Response of Pepper Plants (*Capsicum annuum* L.) to Foliar Spray with Fe, Mn, and Zn.Catrina: Int.J.Env. Sci. 2007; 2(1): 1-5.
32. Asha L, Chidanandappa H.M, Veeranagappa P, Punith T.SR. Effect of different methods of zinc application on growth and yield of maize (*Zea mays* L.). Asian J. Soil Sci. 2012; 7(2):253-256.
33. Dhanalakshmi M, Prabhakaran J, Senthil K, Thiyageshwari S, Sathyamoorthy NK. Effect of chelated micronutrients on the yield attributes and yield of rice. Int. J. Chem. Stud. 2019; 3040- 3043
34. Krishnaraj M, Senthil K, Shanmugasundaram R, Prabhakaran J, Subramanian E. Effect of chelated iron and zinc application on growth and productivity of maize (*Zea mays* L.) in subtropical climate. J PharmacognPhytochem 2020;9(6):1212-1216.
35. Ziaeyan A.H, Rajaie M. Combined effect of Zinc and Boron on yield and nutrients accumulation in corn. Int. J. Plant Prod. 2009; 3(3): 103-108
36. Badiyala D, Chopra P. Effect of zinc and FYM on productivity and nutrient availability in maize (*Zea mays*)–linseed (*Linum usitatissimum*) cropping sequence. Indian J. Agron. 2011; 56(2): 88-91.
37. Aslam Z, Bashir S, Ahmed N, Bellitürk K, Qazi MA, Ullah RM. Effect of different levels of molybdenum and rhizobium phaseoli in rice-mung bean cropping system. Pak. J. Bot. 2020; 52:6.
38. Elizabeth A, Bahadur V, Misra P, Prasad V.M, Thomas T. Effect of different concentrations of iron oxide and zinc oxide nanoparticles on growth and yield of carrot (*Daucus carota* L.). Res. Rev.: J. Pharmacogn. Phytochem.2017; 6(4), 1266-1269.
39. Zhu J, Li J, Shen Y, Liu S, Zeng N, Zhan X, Xing B. Mechanism of zinc oxide nanoparticle entry into wheat seedling leaves. Environ. Sci. Nano. 2020; 7(12):3901-3913.
40. Sahota G.S, Arora J.S. Effect of N and Zn on 'Hamlin' sweet orange. Jap. J. Hort. Sci. 1981; 50:281-286.
41. Kazemi M. Effect of foliar application of iron and zinc on growth and productivity of cucumber. Bull. Env. Pharmacol. Life Sci. 2013; 2(11), 11-14.

42. Adhikari T, Kundu S, Rao A.S. Zinc delivery to plants through seed coating with nano-zinc oxide particles. *Journal of Plant Nutrition*. 2016; 39(1):136-146.
43. García-López J.I, Niño-Medina G, Olivares-Sáenz E, Lira-Saldivar R.H, Barriga-Castro E.D, Vázquez-Alvarado R, Rodríguez-Salinas P.A, Zavala-García F. Foliar application of zinc oxide nanoparticles and zinc sulfate boosts the content of bioactive compounds in Habanero peppers. *Plants*. 2019; 8:2–20.
44. Du W, Yang J, Peng Q, Liang X, Mao H. Comparison study of zinc nanoparticles and zinc sulphate on wheat growth: From toxicity and zinc biofortification. *Chemosphere*. 2019; 227:109-116.
45. Saadati S, Moallemi N, Mortazavi S.M.H, Seyyednejad S.M. Foliar applications of zinc and boron on fruit set and some fruit quality of olive. *Vegetos*. 2016; 29(2):53-57.
46. Haleema B, Rab A, Asghar S, Hussain S.A. Effect of calcium, boron and zinc foliar application on growth and fruit production of tomato. *Sarhad J. Agric.* 2018; 34 (1):19–30.
47. Debnath P, Ghosh S.K. Assessment of critical limit of available boron for pea in acidic alfisols of east sikkim, India. *Legume Res*. 2014; 37 (5):508–14.
48. Han H, Li X, Uren N, Tang C. Zinc fractions and availability to soybeans in representative soils of Northeast China. *J. Soils Sediments*. 2011; 11:596–606.
49. Erdem H. Determination of the effects of zinc fertilization on yield and quality of silage corn varieties. *J. Agric. Faculty Gaziosmanpaşa University*. 2011; 28 (2):199–206.
50. Kumar A, Denre M, Prasad R. Critical limit of boron for maize (*Zea mays* L.) in red and lateritic soil of Jharkhand, India. *Commun. Soil Sci. Plant Anal*. 2018; 49 (22):2802–13.
51. El-Yazied A.A. Effect of foliar application of salicylic acid and chelated zinc on growth and productivity of sweet pepper (*Capsicum annuum* L.) under autumn planting. *Res. j. agric. biol. sci.* 2011; 7 (6):423–33
52. Shil K, Naser H.M, Brahma S, Yousuf M.N, Rashid M.H. Response of chilli (*Capsicum annuum* L.) to zinc and boron application. *Bangladesh J. Agr. Res*. 2013; 38 (1):49–59.
53. Zeidan M.S, Mohamed M.F, Hamouda H.A. Effect of foliar fertilization of Fe, Mn and Zn on wheat yield and quality in low sandy soils fertility. *World J. Agric. Sci*. 2010; 6(6), 696-699.
54. Khoshgoftarmansh A.H, Abadi H.K, Khanmohammadi Z, Sararoudi F.A, Barzin M, Shahri A.P. Critical deficiency level of zinc for corn on calcareous salt-affected soils in central iran. *J. Plant Nutr*. 2012; 35(12), 1806-1818.