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FOLIAR APPLICATIONS OF ZINC, IRON AND MANGANESE INFLUENCE THE PLANT GROWTH AND FRUIT QUALITY OF PAPAYA CV. RED LADY

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ABSTRACT

Prevalence of heavy soil is a major problem for fruit cultivation under Punjab conditions consequently leading to deficiency of several micro-nutrients including zinc (Zn), iron (Fe), and manganese (Mn) which adversely affects the growth and productivity. In this view, a study was planned to investigate the effect of foliar applications of zinc sulphate (ZnSO_4), iron sulphate (FeSO_4), and manganese sulphate (MnSO_4) on vegetative growth, reproductive growth and fruit quality of papaya cv. Red lady. Plants sprayed with ZnSO_4 (0.4 %) exhibited significantly highest plant height, plant girth, number of leaves, petiole length; initiated an earliest flowering and fruiting; and improved fruit quality viz., fruit weight, fruit length, titratable acidity, soluble solids concentrations, ascorbic acid content, total phenols content, and total carotenoids content as compared with the control and all other treatments. In conclusion, foliar application ZnSO_4 (0.4 %) significantly improved plant growth and fruit quality in papaya cv. Red lady.

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1 Introduction

Papaya (*Carica papaya* L.) is one of the popular fruit crops of the tropics due to its higher productivity and ability to produce high quality of fruits year around. Besides this, fruits of papaya have higher nutritive and therapeutic values and rich in carotenoids, ascorbic acid and minerals such Ca, P & Fe. Sandy loam soils with pH between 6.5-7.0 and with adequate drainage facilities are considered as good for papaya cultivation (Anonymous, 2019). In Punjab, around 0.06 m ha of arable land is salt-affected. Such soils are highly alkaline in reaction and having exchangeable sodium percentage (ESP) more than 50 percent thereby leads to the deficiency of one or more micro-nutrient (Sharma et al., 1982). Micro-nutrients are the key elements involved in various growth and development processes such as cell wall development, chlorophyll formation, hormonal regulation, nitrogen fixation, and reduction (Singh et al., 2019).

Zinc (Zn) is an essential trace element that maintains the integrity of cellular membranes, involves in carbohydrate metabolism, synthesizes protein and regulates the synthesis of auxin in higher plants. Deficiency of Zn leads to abnormalities in plants such as smaller leaves, chlorosis, and stunted plant growth. Besides this, its deficiency may also hamper the quality of harvested produce (Hafeez et al., 2013).

Manganese (Mn) is one of the heavy metal micro-nutrients involved in photosynthesis and membrane function as well as serves as an activator of miscellaneous enzymes in the cell. Younger leaves develop the initial symptoms of Mn deficiency. The most visible symptoms of Mn deficiency are pale mottled leaves and interveinal chlorosis (Alejandro et al., 2020).

Iron (Fe) is involved in the biosynthesis of chlorophyll and its deficiency leads to a reduction in the net photosynthesis (Singh et al., 2019). Interveinal chlorosis of nodes and stunting root growth are the visual symptoms of iron deficiency in higher plants (Rout & Sahoo, 2015).

Limited usages of farmyard manures and application of fertilizers containing lower micro-elements leading to deficiencies of micro-nutrients viz., Zn, Mn, Fe, Ca and B in the soil. Improper fruit growth, reduction in the yield, the vulnerability of plant to insect pests, and production of the inferior quality of fruits are subjected to these nutritional deficiencies (Ioannis et al., 2004). Existing literature revealed that foliar application of micro-nutrients improved fruit quality in aonla (Mishra et al., 2017), strawberry (Kazemi, 2014), pomegranate (Hasani et al., 2012), and peaches (Muradi & Godara, 2020). Earlier, the foliar application of several micro-nutrients in a combination or without combination significantly improved plant growth and fruit quality in papaya cv. Red lady (Manjunatha et al., 2014; Yadaw, 2017). However, standardization of micro-nutrients is yet to be done to evaluate their effect on plant growth and fruit quality.

Keeping this view an investigation was carried out to examine the effect of foliar application of ZnSO_4 , MnSO_4 , and FeSO_4 with varied concentration on plant growth and fruit quality of papaya cv. Red lady.

2 Materials and methods

2.1 Plant material

For this experiment one-month-old healthy seedlings of papaya cv. red lady were collected from Punjab Agricultural University of Ludhiana and planted with the spacing of 1.8 m (row to row) x 1.8 m (plant to plant) at the fruit research farm of Lovely Professional University, Jalandhar (31°15'N; 75°42'E). Experimented plants were subjected to different intercultural operations i.e. irrigation, removal of weeds, and management of pest and disease. Foliar application of ZnSO_4 (0.2 and 0.4 %), MnSO_4 (0.2 and 0.4 %) and FeSO_4 (0.2 and 0.4 %) and 0.01 % Tween-20 (as surfactant) were sprayed by using hand-held sprayer after transplanting. The experiment was laid in the randomized block design (RBD) included three replication and three plants per replication for each treatment.

2.2 Vegetative and reproductive growth

The tree vegetative growth (plant height, plant girth, the number of leaves and petiole length) and reproductive growth (days have taken to first flowering and days taken to first fruit set) were determined following the conventional methods previously used by Yadaw (2017).

2.3 Fruit quality

Fruit harvested from the experimental plants were used to determine fruit weight, fruit length, fruit width, and fruit volume following the methods earlier detailed by Yadaw (2017). A digital hand refractometer (Atago Co., Tokyo, Japan) was used to determine the SSC of the fruit pulp and expressed in percentage after making the temperature correction at 20 °C. The TA was estimated following the standard procedure previously outlined by AOAC (2005) and expressed in percentage. Sugars were estimated from the fruit pulp following the method previously detailed by Hortwitz (1960) with moderate modifications earlier detailed by Yadaw (2017) and expressed in percentage. To determine ascorbic acid content fresh fruit pulp was used by following the methods recently detailed by Baswal et al. (2020) and expressed in $\text{mg } 100^{-1} \text{ g pulp}$. Total phenol content and total carotenoids content were estimated following methods recently detailed by Baswal (2019) with slight modifications.

2.4 Statistical design

All the field and lab experimental data were subjected to ANOVA using Statistical Analysis System 9.3 (S.A.S. Institute Inc., Cary, NC, USA) and means were separated by Duncan's multiple range test. Differences at $P \leq 0.05$ were considered as significant.

3 Results and Discussion

3.1 Effect of foliar application of micronutrients on vegetative, reproductive growth and fruit quality

3.1.1 Plant height, plant girth, number of leaves per plant and petiole length

Foliar application of micro-nutrients significantly influenced plant growth. At 90 and 180 days after transplanting (DAT) foliar application of ZnSO₄ (0.4 %) recorded significantly highest mean plant height, plant girth, number of leaves and petiole length followed by MnSO₄ (0.4 %) as compared with the control and all other treatments (Table 1). An increase in plant growth possibly due to a stimulatory effect of Zn on the physiological and metabolic process of plants. Zn acts as a co-factor for several enzymes influences numerous processes including photosynthesis, nucleic acid metabolism, and protein synthesis thereby increases tissue growth and development (Yadaw, 2017). Previously, the foliar application of ZnSO₄ + borax + FeSO₄ resulted significantly highest plant height, plant girth, number of leaves and petiole length in papaya cv. Red lady (Yadaw, 2017; Manjunatha et al., 2014). However, in contrast to our results, Razzaq et al. (2013) reported that foliar application of ZnSO₄ did not influence the number of leaves in 'Kinnow' mandarin. It is speculated that the response of micro-nutrients varies in different fruit crops or may be due to environmental conditions (EI-Khawaga, 2007; Hasani et al., 2012).

3.2 Effect of foliar application of micro-nutrient on reproductive growth

Plant sprayed with foliar application micro-nutrients exhibited a significant influence on flower and fruit initiation. Foliar application of ZnSO₄ (0.4 percent) recorded an earliest flowering and fruit initiation with 138.67 days and 155 days respectively followed by MnSO₄ (0.4 percent) and these two are significantly different than control and all the other treatments. (Table 1). An initiation in earliest flowering and fruiting by foliar application of Zn might be due to its role in various metabolic processes such as synthesis of auxin and absorption of macro-molecules from the soil which regulates cell division and cell enlargement (Yadaw, 2017). Similarly, foliar application of Urea + ZnSO₄ also resulted in an earliest initiation of flowering and fruit in papaya cv. Red lady (Yadaw, 2017).

3.3 Effect of foliar application of micro-nutrients on fruit quality

3.3.1 Fruit weight, fruit length, fruit width and fruit volume

Foliar application of micro-nutrients significantly influenced fruit weight, fruit length, fruit width and fruit volume. Amongst all, foliar application of ZnSO₄ (0.4 percent) exhibited significantly

Table 1. Effect of foliar application of FeSO₄, ZnSO₄ and MnSO₄ on vegetative and reproductive growth of the papaya cv. Red lady

Treatments	Plant height (cm)			Plant girth (cm)			Number of leaves			Petiole length (cm)		Days taken to first flowering	Days taken to first fruiting
	90 DAT	180 DAT		90 DAT	180 DAT		90 DAT	180 DAT		90 DAT	180 DAT		
FeSO ₄													
0.2 %	65.00 ^d ± 2.08	106.00 ^b ± 2.30		10.00 ^{cd} ± 0.57	16.67 ^{cd} ± 0.88		12.67 ^{cd} ± 0.33	29.33 ^{bc} ± 0.88		31.67 ^b ± 0.88	37.33 ^{cd} ± 0.33	148.67 ^{ab} ± 1.45	164.33 ^b ± 2.18
0.4 %	67.33 ^{cd} ± 1.20	110.67 ^b ± 1.45		11.00 ^{bc} ± 1.15	17.33 ^{bc} ± 1.20		13.00 ^{cd} ± 0.57	29.67 ^{bc} ± 1.20		36.33 ^b ± 1.20	40.00 ^{cd} ± 0.57	143.33 ^{cd} ± 2.33	163.67 ^b ± 1.45
ZnSO ₄													
0.2 %	65.67 ^{cd} ± 1.85	103.00 ^b ± 2.64		12.33 ^{ab} ± 0.44	18.67 ^b ± 0.44		15.67 ^{ab} ± 0.33	32.33 ^{bc} ± 1.76		38.00 ^b ± 2.51	40.67 ^{bc} ± 0.88	144.33 ^{bc} ± 1.20	166.00 ^b ± 1.15
0.4 %	75.67 ^a ± 2.02	120.67 ^a ± 3.84		13.83 ^a ± 0.44	22.00 ^a ± 1.15		17.00 ^a ± 0.57	36.00 ^a ± 1.52		43.00 ^a ± 0.57	51.67 ^a ± 2.90	138.67 ^{ab} ± 2.02	155.00 ^a ± 3.05
MnSO ₄													
0.2 %	70.33 ^{bc} ± 1.85	109.33 ^{bc} ± 3.92		13.33 ^a ± 0.44	19.67 ^{ab} ± 1.20		14.33 ^{bc} ± 0.88	32.67 ^{bc} ± 1.45		36.33 ^b ± 1.45	42.67 ^b ± 2.96	143.67 ^{bc} ± 1.76	165.67 ^b ± 1.76
0.4 %	74.67 ^{ab} ± 1.20	111.00 ^b ± 3.46		14.00 ^a ± 0.57	20.00 ^b ± 0.57		16.00 ^{ab} ± 0.57	33.33 ^{ab} ± 1.45		38.00 ^b ± 0.57	44.00 ^b ± 0.57	141.67 ^{cd} ± 2.33	161.00 ^b ± 3.05
Control	63.67 ^d ± 1.20	100.67 ^c ± 1.85		8.33 ^d ± 0.88	14.33 ^d ± 0.88		11.33 ^d ± 0.66	29.00 ^c ± 0.57		29.00 ^c ± 0.57	35.00 ^d ± 1.00	153.00 ^d ± 2.30	176.33 ^d ± 1.45
Mean ± S.E.	68.90 ± 1.67	108.76 ± 2.93		11.83 ± 0.69	18.38 ± 0.94		14.28 ± 0.59	31.76 ± 1.32		36.05 ± 1.29	41.62 ± 1.68	144.76 ± 1.96	164.57 ± 2.14
LSD (<i>P</i> ≤ 0.05)	5.08	8.88		2.10	2.87		1.79	4.00		3.91	5.09	5.19	6.59

Mean ± SE value followed by the different letter in same vertical column are significantly different according to Duncan's multiple range test (*p* ≤ 0.05); *DAT (Days after transplanting)

Table 2 Effect of foliar application of FeSO₄, ZnSO₄ and MnSO₄ on fruit quality of papaya cv. Red lady

Treatments		Fruit weight (g)	Fruit length (cm)	Fruit width (cm)	Fruit volume (ml)	Titrateable acidity (%)
FeSO ₄	0.2 %	569.67 ^b ± 70.48	11.50 ^b ± 0.45	8.90 ^{bc} ± 0.40	473.33 ^b ± 76.78	0.21 ^{ab} ± 0.02
	0.4 %	721.33 ^a ± 17.13	12.87 ^a ± 0.12	9.90 ^{ab} ± 0.45	588.33 ^{ab} ± 6.66	0.19 ^{ab} ± 0.03
ZnSO ₄	0.2 %	707.33 ^a ± 8.19	13.17 ^a ± 0.24	10.23 ^{ab} ± 0.08	539.66 ^{ab} ± 71.39	0.18 ^{ab} ± 0.00
	0.4 %	778.00 ^a ± 51.93	13.73 ^a ± 0.23	10.93 ^a ± 0.99	630.00 ^a ± 7.63	0.14 ^b ± 0.02
MnSO ₄	0.2 %	710.00 ^a ± 10.40	11.70 ^b ± 0.46	10.57 ^a ± 0.49	600.00 ^a ± 17.55	0.17 ^b ± 0.02
	0.4 %	771.00 ^a ± 26.76	13.70 ^a ± 0.11	10.83 ^a ± 0.23	626.66 ^a ± 6.00	0.16 ^b ± 0.01
Control		586.00 ^b ± 33.08	10.10 ^c ± 0.15	8.03 ^c ± 0.18	336.66 ^c ± 7.26	0.24 ^a ± 0.01
Mean ± S.E.		691.90 ± 37.69	12.39 ± 0.28	9.91 ± 0.49	542.09 ± 40.54	0.19 ± 0.02
LSD (P ≤ 0.05)		116.14	0.89	1.51	124.93	0.068

Mean ± SE value followed by the different letter in same vertical column are significantly different according to Duncan's multiple range test ($p \leq 0.05$)

highest mean fruit weight, fruit length, fruit width and fruit volume with 778.0 g, 13.73 cm, 10.93 cm and 630.0 ml respectively followed by MnSO₄ (0.4 percent) with 771.0 g, 13.70 cm, 10.83 cm and 626.66 ml respectively as compared with the control where it was recorded lowest (Table 2). An increase in fruit weight, fruit length, fruit width, and fruit volume with foliar application ZnSO₄ can be attributed to its role in the synthesis of an amino acid 'tryptophan' a precursor for the synthesis of IAA influence the growth and development of the fruit (Cakmak et al., 1989). Following an increase in the level of Zn in the leaves, the plant starts producing more tryptophan simultaneously improves the fruit growth. Likewise, the foliar application of Urea + ZnSO₄ exhibited significantly highest fruit weight, fruit length, fruit width, and fruit volume in papaya cv. Red lady (Yadaw, 2017). Similar results were reported in 'Kinnow' mandarin and sweet orange by Razzaq et al. (2013) and Sahota & Arora (1981).

3.3.2 Titrateable acidity

Fruit harvested from the experimental plants showed a significant difference for TA (Table 2). Foliar application of ZnSO₄ (0.4 percent) recorded significantly lowest mean titrateable acidity with 0.14 percent followed by MnSO₄ (0.4 %) with 0.16 percent as compared with the control where it was registered as maximum with 0.24 percent (Table 2). Foliar application of ZnSO₄ decreased TA may be due to its effect on various enzymes involved in the formation of acid, protein and sugars (Srivastava & Gupta, 1996). Previously, foliar application of Urea + ZnSO₄ resulted significantly reduced TA in papaya cv. Red lady (Yadaw, 2017). Likewise, the foliar application of micro-nutrients recorded significantly reduced TA in aonla cv. NA-7 and 'Khasi' mandarin (Babu & Yadav, 2005; Chandra & Singh, 2017). However, contrarily, in case of pomegranate, the foliar application of Zn increased TA may be due to the response of micro-nutrients that

can be different for different fruit crops or may due to environmental conditions (EI-Khawaga, 2007; Hasani et al., 2012). Similarly, the foliar application of Zn significantly increased TA in 'Kinnow' mandarin and 'Balady' mandarin (Dawood et al., 2001; Razzaq et al., 2013).

3.3.3 Soluble solids concentration

The fruits collected from the plants sprayed with different micro-nutrients showed a significant difference for SSC. Foliar application of ZnSO₄ (0.4 %) exhibited significantly highest mean SSC as 12.20 percent followed by MnSO₄ (0.4 %) with 11.88 percent as compared with the control where it was recorded as lowest with 8.65 percent (Table 3). Foliar application of micro-nutrients increases vegetative growth and influence the rate of photosynthesis consequently increase the transportation of photo-assimilates from leaves to fruit thus results in an increase in SSC (Obaid & Al-Hadethi, 2013). Previously, Yadaw (2017) reported that the foliar application of Urea + ZnSO₄ resulted significantly highest SSC in papaya cv. Red lady. Similarly, foliar application of micro-nutrients recorded significantly highest SSC in aonla cv. NA-7 and ber (EI-Rhman & Shadia, 2012; Chandra & Singh, 2017). However, in contrast to the results of the current study, Sahota & Arora (1981) reported that SSC was not influenced by foliar application micro-nutrients in sweet orange cv. Hamlin this might be because of the response of micro-nutrients can be different for different fruit crops or may due to environmental conditions (EI-Khawaga, 2007; Hasani et al., 2012).

3.3.4 Total sugars & reducing sugars

Fruits harvested from the treated plants showed a significant influence on total sugars and reducing sugars. Amongst all, foliar application of ZnSO₄ (0.4 %) recorded the maximum mean total sugars and reducing sugars as 9.23 and 7.96 percent respectively,

Table 3 Effect of foliar application of FeSO₄, ZnSO₄ and MnSO₄ on fruit quality of papaya cv. Red lady

Treatments	Soluble solids concentration (%)	Total sugars (%)	Reducing sugars (%)	Ascorbic acid (mg 100 g ⁻¹ pulp)	Total phenols (mg 100 g ⁻¹ pulp)	Total carotenoids (mg 100 g ⁻¹ pulp)
FeSO ₄	0.2 %	9.71 ^{de} ±0.31	6.34 ^d ±0.18	5.35 ^d ±0.29	52.85 ^{cd} ±0.87	60.45 ^{bc} ±7.11
	0.4 %	10.89 ^{bc} ±0.33	7.59 ^c ±0.49	6.19 ^c ±0.19	53.86 ^{cd} ±3.62	115.32 ^{abc} ±29.09
ZnSO ₄	0.2 %	11.13 ^{bc} ±0.16	8.18 ^{bc} ±0.16	7.33 ^b ±0.21	58.59 ^{bc} ±0.46	110.74 ^{abc} ±32.95
	0.4 %	12.20 ^a ±0.40	9.23 ^a ±0.18	7.96 ^b ±0.08	66.44 ^a ±2.30	187.28 ^a ±34.31
MnSO ₄	0.2 %	10.74 ^{cd} ±0.48	8.80 ^{ab} ±0.16	7.77 ^{ab} ±0.10	61.41 ^{ab} ±2.00	138.51 ^{ab} ±28.66
	0.4 %	11.88 ^{ab} ±0.34	8.92 ^{ab} ±0.28	7.81 ^{ab} ±0.11	61.58 ^{ab} ±0.89	178.65 ^a ±23.27
Control		8.65 ^e ±0.28	6.00 ^d ±0.07	5.06 ^d ±0.11	48.04 ^d ±0.91	52.16 ^c ±7.03
Mean±S.E.		10.74 ± 0.34	7.87 ± 0.25	6.78 ± 0.18	57.53 ± 1.89	120.44 ± 25.55
LSD (P≤0.05)		1.07	0.76	0.52	6.67	78.75

Mean ± SE value followed by the different letter in same vertical column are significantly different according to Duncan's multiple range test ($p \leq 0.05$)

this was followed by MnSO₄ (0.4 %) and these two are significantly different from the control where it was recorded as lowest with 6.00 and 5.06 percent, respectively (Table 3). An increase in the levels of sugars by foliar application of ZnSO₄ is ascribed to its influence on aldolase activity which is responsible for the formation of sugars in fruits (Alloway, 2008). Earlier, the foliar application of Urea + ZnSO₄ resulted in significantly highest sugars level in papaya cv. Red lady (Yadaw, 2017). Similar results were also reported in 'Kinnow' mandarin and 'Khasi' mandarin (Babu & Yadav, 2005; Razzaq et al., 2013).

3.3.5 Ascorbic acid

Plants sprayed with foliar application of micro-nutrients showed a significant influence on ascorbic acid content. Foliar application of ZnSO₄ (0.4 %) resulted in the maximum mean ascorbic acid content as 66.44 mg 100 g⁻¹ pulp, followed by MnSO₄ (0.4 %) with 61.58 mg 100 g⁻¹ pulp, whereas it was registered as lowest in control with 48.04 mg 100 g⁻¹ pulp (Table 3). Exhibition of higher ascorbic acid content by foliar application of Zn may be due to its role in the synthesis of auxin which helps in the accumulation of higher ascorbic acid content (Nawaz et al., 2008). Previously, the foliar application of Urea + ZnSO₄ significantly increased the synthesis of auxin consequently resulted in higher ascorbic acid content in papaya cv. Red lady (Yadaw, 2017). Similarly, the foliar application of Zn also resulted in significantly higher ascorbic acid content in 'Kinnow' mandarin and 'Balady' mandarin (El-Menshawi et al., 1997; Razzaq et al., 2013).

3.3.6 Total phenols

The foliar application of micro-nutrients significantly influenced the total phenols. Amongst all, foliar spray with ZnSO₄ (0.4 %) recorded the maximum mean total phenols as 187.28 mg 100 g⁻¹

pulp followed by MnSO₄ (0.4 %) with 178.65 mg 100 g⁻¹ pulp as compared with the control where it was recorded as lowest with 52.16 mg 100 g⁻¹ pulp (Table 3). Previously, Razzak et al. (2013) also reported that foliar spray of ZnSO₄ recorded significantly higher contents of total phenols in 'Kinnow' mandarin. However, there is no clear evidence as how foliar applications of micro-nutrients influence the phenolic compounds in fruit crops thus requires further investigations.

3.3.7 Total carotenoids

Plants sprayed with foliar application micro-nutrients exhibited a significant influence on total carotenoids content. Amongst all the treatments, foliar application of ZnSO₄ (0.4 %) exhibited significantly highest mean total carotenoids content as 1.27 mg 100 g⁻¹ pulp, followed by MnSO₄ 0.4 percent with 1.25 mg 100 g⁻¹ pulp (Table 3). These results are in agreement with the findings of Singh et al. (2010), those who reported, higher total carotenoids in papaya cv. Ranchi on the foliar application of ZnSO₄ + borax. However, the exact mechanism of how micro-nutrients influenced the total carotenoids content is still unknown and therefore needs further investigations.

In conclusion foliar application of ZnSO₄ (0.4 %) significantly influenced plant growth and fruit quality of papaya cv. Red lady.

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Conflict of interests

We declare that there is no conflict of interest between us.

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