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Effect of zinc-based fertilizers on the growth and development of Tomato plant (*Solanum lycopersicum* L.) and fruit storability

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Abstract

Micronutrient deficiency is a common and widely spread problem that affects yield and quality of plant products. Zinc deficiency especially in fresh commodities enhances fruit deterioration during postharvest storage. This study was aimed at investigating effects of foliar applications of Zinc-based fertilizer on tomato (*Solanum lycopersicum*) growth and development, as well as fruit behaviour during storage. Four different concentrations of Zinc-based fertilizer were applied on tomato plants (0ml/l, 5ml/l, 10ml/l and 15ml/l). Zinc-based fertilizer applications started fourteen days after transplanting and continued weekly till harvest. A completely randomized block design with four treatments and six replications was used for the experiment. Parameters for plant growth and development, fruit quality and storability were determined. Results showed that Zinc-based fertilizer significantly influence most growth parameters at ($p < 0.05$). Zinc-based fertilizer has a significant effect on development parameters. There was no significant difference among treatments for fruit diameter ($p < 0.05$). Most storability parameters, except for PWL at 5th and 8th, Firmness and TSSC, showed a significant difference among treatments at ($p < 0.05$). The dose of 15ml/l was the most efficacious on many parameters evaluated.

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Introduction

Solanum lycopersicum (Cultivated tomato) is a tropical plant that originated from Mexico (Bai and Lindhout, 2007). Tomatoes annual production in the world was estimated at about 129 million tons (FAO, 2014). Tomato is the second most consumed horticultural crop in the world after potato (Haile, 2018). However, tomato production is submitted to many threats during preharvest and postharvest periods that reduce productivity and shorten storability time of fruits (Arah *et al*., 2015). Annual economic values associated to postharvest losses and waste of food in Sub-Saharan Africa (SSA) are higher than total alimentary aid received by the region during the last decade (Affognon *et al*., 2015). Thus, postharvest losses represent a serious problem in SSA. Fresh commodities especially, quickly lose quality and deteriorate during storage due to their high-water content (Arah *et al*., 2015). These losses ranged between 20 to 50% in SSA (Kasso and Bekele, 2016). In fact, biotic and abiotic threats that arise in preharvest period are tightly associated with the behaviour of fresh products during postharvest storage (Sams, 1999; Melkamu *et al*., 2008; Haile, 2018). Therefore, mineral nutrition in preharvest influence quality components and storability of fresh commodities (Sams, 1999). Micronutrients such as calcium, bore, and zinc are known to improve quality and shelf life of many fresh commodities (Aghofack-Nguemezi *et al*., 2014; Djabou *et al*., 2018; Luo *et al*., 2018). But, soil deficiency in mineral content is widespread and continue to extend since the advent of green revolution (Alloway, 2009; Khoshgoftarmanesh *et al*., 2010; Dimkpa and Bindraban, 2016). Most efforts aimed at correcting soil mineral deficiencies mainly focus on macronutrients in detriment to micronutrients which are essential for crop productivity and storage of many fresh commodities (Khoshgoftarmanesh *et al*., 2010).

Zinc is a micronutrient whose deficiency is widespread in tropical soil (Alloway, 2008; Nielsen, 2012). Close to one billion people in the world, especially children and pregnant women, are exposed to health problems related to Zn deficiency (Khoshgoftarmanesh *et al*., 2010; Swamy *et al*., 2016). More efforts are being made to promote the link between human health and nutrition (Cakmak *et al*., 2016; Montalvo *et al*., 2016). Alleviating Zn deficiency in food has become a research area of significant interest (Cakmak *et al*., 1999). In plant, Zn is one of the eight essential micronutrients implicated in growth and development of cells (Mousavi *et al*., 2013); it is the only micronutrient that intervenes in the activities of all the six classes of enzymes (Sadeghzadeh, 2013); it is involved in the biosynthesis of more than 1200 proteins (Vallee and Falchuk, 1993) and carbohydrates, and in the photosynthetic activity (Alloway, 2008). It is reported that Zn deficiency has negative influence on productivity and quality of products at harvest (Hussain *et al*., 2010; White and Broadley, 2011). Enhanced Zn bioavailability affects yield, quality, Zn content of product and induced the prolongation of the shelf life (White and Broadley, 2011; Luo *et al*., 2018). In tomato production, it was reported that Zn helped achieve optimal plant development and increased yield Karnwal (2020). However, there are currently no data in the literature on the potential effect of preharvest application of fertilizers containing Zn on postharvest storability and shelf life of fruit. The focus of this study was to evaluate the linkage between preharvest cultural practices and the behaviour of tomato fruit in storage during postharvest period.

Materials and methods

Experiment site and plant material

The field experiment was conducted from November 2019 to February 2020 in the city of Bafoussam in the West Region of Cameroon. Tomato seeds (*Solanum lycopersicum* L. var Rio de Grande) from the seed producing firm Technisem were used for the experiment. Tomato seeds were nursed on a soil nursery bed of 2m x 1m. Thirty days after sowing, seedlings were transplanted in plastic pots (15cm × 30cm) each of which contained 5kg of soil. All the pots had six holes at their bottom and sides for drainage of excess of water. The pots were disposed in a complete randomize block design with four levels of Zn-based fertilizer (0ml/l, 5ml/l, 10ml/l and 15ml/l) and six repetitions. Zinc-based fertilizer applications started fourteen days after transplanting and continued a weekly till harvest. Synthetic insecticides and fungicides were used for pest and disease control. Plants were sufficiently irrigated everyday most often minutes prior to sunset.

Growth parameters

Plant height, number of leaves and stem diameters were measured at the 2^{nd}, 4^{th} and 6^{th} week after transplanting. A decameter and a Vernier caliper were used to measure plant height and stem diameter respectively. The number of branches per plant was determined at the 6^{th} week after seedling transplanting.

Development parameters

The number of days between transplanting day and the day of the appearance of the first flower (TETAF) was determined by counting flowering plants daily. The number of flower buds (NFB/P), the number of flowers per plant (NFl/P), the number of fruits per plant (NFr/P) and the number of grapes per plant (NG/P) were progressively measured during plants growth and development cycle. Fruit's lateral and longitudinal diameters (LaD and LoD) and fruit weight (FW) were measured at harvest time with a Vernier caliper.

Fruit quality and storability parameters

To have a better understanding of the implication of preharvest application of Zn on fruit quality and storability, total soluble solid content (TSSC) was measured using the method of Navarre and Navarre (1986) with an ATC brand refractometer (brand name: Aichose; model: SR0017-ATC; China) ranging from 0 to 32° Brix. Two drops of tomato fruit juice free of bubbles and floating particles were deposited on the prism of refractometer and the value was read in the using an incandescent lamp.

The titratable acidity (TA) of fruits was evaluated by the potentiometric method of Gharezi *et al.* (2012). 5ml of tomato juice were mixed with 20ml of distilled water and homogenised with a magnetic stirrer. The solution was titrated with 0.1 M sodium hydroxyl (NaOH) until pH reached 8.1 under continuous stirring. TA was expressed as the percentage of citric acid as followed:

TA (%) = [(Titre value × Normality × m.eq.wt of acid)/volume] × 100

Where milli-equivalent weight of citric acid = 0.06404

Pigment content was determined using the method of Nagata and Yamashita (1992). A 4g sample of red tomato fruit was crushed with sand and introduced into a test tube containing 10ml of acetone/hexane mixture (4/6, v/v). The tube was covered with aluminium paper impervious to light rays and conserved inside the ice for 10 minutes to obtain two separate phases. The optical densities (ODs) of the extracts (supernatant) were measured at wavelengths of 453nm, 505nm, 645nm, and 663nm, using a spectrophotometer (brand: Biochrom Libra; model: S22 UV/Vis; Germany). The ODs obtained were used in the formula elaborated by Nagata and Yamashita (1992) to evaluate the content of β-carotene and lycopene in tomato fruits.

$$\text{Lycopene (mg/ 100 g)} = -0{,}0458A_{663} + 0{,}204A_{645} + 0{,}372A_{505} - 0{,}0806A_{453}$$

$$\beta\text{-carotene (mg /100 g)} = 0{,}216A_{663} - 1{,}22A_{645} - 0{,}304A_{505} + 0{,}452A_{453}$$

The weight of fruits was measured on the 0, 2^{nd}, 5^{th}, 8^{th} and 11^{th} day after harvest with an electronic balance (generic brand; model: SF-400; France). The physiological weight loss (PWL) was expressed as a percentage of the initial weight according to the formula of Gharezi *et al.* (2012) below:

PWL (%) = [(IW-WT) / (IW)] x 100

Where PWL represents the physiological fruit weight loss, IW corresponds to the initial weight of the tomato fruits and WT for the weight of the tomato fruits at a definite time.

The firmness of fruits was evaluated with a penetrometer (brand name: SAUTER GmbH; model: GY-2; Germany) by to the method described by Mehinagic *et al.* (2003). Tomato peels were collected at three different spots on the equatorial region of the fruit to determine fruit firmness. The firmness of the pulp was expressed in kilogram-force.

Statistical analysis

The statistical analysis of data was done using R software version 3.6.2. The data obtained were submitted to an analysis of variances (ANOVA) to verify if differences exist between the means. The multiple comparison Turkey test was use at 5% threshold probability to separate means in cases of differences.

Results

Growth parameters of plant

The field data on growth parameters are presented in Table 1. The analysis of variance (ANOVA) revealed that height of spraying plants was influenced at (p = 0.05) during the sampling period. Thus, increasing Zn concentration significantly improved plant height in the three levels of Zn-based fertilizer at all levels of sampling. These data show that preharvest spraying of Zn fertilizer effectively improved the number of leaves and stem diameter during the 4th and 6th WAT in comparison to control. Plants that received Zn-based fertilizer exhibit highest number of leaves. There is a significant difference ($p \leq 0.05$) in stem diameter between plants treated with Zn fertilizer and the control. Stem diameter of plant fertilized with Zn are significantly improved at 4th and 6th WAT. Also, higher concentrations of Zn lead to higher increase in stem diameters. The number of branches per plant revealed a high influence of treatments ($p = 0.003$). Control (T00) and plants that received 5ml/l of Zn had the lowest number of branches, meanwhile plants treated with 15ml/l (T06) had a higher number of branches per plant.

Table 1. Growth parameters of tomato plant received Zn-based Zn fertilizer.

	Treatments				
Parameters	T00	T04	T05	T06	P-values
PH 2	18.06±1.74a	21.80±1.74b	21.16±1.13b	20.95±2.32ab	0.008 **
PH 4	31.08±2.33a	33.70±2.84ab	35.33±1.69b	37.25±2.38b	0.001 **
PH 6	55.53±1.65a	62.48±3.28b	57.31±3.24a	59.36±3.75ab	0.005 **
NL 2	4.66±0.81a	4.83±0.40a	4.83±0.75a	5.00±0.63a	0.863 ns
NL 4	10.83±1.16a	17.16±1.94b	17.00±2.09b	16.66±1.75b	0.000 ***
NL 6	28.00±2.09a	43.33±2.65b	39.83±2.31b	40.33±3.26b	0.000 ***
PD 2	4.21±0.43a	4.75±0.55a	4.85±0.60a	5.11±0.84a	0.121 ns
PD 4	7.10±0.63a	7.88±1.33ab	8.36±1.20ab	9.30±0.49b	0.007 **
PD 6	7.85±0.92a	9.98±1.18b	10.21±0.89b	11.73±0.60c	0.000***
NB/P 6	10.16±1.16a	10.50±1.04a	11.33±1.21ab	12.50±0.54b	0.003 **

Values followed by the same letters in the same row are not significantly different at 5% probability threshold according to the Turkey test. PH 2: plant height on the 2nd week after transplantation; NL 2: number of leaves per plant on the 2nd week after transplantation; PD 2: plant diameter on the 2nd week after transplantation; NB/P 6: number of branches per plant on the 6th week after transplantation. T00: control plants; T04: plants that received liquid Zn fertilizer at 5ml/l; T04: plants that received the liquid Zn fertilizer at 10ml/l; T06: plants that received liquid Zn fertilizer at 15ml/l.

Tomato plant development parameters

The analysis of variance (ANOVA) of plant development parameters is presented in table 2. Zn-based fertilizer has a significant effect on the time elapsed between seedling transplanting day and the day of the appearance of the first flower (TETAF). Plants that received Zn fertilizer exhibit a rapid appearance of first flowers. A greater difference is observed between treatment on the number of grapes per plant ($p = 0.003$). A linear increase of the number of grapes per plant is observed as the concentration of Zn-based fertilizer increases.

A distinct difference can be noted on the number of flower buds per plant (NBF/P), Number of flowers per plant (NFl/P) and number of fruit per plant (NFr/P) as related to spraying of plant. Plant treated with Zn fertilizer show greater values compare to control plants. No significant difference is observed between treatments in terms of fruits lateral diameter (LaD), fruits longitudinal diameter (LoD) and fruit weight (FW).

Table 2. Development parameters of tomato plants received Zn-based fertilizer.

	Treatments				
Parameters	T00	T04	T05	T06	P-values
TETAF (days)	25.00±1.41b	20.66±1.03a	20.50±1.87a	20.16±1.72a	0.000 ***
NG/P	10.16±1.16a	10.50±1.04a	11.33±1.21ab	12.50±0.54b	0.003 **
NBF/P	56.00±4.89a	63.66±8.59ab	67.83±1.72b	66.83±2.31b	0.003 **
NFl/P	46.50±4.96a	52.00±7.61ab	56.33±4.08b	55.33±4.22b	0.021 *
NFr/P	35.00±3.34a	38.16±3.86ab	39.66±3.26ab	41.00±1.41b	0.020 *
LaD (cm)	42.43±4.42a	42.79±4.69a	42.02±4.29a	40.87±4.00a	0.694 ns
LoD (cm)	51.19±5.11a	54.09±7.33a	51.5±6.17a	50.10±7.62a	0.397 ns
FW (g)	56.53±12.88a	60.87±17.72a	56.88±18.55a	55.83±19.77a	0.854 ns

Values followed by the same letters in the same row are not significantly different at 5% probability threshold according to the Turkey test. TETAF: the time elapsed between the seedling transplanting date and the date of the appearance of the first flower; NG/P: number of grapes per plant; NFB/P: number of flower buds per plant; NFl/P: number of flowers per plant; NFr/P: number of fruits per plant; LoD: longitudinal fruit diameter; LaD: lateral fruit diameter; FW: fruit weight; T00: control plants; T04: plants that received liquid Zn fertilizer at 5ml/l; T04: plants that received the liquid Zn fertilizer at 10ml/l; T06: plants that received liquid Zn fertilizer at 15ml/l.

Tomato fruit quality and storability parameters

Preharvest Zn-based fertilizer applications show no effect on physiological weight losses (PWL) of fruit in the first days after harvest (2nd day after harvesting) and in the days preceding senescence (11th day after harvesting). A significant difference was observed in the intermediate storage days (5th and 11th day after harvesting). Zn-based fertilizer decreased the PWL of fruit in comparison to control fruit (T00).

There is no significant difference ($p < 0.05$) among treatments for total soluble solid content (TSSC) and firmness (FNESS) of fruit. Significant response to preharvest Zn-based fertilizer application was observed on titratable acidity ($p = 0.017$). Titratable acidity of fruit increases with Zn concentration. Zn-based fertilizer application has a significant effect on fruit's lycopene content. Lycopene content is higher in fruits of plants treated with Zn fertilizer compare to control fruits.

Table 3. Quality and storability parameters of tomato fruits received preharvest Zn-based fertilizer.

	Treatments				
Parameters	T00	T04	T05	T06	P-values
PWL 2 (%)	0.83±1.11a	0.55±0.71a	0.61±0.78a	0.57±0.73a	0.788 ns
PWL 5 (%)	4.04±1.13b	3.63±0.89ab	3.40±1.03ab	3.12±0.56a	0.044 *
PWL 8 (%)	7.67±1.96ab	8.14±1.23b	6.59±1.59a	6.71±0.95a	0.014 *
PWL 11 (%)	11.62±3.27a	12.62±0.36a	10.94±1.77a	10.52±1.47a	0.484 ns
SL (days)	11.57±1.65a	12.46±1.06a	12.33±1.11a	12.73±1.09a	0.0884
SR 11(%)	74.82±3.90b	67.77±4.89ab	65.25±4.39ab	59.54±6.35a	0.032 *
FNESS (kg/f)	3.98±0.03a	4.00±0.00a	4.00±0.00a	4.00±0.00a	0.405 ns
Lyco (mg/100g)	0.25±0.05ab	0.24±0.02a	0.27±0.03a	0.43±0.08b	0.005 **
β-Car (mg/100g)	0.14±0.02b	0.07±0.01a	0.05±0.00a	0.11±0.02b	0.000 ***
TA (%)	0.24±0.02a	0.27±0.05ab	0.29±0.04ab	0.38±0.04b	0.017 *
TSSC (°Brix)	5.66±0.57a	5.60±1.21a	6.16±0.28a	6.23±0.25a	0.597 ns

Values followed by the same letters in the same row are not significantly different at 5% probability threshold according to the Turkey test. PWL5: physiological weight loss of fruits on the 5th day after harvesting; SL; shelf life; TSSC: total soluble solid content; TA: titratable acidity; RI: ripening index; Lyco: lycopene; β-Car: β-carotene; SR 11: senescence rate of fruits on the 11th day after harvesting; FNESS: firmness; T00: control plants; T04: plants that received liquid Zn fertilizer at 5ml/l; T04: plants that received the liquid Zn fertilizer at 10ml/l; T06: plants that received liquid Zn fertilizer at 15ml/l.

Discussion

Growth parameters of plant

Soil zinc deficiency is a problem that is common and widespread worldwide (Cakmak, 2000).

This deficiency in zinc results in physiological and biochemical depressions in plant (Alloway, 2008). In this study, tomato growth parameters namely plant height, number of leaves, plant diameter and number of branches per plant showed a positive response to Zn-based fertilizer. Plants that received Zn-based fertilizer exhibited the highest height and number of branches per plant as compared to control plant (T00). As shown in Table 1, growth parameters augmented progressively with increasing zinc concentrations. Similar results have previously been reported by Haleema *et al.* (2018) on *Solanum lycopersicum*, Ahmed *et al.* (2011) on *Solanum tuberosum* and Bhatt and Maheshwari (2020) on *Capsicum annum* where foliar application of zinc improved plant height and numbers of branches. Karnwal (2020) had noted similar effect by improving soil bioavailability of Zn using Zn-solubilizing microorganisms. Also, Cakmak (2000) reported that Zn intervenes in many physiological and biochemical processes such as biosynthesis of indole-acetic acid (Cakmak, 2000). Zn is an essential nutrient in tryptophan synthesis which is a precursor in auxin biosynthesis (Mousavi *et al.*, 2013). Moreover, Zn also boost nitrogen uptake and accumulation in plant cells which is an essential macronutrient in plant growth Grzebisz *et al.* (2008). Furthermore, Vallee and Falchuk (1993) had noted that Zn is an essential component in biosynthesis of many proteins and enzymes. Zn is a main component of carbonic anhydrase enzyme which led to photosynthesis activities (Cakmak, 2000).

Development parameters of plant

The improvement of growth parameters because of zinc fertilizer application promoted early appearance of flowers. Zinc fertilizer application also increased several development parameters. These results are supported by the fact that Zn has an important metabolic role in plant growth and development (Mousavi *et al.*, 2013). Most of the development parameters in this study were influenced by Zn-based fertilizer. The time elapsed between the seedling transplanting date and the date of the appearance of the first flower (TETAF) of Zn fertilized plants was significantly shortened in contrast to control plant, suggesting that Zn has a key role in plant reproduction and flowering enhancement. Pandey *et al.* (2006) obtained similar results on *Lens culinaris* where flowering occurred significantly earlier by five to six days due to Zn application. According to Alloway (2008), Zn intervenes in plant reproduction and improves pollen development. Pollen grains and anthers development required high level of Zn in comparison to other plant parts (Sharma *et al.*, 1990). Early flowering also contributed to a significant increase in the numbers of bud flowers, number of flowers and number of fruits per plant. Similar results have been reported previously by Ejaz *et al.* (2012) and Haleema *et al.* (2018) on tomato plant. Early flowering and enhancement of pollen viability after Zn fertilizer application can thus explain the improvement of flowers buds, number of flowers and number of fruits (Alloway, 2008). Moreover, Zn is reported to decrease biosynthesis of abscisic acid in cells (Pandey *et al.*, 2006; Das and Green, 2013). Fruit development namely lateral and longitudinal diameters were not affected by application of Zn fertilizer. Similar results were reported by Luo *et al.* (2018) on *Dimocarpus longan* where foliar treatment of $ZnSO_4$ had not significant effect on longitudinal and lateral diameter of fruits and didn't affect fruit weight. This result contradicts that of Abd El-Baky *et al.* (2010) that showed that length and diameter of *Ipomea batatas* tubers are significantly affected after application of Zn-based fertilizer. A tentative explanation of this contrast can be that a slight and non-sufficient Zn concentration during vegetative growth of crop may result to improve Zn tissue concentrations in detriment of yields components (Montalvo *et al.*, 2016).

Fruit quality and storability

Zinc is a necessary element in the maintenance of living membranes (Mousavi *et al.*, 2013). Application of Zn fertilizer exhibited significantly effect on the storability and quality parameters of tomato fruit. Thus, a drastic decrease of physiological weight losses (PWL) and senescence rate of fruit was observed as the concentration of Zn-based fertilizer increased. Unlike, lycopene content, titratable acidity and β-carotene showed increasing values with increasing concentrations of Zn application. Similar finding was reported by Luo *et al.* (2018) on *Dimocarpus longan* that preharvest Zn-based fertilizer decreased PWL, rate of rotting, browning rate of fruit and increasing resistance against quiescent microbial infection. Increasing respiration rate and biosynthesis of ethylene in climacteric fruit at ambient temperature led to significant weight losses and senescence of fruit (Haile, 2018). PWL in fresh product occur due to water loss after harvest and lead to water stress in the fruit which enhance or accelerate senescence (Diaz-Pérez, 2019). Zn is accumulated mainly in cell wall and contributes to decrease cation exchange capacity of cell wall (Muschitz *et al.*, 2015). Additionally, Zn may be involved in maintaining the integrity of cellular membranes, structural orientation of macromolecules and maintenance of ions transport systems (Cakmak, 2000; Alloway, 2008). A sufficient Zn uptake by plant lead to bind of Zn^{2+} ions to cysteine, blocking binding of Fe to cysteine and thus preventing formation of $Fe^{2+}(RS^{-})_2$ and ROS during cycling of Fe-cysteine complex (Alloway, 2008). An improvement of carotenoids content in sweet potato (*Ipomea batatas*) tubers had been reported by Abd El-Baky *et al.* (2010).

Conclusion

Zinc is an essential component which intervenes in many physiological and biochemical processes. Preharvest application of Zn on tomato plant has contributed in improving growth and development parameters such as plant height and early flowering of plants, leading to an increase in productivity. Furthermore, Zn affects quality and storability parameters of fruits by decreasing PWL and senescence rate. It also causes a significant increase in carotenoids content and titratable acidity. The concentration of 15ml/l exhibited the best results on most of the parameters evaluated.

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