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Effects of mulching and zinc on physiological responses and yield of sweet pepper (*Capsicum annuum*) under high altitude cold desert condition

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ABSTRACT

In arid regions of the world, drought stress, lack of water availability and micro nutrient deficient sandy soils affect normal growth and development of plants resulted in poor growth and yield. The aim of the study was to evaluate combined effects of mulching and zinc application on growth, physiological responses and yield of capsicum (*Capsicum annuum* L.) under high altitude cold desert conditions. Field experiment was conducted in the cold desert environment of trans-Himalayan Ladakh region with five levels of zinc ($ZnSO_4$), viz. 0, 10, 20, 30 and 40 kg ha^{-1} with and without polythene mulching during 2013 and 2014 cropping season. Results showed that mulching with zinc significantly improved leaves membrane stability index (MSI) and relative water content (RWC) and also helped in reducing leaf water loss (LWL) and electrolyte leakage (EL) indicating better plant physiological responses. Significant improvement in leaf chlorophyll content was also observed. Both mulching and zinc application remarkably enhanced plant growth characters and capsicum yield. But, during 2014, sudden decrease in minimum and maximum temperature at flowering and fruiting stage adversely affected proper fruit set and its development resulting into poor capsicum yield. Application of mulch also reduced irrigation water requirement of plants. Knowledge from the present study indicated that combined application of $ZnSO_4$ and mulching could be the feasible strategy against weather abnormality, water savings and obtaining better yield of vegetables grown in zinc deficient sandy soils of arid regions.

Key words: Capsicum, Cold arid, High altitude, Plastic mulch, Zn deficiency

Irrigation water availability is a crucial input in crop production systems. Among various environmental stresses, drought stress holds significant effect (Kusvuran and Dasgan 2017) on plant growth and crop production in arid and semi-arid regions of the world. This is mainly due to the high rate of evapo-transpiration, particularly in arid and most of the semi-arid regions having very little rainfall. It causes changes in normal physiological function of all plants, reduced biosynthetic capacity of plants, oxidative damage of cell membranes resulting in poor plant growth and yield (Avramova *et al*. 2015).

Mulching has an influence on various aspects of soil environments and crop requirements especially in arid and desert regions. Mulches improve many soil properties and conditions, either directly or indirectly. Mulching provides many advantages which include: soil water conservation, regulation of soil temperatures, reduced crop-weed competition attributed to weed suppression and consequently increased crop production and higher quality produce (Murungu *et al*. 2011). Retention of soil moisture and increased soil temperatures due to mulch application can also affect soil fertility by influencing the biological activity in soils (Marinari *et al*. 2015) by increasing the level of enzyme and mineralization rates making it available to plants.

Zinc is an important and essential limiting micronutrient for proper growth and development of plants. Zn is known to have functioned as the metal component of enzymes or as a functional, structural or regulatory cofactor of a large number of enzymes (Wang and Jin 2005). Zn also plays an important role in the production of plant biomass. Zn deficiency in soils is prevalent worldwide, especially in high pH calcareous soils of arid and semi-arid regions (Cakmak 2008). The problem of Zn deficiency is worldwide and mainly found in coursed textured sandy, calcareous soils of arid and semi-arid regions. The low solubility of Zn in soils rather than the low total amount of Zn is the major reason for the widespread occurrence of Zn deficiency problem in crop plants (Cakmak 2008). Low availability of Zn in the soil can lead to reduced plant growth and yield.

India contributes approximately one-fourth part of world production of capsicum (*Capsicum annuum* L.) with covered 0.885 million ha and annual average production of 0.9 million tonnes with a standard productivity of 1266 kg per ha (Biwalkar *et al*. 2015). Capsicum is an important vegetable of Ladakh region, a good cash crop in summer

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season (Kanwar *et al*. 2014) due to its high consumption in fresh condition and fetches high value. Cold, arid and high altitude regions of trans-Himalayas are exceptionally unique in the world and are characterized by extreme temperature variation, thin atmosphere with high UV radiation and less oxygen availability. The soil of Ladakh is taxonomically classified as typic cryorthids, physically thin, porous, with low water holding capacity and sandy in nature, which may be because of more quantity of stone and gravels content in dry mountains of this region. Only one cropping season in a year (span from May to October) is typical characteristics of this region. In Ladakh (trans-Himalayan cold arid region), major challenges in agriculture are less fertile sandy soil with high pH, poor water holding capacity and availability of water for irrigation because of very less rainfall (<100 mm annually). Although the literature on plastic mulch is abundant, however very limited information is available about the combined effect of mulching and zinc application on plant physiological parameters and yield of vegetables grown in sandy soils at cold desert regions. In view of the above, the objective of the present investigation was to examine the influence of mulching and Zn treatments on physiological parameters and yield of capsicum in cold arid environment of trans-Himalayan Ladakh region.

MATERIALS AND METHODS

The experiment was conducted at experimental field of Defence Institute of High Altitude Research (DIHAR) Leh, India (11526±32.30 ft. amsl) during the 2013 and 2014 cropping seasons. Due to high altitude and low humidity, the radiation level is amongst the highest in the world (up to 6-7 Kwh/mm). Longer photoperiod; about 325 sunny days and only one cropping season in a year (May to October) are typical characteristics of this region. Mean monthly air temperature, relative humidity and total rainfall during the period of study are presented in Table 1. Soils of the experimental fields were sandy and coarse textured. Physico-chemical properties of the soil of the experimental site are shown in the Table 2.

Capsicum variety California wonder was selected for the experiment. For mulching treatments, black polythene sheet of 2mm standard size was used. Zinc sulphate ($ZnSO_4$) was used as a fertilizer with 21% Zn content. The study was carried out with five application rates of $ZnSO_4$ with and without black plastic mulch cover. The treatments are depicted as follows: Control without $ZnSO_4$ and mulching (T_0M_0); Control with only mulching (T_0M_1); $ZnSO_4$@10 kg/ha without mulching (T_1M_0); $ZnSO_4$@20 kg/ha without mulching (T_2M_0); $ZnSO_4$@30 kg/ha without mulching (T_3M_0); $ZnSO_4$@40 kg/ha without mulching (T_4M_0); $ZnSO_4$@10 kg/ha with mulching (T_1M_1); $ZnSO_4$@20 kg/ha with mulching (T_2M_1); $ZnSO_4$@30 kg/ha with mulching (T_3M_1) and $ZnSO_4$@40 kg/ha with mulching (T_4M_1). The experimental setup was two-factorial, completely random block design, with three replications. $ZnSO_4$ was incorporated and uniformly mixed into the soil before transplanting. Each treatment applied in three plots randomly and after capsicum seedling establishment, three plants were selected randomly from each plot to observe growth parameters and to evaluate plant physiological responses on different levels of Zn and mulching treatments.

The size of each experimental plot was kept at 2.5m × 1.0m. Capsicum seedlings were planted with row spacing of 30 cm and interplant spacing of 40 cm within one row. Cropping history (Table 3) showed that in 2013 flowering was stared at 57 DAT, fruiting at 63 DAT and finally fruit

Table 1 Weather conditions during the period of study

Months	Minimum temperature (°C)	Maximum temperature (°C)	Mean temperature (°C)	Rainfall (mm)	Relative humidity (%)
2013					
May	2.4	26.8	14.6	5.01	46.45
June	4.6	33.6	19.1	13.21	38.53
July	12	36.6	24.3	6.40	36.97
August	11.0	33.8	22.4	6.11	47.29
September	4.6	28.8	16.7	0.80	39.14
October	-4.5	26.4	10.9	6.00	45.94
2014					
May	0.7	24.3	12.5	1.36	38.81
June	4.1	30.3	17.2	0.33	33.93
July	11.4	34.7	23.1	6.02	38.03
August	7.9	33.0	20.4	8.01	34.23
September	3.2	26.5	14.8	5.03	50.93
October	-3.9	25.9	11.0	0.01	40.29

Table 2 Physico-chemical properties of soil at experimental fields of Leh-Ladakh

Sand (%)	Silt (%)	Clay (%)	PH	EC (μs/cm)	SOC (%)	TDS (ppm)
81.81	9.27	8.92	7.92	289.42	0.92	143.00
N (kg/ha)	P (kg/ha)	K (kg/ha)	Zn (ppm)	Fe (ppm)	Cu (ppm)	Mn (ppm)
332.5 ± 9.15	18.8 ± 0.08	219.6 ± 7.9	0.29 ± 0.03	6.1 ± 0.05	1.4 ± 0.06	4.39 ± 0.07

Table 3 Year wise cropping history during the study period

Year	Transplanting date	Starting of flowering	Staring of fruiting	Harvesting			
				1st	2nd	3rd	Final
2013	20 May	17 July	23 July	05 Sept.	13 Sept.	26 Sept.	05 Oct.
2014	26 May	27 July	02 Aug.	16 Sept.	29 Sept.	-	09 Oct.

matured for harvesting at 109 DAT.

During this season capsicum fruit was harvested four times and total crop period was 139 days. In 2014 crop season flowering was started at 53 DAT and 59 days were taken by plants for fruiting. Fruit was harvested three times during this season and total crop period was 137 days. Black waterproof polythene sheet was laid over the plots before transplanting. Irrigation treatments were given on the basis of soil moisture content in both years.

Growth parameters, viz. plant height, number of branches, stem diameter were measured before harvesting starts. During first flower initiation stage, number of flowers per plant as influenced by various treatments was also recorded. After each harvesting, total fresh capsicum weight was measured from each and every treatment by digital weighing balance and final data were calculated per hectare basis. Fruit length and diameter were measured with a digital vernier caliper. Leaf area was measured using leaf area meter.

Leaf samples were collected after 50 DAT for determination of physiological parameters as influenced by mulching and zinc treatments viz. membrane stability index (MSI), relative water content (RWC), electrolyte leakage (EL) and leaf water loss (LWL) by methods described below. MSI was calculated according to the method described by Sairam *et al*. (1997). RWC was determined for detached capsicum leaves using the method of Mata and Lamattina (2001). EL was measured using an electrical conductivity meter (HACH, USA) as described by Lutts *et al.* (1996). LWL was measured according to the method of Xing *et al*. (2004). Leaf chlorophyll content was determined by portable chlorophyll meter in all treatments and control plots after 50 DAT.

TSS content of capsicum in various treatments was measured by refractometer Refractometer was cleaned every time using methanol dipped tissue paper, washed with distilled water and dried before taking the reading and was standardized against distilled water (0 °Bx TSS).

All experimental data were expressed as mean ± SD using statistical analysis with SPSS 16 (SPSS Corporation, Chicago, Illinois, USA) and MS excel 2007. Differences between mean values were evaluated using one way analysis of variance (ANOVA). Significant difference level was set at $P<0.05$ for all the statistical analysis.

RESULTS AND DISCUSSION

Plant physiological responses

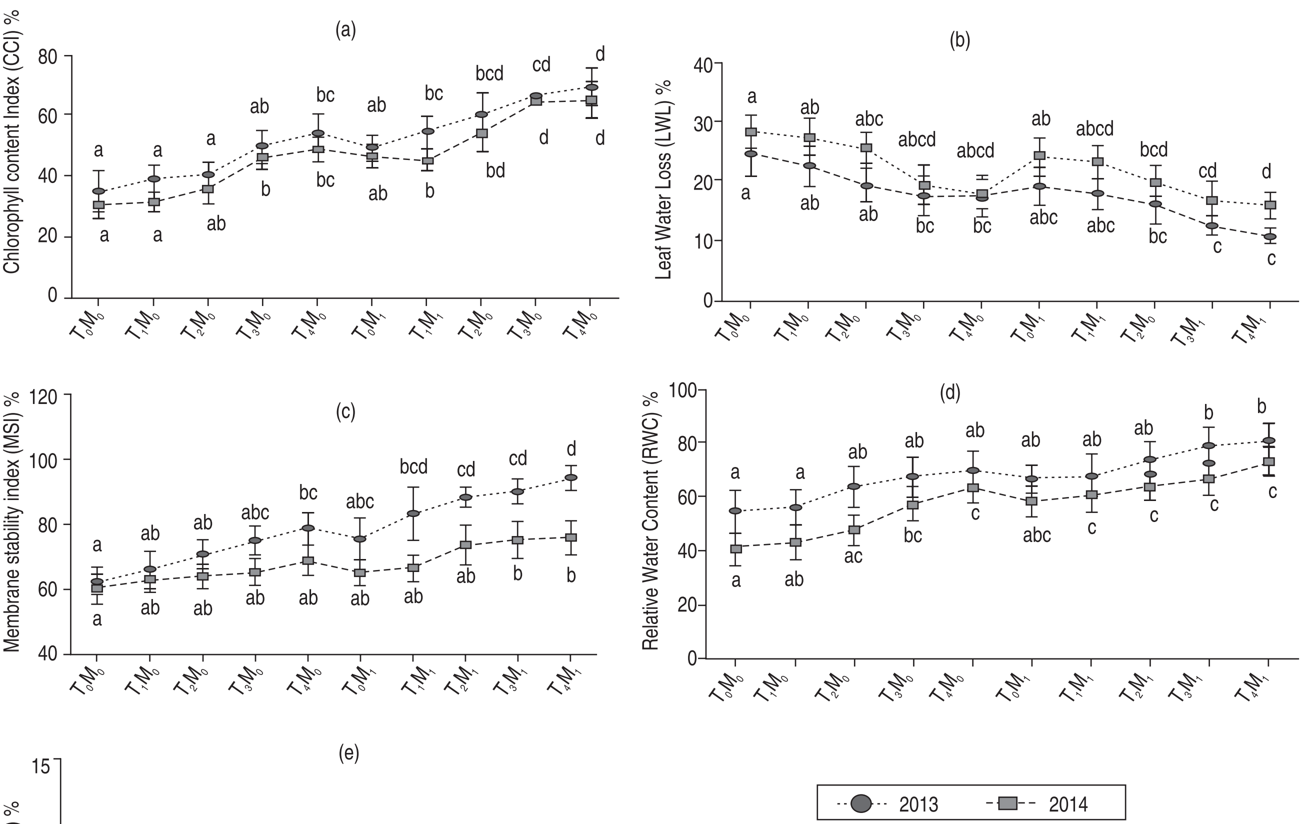
Plant physiological parameters in all treated and control plants were recorded as influenced by mulching and zinc treatments (Fig. 1). In relation to chlorophyll content except T_1M_0 and T_2M_0 all other treatments showed significant ($P<0.05$) increase in leaf chlorophyll content over control in both the season (Fig 1A). But no significant variations ($Ps>0.05$) in chlorophyll content was observed among T_3M_0, T_4M_0 and T_0M_1. Similarly, highest chlorophyll content was recorded in T_3M_1 and T_4M_1 (63.53 and 65.23 CCI unit and 60.74 and 63.41 CCI unit in 2013 and 2014 respectively) but no significant difference between the treatments was found. Increase in chlorophyll content at high Zn level may be associated with high Zn and/or Mg because Zn does not directly affect chlorophyll formation, but it can affect the concentration of nutrients involved in chlorophyll formation or which is part of the chlorophyll molecule (Fe and Mg) (Kaya and Higgs 2002). Acharya *et al*. (2012) also reported increase in chlorophyll content when Zn was applied @ 0.1 and 0.5 mM in *Jatropha curcas* seedlings grown hydroponically. The reduction of chlorophyll due to drought stress is related to the increase of production of free oxygen radicals in the cell.

Similar to chlorophyll content, Membrane Stability Index (MSI) also showed considerable improvement with the application of zinc and mulching as depicted in Fig. 1B. Increasing level of zinc improved the MSI with T_4M_0 showing the highest value of MSI of 90.09 in 2013 and 75.37 in 2014 respectively. The most significant improvement in MSI was observed in both mulching and zinc treatment i.e. in T_4M_1, which shows an MSI of 94.54 in 2013 and 76.08 in 2014 respectively. Water stress causes accumulation of reactive oxygen species resulting into decreased MSI compared to non stress conditions (Gupta *et al.* 2012).

EL significantly affected by both crop seasons with mulch and $ZnSO_4$ application (Fig 1C). Mean comparison results showed highest EL in control plots in both crop seasons. EL reduced in $ZnSO_4$ treatment with the significant reduction ($P<0.05$) of EL was recorded in T_4M_0. In both crop seasons, the highest result was found in T_4M_1 followed by T_3M_1. Combination of mulching and Zn also helped in reducing EL. The increase in EL is an indicator of cell membrane injury which was found in plants without mulch and Zn treatments. Alexieva *et al*. (2001) reported that drought and UV stress through amplification of reactive oxygen species increased EL in pea and wheat plant. Similar result was also shown in experiments of Srivastav *et al*. (2010) in water stress condition.

Mulching and Zn effects on LWL were significant in both the years. Reduced LWL was recorded with increasing dosage of Zn. But application of mulch along with Zn further reduced LWL (Fig. 1D). Consistent decrease in LWL was recorded in increasing concentrations of zinc with mulch ($T_2M_1>T_3M_1>T_4M_1$). T_4M_1 showed most significant decrease in LWL of 12.82% in 2013 and 16.08% in 2014 respectively.

Mulching along with increasing level of zinc significantly improved RWC of capsicum leaves (Fig.1E). Even in weather fluctuations during 2014, RWC significantly improved in mulch with zinc applications. Among the treatments, maximum value of RWC was recorded in T_4M_1 which is significant ($p<0.05$) compared to other treatments except with T_3M_1. Higher RWC in wheat leaves grown under rice husk mulch in semi-arid condition was reported by Chakraborty *et al*. (2008). Results of Khadem *et al*. (2010) showed the reduction of RWC in water/drought stress is connected to soil moisture content and stomata closure.



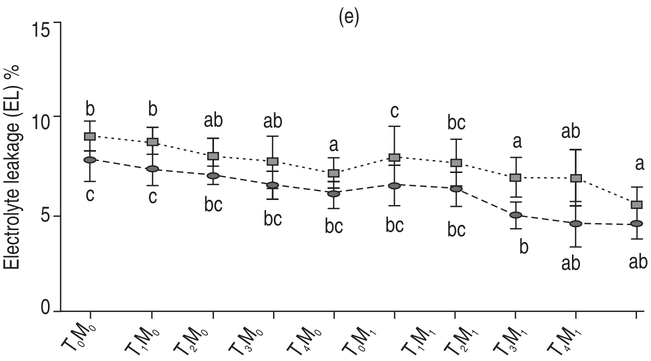


Fig 1 Effect of mulching and zinc treatments on physiological response of capsicum plant grown during 2013 and 2014 crop season a) Chlorophyll Content Index (CCI Unit); b) Membrance Stability Index (MSI); c) Electrotype Leakage (EL); d) Leaf Water Loss (LWL) and E) Relative Water Content (RWC); mean values bearing same supercript within a column did not differ significantly (P>0.05).

Interaction of Zn with membrane proteins contributes to maintenance and stability of membranes (Dang *et al*. 2010) and also helps to reduce adverse effects of short periods of environmental stress (Disante *et al*. 2011). From our results, it is clear that Zn and mulch plays an essential role in protecting cell membrane damage.

Plant growth parameters

As evident from Table 4, it was observed that plant growth characters viz. plant height, nos. of branches have been increased in T_0M_1 and in combined mulch and zinc treatments. T_1M_0 and T_2M_0 did not significantly increased plant height (p>0.05) over the control. But T_3M_0 and T_4M_0 was found to be quite effective in increasing plant height as well as nos. of branches, stem diameter and individual leaf area. Also, T_0M_1 found to be equally effective as T_3M_0 and T_4M_0. Whereas, T_4M_1 showed maximum increase in plant height (41.33 and 35.78 cm in 2013 and 2014 respectively), nos. of branches (6.22 and 3.55 in 2013 and 2014), stem diameter (15.09 and 11.28 mm in 2013 and 2014) and individual leaf area (41.02 and 34.44 cm^2 in 2013 and 2014 respectively) over control. Leaf area enhanced significantly in T_0M_1 as well as in combined zinc and mulching application indicating the enhanced rate of photosynthesis and improved plant vigour. Because of weather fluctuations, during 2014, significant reduction in nos. of branches, stem diameter, leaf area was observed. During first flowering stage in both the season, it was observed that because of fluctuations in diurnal temperatures especially in flowering and fruit formation stage in 2014, nos. of flowers also significantly reduced which resulted into less no of fruits per plant. The results obtained from this experiment showed that application of mulch with $ZnSO_4$ had increased all plant growth parameters (Table 4) especially in 2014 crop season. Improved crop growth and establishment under straw mulch, due to reduced water stress during dry periods was also reported by several researchers. Improvement in growth characters as a result of soil application of zinc and mulching might be due to the enhanced photosynthetic and other metabolic activity which leads to an increase in various plant metabolites responsible for cell division and elongation (Hatwar *et al.* 2003). Enhancement of photosynthetic activity in presence of zinc was also reported by researchers. Zinc also activates synthesis of tryptophan, the precursor of IAA

Table 4 Growth parameters of capsicum as influenced by mulching and $ZnSO_4$ application during 2013 and 2014 crop season.

Treatment	Plant height (cm)		No. of branches		No. of fruits/plant		Stem diameter (mm)		Leaf area (cm^2)	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
T_0M_0	29.67 ± 2.5^{a}	28.67 ± 4.4^{a}	2.22 ± 0.4^{a}	1.88 ± 0.7^{a}	6.11 ± 1.5^{a}	2.55 ± 0.4^{a}	7.82 ± 1.3^{a}	5.68 ± 1.6^{a}	19.75 ± 5.1^{a}	12.94 ± 1.3^{a}
T_1M_0	29.88 ± 3.0^{a}	28.78 ± 6.9^{a}	2.77 ± 0.5^{ab}	2.22 ± 0.7^{a}	7.11 ± 1.8^{ab}	2.67 ± 0.7^{a}	8.25 ± 1.0^{ab}	6.30 ± 0.9^{ab}	22.27 ± 3.2^{a}	14.67 ± 2.6^{ab}
T_2M_0	31.78 ± 2.7^{ab}	31.89 ± 6.6^{a}	4.00 ± 0.3^{bc}	2.45 ± 0.69^{a}	10.55 ± 2.3^{bc}	4.89 ± 0.7^{ab}	9.29 ± 1.0^{abc}	6.52 ± 1.2^{ab}	27.07 ± 8.5^{ac}	20.20 ± 2.6^{ac}
T_3M_0	34.43 ± 3.4^{ab}	26.78 ± 4.1^{a}	4.78 ± 0.8^{bc}	2.56 ± 0.51^{a}	11.99 ± 3.3^{c}	6.55 ± 1.4^{ab}	11.3 ± 1.3^{abcd}	7.14 ± 1.4^{abc}	37.87 ± 4.7^{c}	27.12 ± 3.4^{bc}
T_4M_0	36.11 ± 3.2^{ab}	26.44 ± 2.2^{a}	5.22 ± 0.8^{dc}	2.33 ± 0.34^{a}	12.67 ± 2.6^{c}	6.78 ± 1.3^{ab}	11.75 ± 1.4^{bcd}	8.04 ± 1.0^{acb}	38.54 ± 3.9^{c}	29.26 ± 3.9^{cd}
T_0M_1	34.66 ± 4.2^{ab}	34.34 ± 4.2^{a}	3.11 ± 0.5^{ac}	2.22 ± 0.51^{a}	7.44 ± 0.9^{ab}	4.11 ± 1.2^{ab}	8.81 ± 1.3^{acb}	8.02 ± 1.7^{abc}	24.84 ± 4.6^{ab}	19.70 ± 2.4^{abc}
T_1M_1	33.56 ± 3.9^{ab}	36.44 ± 6.5^{a}	3.78 ± 0.5^{ac}	2.44 ± 0.20^{a}	9.33 ± 1.3^{ac}	4.33 ± 0.7^{ab}	9.52 ± 1.4^{abc}	8.58 ± 1.3^{abc}	25.51 ± 5.4^{ab}	23.58 ± 2.4^{abc}
T_2M_1	33.88 ± 3.7^{ab}	33.11 ± 2.8^{a}	4.44 ± 0.7^{cd}	2.56 ± 0.20^{a}	12.56 ± 2.2^{cd}	6.22 ± 1.4^{ab}	12.55 ± 1.6^{cd}	9.23 ± 1.5^{abc}	30.76 ± 4.7^{abc}	27.20 ± 2.3^{abc}
T_3M_1	38.34 ± 6.4^{ab}	37.45 ± 3.0^{a}	5.67 ± 0.3^{de}	3.00 ± 0.33^{a}	12.89 ± 1.7^{de}	8.33 ± 1.7^{b}	14.54 ± 1.6^{d}	10.64 ± 1.5^{bc}	40.48 ± 4.0^{c}	33.62 ± 2.7^{d}
T_4M_1	41.33 ± 4.0^{b}	35.78 ± 5.8^{a}	6.22 ± 0.5^{e}	3.55 ± 0.69^{a}	13.33 ± 1.7^{e}	8.56 ± 1.8^{b}	15.09 ± 1.4^{d}	11.28 ± 1.5^{c}	41.02 ± 3.9^{c}	34.44 ± 2.5^{d}

Values represented are average of three mean ± SD; mean values bearing same superscript within a column did not differ significantly (P>0.05)

and is responsible for plant growth enhancement.

Capsicum yield and yield components

Both fruit length and diameter of capsicum significantly ($P<0.05$) increased with the application of mulching (Table 5). Effect of mulching on fruit length is evident from the results which showed an increase from 48.19 mm in T_0M_0 to 60.41mm in T_0M_1 in 2013 and from 32.45 mm in T_0M_0 to 38.74mm in T_0M_1 in 2014 respectively. There was steady increase in fruit length with increasing concentrations of Zn when applied along with mulch in groups T_1M_1, T_2M_1, T_3M_1, T_4M_1 as compared to only Zn applications (T_1M_0, T_2M_0, T_3M_0 and T_4M_0). Similar effects were found with fruit diameter where application of mulch and Zn significantly increased fruit diameter in both the seasons. Among the treatments, T_3M_1 and T_4M_1 showed significantly ($P<0.05$) greater increase in size as compared to T_3M_0 and T_4M_0. The maximum fruit length (98.58mm in 2013 and 77.65mm in 2014) and diameter (74.69mm in 2013 and 65.47mm in 2014 respectively) in each season was recorded with the highest concentration of Zn (40 kg ha^{-1}) in combination with mulch (T_4M_1).

Average fruit weight (g) was significantly influenced by different treatments with soil application of Zn and mulching treatments. During 2013 and 2014, it ranged from 58.12g to 116.35g and 44.77g to 103.9g respectively. Only mulching (T_0M_1) significantly influenced average fruit weight and 46.3% and 65.8% increase in fruit weight was observed compared to control during 2013 and 2014 respectively. It was also observed that T_3M_0 and T_4M_0 had similar effect as T_0M_1 on average fruit weight. Further significant enhancement of fruit weight was recorded in T_3M_1 and T_4M_1; whereas maximum fruit weight was recorded in T_4M_1 in both the seasons (100 and 132% increase in 2013 and 2014 respectively). It was observed that yield of capsicum increased by only 12% in T_0M_1 (11.04 t/ha) over the control (9.87 t/ha) during 2013 but about 96% (4.23 t/ha in T_0M_1 and 2.16 t/ha in T_0M_0) during 2014 (Table 5). Overall yield was substantially reduced during 2014 because of weather abnormality. Mulching could provide favorable soil micro climate for plant growth and protected the plants against diurnal temperature fluctuations. Hence, significant yield improvement was noticed in T_0M_1 over the control. However, combined effect of zinc and mulching (T_3M_1 and T_4M_1) was substantially significant as it increased average capsicum yield by 82.7% and 87.9% over control in 2013 and 4.5 and 4.9 fold in 2014 cropping season.

This was due to increasing number of branches and fruits per plant besides increase in fruit size. It was explained by the fact that, besides mulching, zinc plays an important role in increasing nos. of flowers and fruiting per plant resulting in overall significant yield enhancement under zinc deficient conditions. Zinc helps in tryptophan biosynthesis which induces production of auxin; potentially useful in increasing fruit size as well as its quality (Alloway 2008). Zinc may play a key role in both flower and normal fruit development. Minimum air temperature affects plant respiration rates during the night and can potentially reduce

Table 5 Capsicum fruit quality parameters, viz. fruit length, fruit diameter, fruit weight, TSS% and capsicum yield in mulching and open field condition with $ZnSO_4$ application

Treatment	Fruit length (mm)		Fruit Diameter (mm)		Fruit weight (gm)		Fresh yield (t ha^{-1})		TSS (%)	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
T_0M_0	48.19 ± 7.02^{a}	32.45 ± 7.31^{a}	36.70 ± 5.65^{a}	26.45 ± 10.22^{a}	58.12 ± 6.27^{a}	44.77 ± 5.48^{a}	9.87 ± 0.99^{a}	2.16 ± 0.16^{a}	4.53 ± 0.35^{a}	3.20 ± 0.36^{a}
T_1M_0	59.55 ± 8.69^{ab}	36.10 ± 6.07^{a}	39.49 ± 6.06^{a}	28.44 ± 4.66^{a}	61.01 ± 6.49^{a}	51.33 ± 7.12^{a}	10.20 ± 1.25^{a}	2.83 ± 0.33^{a}	4.8 ± 0.20^{ab}	3.07 ± 0.25^{a}
T_2M_0	60.13 ± 6.64^{ab}	44.23 ± 6.51^{ab}	46.70 ± 5.82^{a}	34.63 ± 8.84^{ab}	71.12 ± 7.03^{ab}	57.94 ± 8.90^{abc}	12.12 ± 1.51^{abc}	3.25 ± 0.39^{ab}	5.07 ± 0.45^{abc}	3.33 ± 0.21^{a}
T_3M_0	80.92 ± 8.26^{bc}	59.74 ± 5.71^{bcd}	55.32 ± 11.68^{ab}	41.3. ± 6.38^{ac}	84.85 ± 5.58^{bc}	67.66 ± 9.64^{b}	14.87 ± 1.29^{cd}	4.74 ± 0.93^{c}	5.87 ± 0.45^{bcd}	4.23 ± 0.40^{ab}
T_4M_0	84.59 ± 6.63^{bc}	64.28 ± 8.63^{dc}	57.88 ± 9.98^{ab}	43.36 ± 7.40^{ac}	90.44 ± 9.31^{bcd}	72.30 ± 5.37^{bc}	15.58 ± 1.46^{cde}	5.70 ± 1.14^{cd}	6.07 ± 0.45^{cde}	4.63 ± 0.47^{b}
T_0M_1	60.41 ± 8.66^{ab}	38.74 ± 5.35^{a}	48.93 ± 8.93^{a}	37.35 ± 5.06^{ab}	85.05 ± 6.75^{bc}	74.26 ± 6.36^{bc}	11.04 ± 0.93^{ab}	4.23 ± 0.50^{bc}	5.57 ± 0.31^{abc}	4.13 ± 0.32^{ab}
T_1M_1	64.41 ± 8.17^{ab}	45.80 ± 6.66^{abc}	50.61 ± 7.25^{ab}	42.58 ± 7.74^{ac}	91.64 ± 8.46^{bcd}	76.55 ± 7.61^{bc}	13.01 ± 1.40^{cde}	4.48 ± 0.65^{c}	5.80 ± 0.26^{bcd}	4.53 ± 0.32^{b}
T_2M_1	73.13 ± 7.87^{abc}	60.07 ± 6.24^{bcd}	56.78 ± 9.07^{ab}	45.12 ± 5.82^{ac}	102.84 ± 11.1^{cde}	91.31 ± 6.69^{de}	14.61 ± 0.97^{bcd}	7.14 ± 1.11^{d}	6.07 ± 0.51^{cde}	5.00 ± 0.46^{bc}
T_3M_1	94.12 ± 16.12^{dc}	76.28 ± 5.99^{d}	70.44 ± 10.64^{bc}	61.02 ± 9.40^{bc}	110.97 ± 7.75^{de}	100.99 ± 6.25^{de}	18.03 ± 0.99^{de}	9.89 ± 0.49^{e}	6.83 ± 0.55^{de}	6.00 ± 0.70^{cd}
T_4M_1	98.58 ± 14.27^{dc}	77.65 ± 6.98 ^{d}	74.69 ± 10.59^{c}	65.47 ± 9.67^{c}	116.35 ± 8.32^{e}	103.91 ± 5.56^{e}	18.54 ± 1.40^{e}	10.56 ± 0.32^{e}	7.23 ± 0.47^{e}	6.37 ± 0.35^{d}

Values represented are average of three mean ± SD; mean values bearing same superscript within a column did not differ significantly ($P>0.05$)

biomass accumulation and crop yield (Hatfield *et al*. 2011). Yield of capsicum in the mulched treatments was higher probably because mulching with black plastic film reduced soil evaporation and augmented infiltration of water into soil and helps in soil water retention (Ramakrishna *et al*. 2006). Increased yield due to Zn and mulching application may be attributed to enhanced photosynthetic activity, improvement in soil microclimate and favorable effect on vegetative growth and retention of flowers and fruits which eventually increased number of fruits per plant beside increasing fruit size and overall capsicum yield.

It was observed that zinc and mulching had significant influence on TSS (%) of fruit. Highest TSS content of capsicum was observed in T_3M_1 and T_4M_1 (6.83 and 7.23 and 6.00 & 6.37 in 2013 and 2014 respectively) whereas year wise difference was also noted among the treatments as seen in Table 5. T_0M_1 found to be better than T_1M_1 and T_2M_1. The result clearly indicated the beneficial effect of added zinc and mulching on fruit quality.

Conclusions

Zinc and black polythene mulching improve physiological and growth parameters of capsicum. Plant growth and capsicum yield significantly enhance when treated with $ZnSO_4$ @ 30-40 kg/ha and black polythene mulching. From our field study, we conclude that $ZnSO_4$ @ 30-40 kg/ha with black polythene mulching will provide significant yield benefits for small and marginal farmers in zinc deficient sandy soils of cold desert high altitude regions. Results from the present study provide a useful guide for improving vegetable production in cold desert high altitude regions of India.

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