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The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; 12(10): 1728-1731

www.thepharmajournal.com
Received: 03-08-2023
Accepted: 07-09-2023

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Improving the physicochemical characteristics of pomegranate (*Punica granatum* L.) cv. Bhagwa via soil and foliar nutrient treatments in arid zone of western Rajasthan

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Abstract
Pomegranate (*Punica granatum* L.) is a valuable fruit crop known for its health benefits and adaptability to diverse climates. In the arid region of Rajasthan, pomegranate cultivation has thrived, particularly with the Bhagwa cultivar, due to its economic significance and suitability for the challenging climate. This study investigates the impact of nutrient management, involving the individual and different combinations of NPK and $ZnSO_4$, $FeSO_4$, $MgSO_4$, Boric acid on the physicochemical attributes of pomegranate fruit. A two-year experiment (2020-21 and 2021-22) was conducted, employing various nutrient application methods, including soil and foliar treatments. Results revealed that among the different treatments T_{12} $ZnSO_4$ @ 50 g + $FeSO_4$ @ 50 g + $MgSO_4$ @ 50 g + Boric acid @ 25 g + $ZnSO_4$ @ 0.2% +$FeSO_4$ @ 0.2% + $MgSO_4$ @ 0.2% + Boric acid @ 0.1% superior and shows the maximum total soluble solids (TSS), sugar content and minimum titratable acidity (TA) when a combination of both soil and foliar applications was employed. These findings underscore the importance of judicious nutrient management in enhancing pomegranate quality and yield, particularly in arid regions of Rajasthan.

Keywords: Pomegranate, *Punica granatum*, nutrient management, physicochemical attributes

Introduction
Pomegranate (*Punica granatum* L.) is an economically significant fruit crop known for its vibrant red arils and numerous health benefits. Cultivated in diverse climates worldwide, pomegranate has gained popularity for its antioxidant-rich properties and the versatility of its products, such as juices, fresh fruit, and extracts. Pomegranate cultivation in the arid climate of Rajasthan, India, has emerged as a significant agricultural endeavour. Climate of Rajasthan is characterized by high temperature and limited rainfall, presenting challenges for many crops. However, pomegranate cultivation has flourished in this region due to its inherent drought resistance and adaptability to arid conditions (Hasani *et al.*, 2015) [7]. Specifically, pomegranate cultivars like Bhagwa have been carefully selected and adapted to thrive in unique environmental condition of Rajasthan. It is known for its large and luscious arils, rich flavor, and vibrant color. This economic viability of fruit, extended shelf life and strong demand in both domestic and international markets have made it an attractive option for local farmers. Furthermore, pomegranate farming has allowed for crop diversification, reducing dependency on traditional crops that may be more vulnerable to arid conditions. The success of pomegranate cultivation has contributed to increased farm income, improved livelihoods, and economic development in rural Rajasthan. To maximize yields and quality, farmers in the region employ various strategies, including efficient irrigation methods, soil amendments, and nutrient management practices, aimed at optimizing pomegranate growth in the face of the challenging arid climate.

The application of essential nutrients such as Nitrogen (N), Phosphorus (P), Potassium (K), Zinc (Zn), Iron (Fe), and Boron (B) exerts a profound influence on the physicochemical attributes of pomegranate fruit. These nutrients play pivotal roles in the growth and development of pomegranate trees, directly shaping the characteristics of the resulting fruit. Nitrogen, for instance, is essential for stimulating vigorous vegetative growth, potentially leading to larger fruit size and increased yield. However, careful management is crucial, as excessive nitrogen can dilute fruit sugar content, affecting sweetness.

Phosphorus, potassium and magnesium are vital for overall plant health and fruit quality, contributing to fruit size, appearance and color. Zinc and iron, as micronutrients, play essential roles in enzymatic reactions that enhance fruit color and overall aesthetic appeal (Motesharezade *et al*., 2001) [10]. Boron, another micronutrient, influences flowering, pollen viability, and fruit set, ultimately impacting fruit size and yield. It is also indirectly accountable for activation of dehydrogenase enzymes, sugar translocation, nucleic acids and hormones (Marschner, 2012) [9]. While these nutrients offer significant benefits, their precise influence on pomegranate physicochemical attributes may vary depending on soil conditions, climate, and nutrient management practices. Therefore, a balanced and well-informed approach to nutrient management is essential to optimize pomegranate fruit quality while avoiding potential imbalances or toxicities

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Materials and Methods

Studies were carried out at the Integrated Farming System Unit, Swami Keshwanand Rajasthan Agricultural University, Bikaner during subsequent two years during 2020-21 and 2021-22. The pomegranate trees were of four-year-old. Trees were planted in regular rows and spaced at 5 × 5 m (400 trees ha^{-1}) and irrigated by a drip irrigation system. Two methods of application of nutrients are employed, a foliar spray and soil application. Experiment was carried out based on completely randomized block design with twelve treatments T_1 Control (RDF), T_2 RDF + Soil application of $ZnSO_4$ @ 100 g, T_3 RDF + Soil application of $FeSO_4$ @ 100 g, T_4 RDF + Soil application of $MgSO_4$ @ 100 g, T_5 RDF + Soil application of Boric acid @ 50 g, T_6 RDF + Foliar spray of $ZnSO_4$ @ 0.4%, T_7 RDF + Foliar spray of $FeSO_4$ @ 0.4%, T_8 RDF + Foliar spray of $MgSO_4$ @ 0.4%, T_9 RDF + Foliar spray of Boric acid @ 0.2%, T_{10} RDF + Soil application of $ZnSO_4$ @ 100 g + $FeSO_4$ @ 100 g + $MgSO_4$ @ 100 g + Boric acid @ 50 g, T_{11} RDF + Foliar spray of $ZnSO_4$ @ 0.4% + $FeSO_4$ @ 0.4% + $MgSO_4$ @ 0.4% + Boric acid @ 0.2%, T_{12} RDF + Soil application of $ZnSO_4$ @ 50 g + $FeSO_4$ @ 50 g + $MgSO_4$ @ 50 g + Boric acid @ 25 g + Foliar spray of $ZnSO_4$ @ 0.2% +$FeSO_4$ @ 0.2% + $MgSO_4$ @ 0.2% + Boric acid @ 0.1%. The plants were given uniform recommended dose of fertilizers i.e., N_2 @ 650 g/plant, P_20_5 @ 500 g/plant, K_2O @ 500 g/plant. The fertilizer solution was prepared by diluting the commercial grade $ZnSO_4$, $FeSO_4$, $MgSO_4$, and Boric acid on the day of the application of treatment. All the trees were either foliar sprayed or soil applied or treated by both methods according to their treatments. The soil application and first spray were done in the second week of July, followed by one month after the first spray. Subsequently, in the next year soil application and the first spray and second spray were carried out in the same manner.

To determine the fruit quantitative and qualitative parameters, six fruits were randomly selected from each tree replication. Titratable acidity (TA) was determined by the titration method (to pH 8.2 with 0.1 N NaOH), and results were expressed as a percentage of citric acid (Ranganna, 2001) [14]. Total soluble solids (TSS) was measured at room temperature using a digital refractometer. The TSS/TA ratio was calculated. To determine the total sugar in juice, the anthrone reagent method was used (Dubois *et al*., 1951) [5]. A certain volume (1 ml) of juice was diluted with distilled water, and then 0.1 ml of the diluted juice was added to 4 mL of anthrone reagent (150 mg pure anthrone in 100 ml of H_2SO_4 72%). The sample was heated for 10 min in a water bath, and after cooling at room temperature absorbance was measured at 630 nm on a spectrophotometer. The total sugar contents were calculated by using a glucose standard curve. Reducing sugar content was measured following Nelson's modification of Somogyi's method (Somogyi, 1952) [17] using areseno molybdate colour-forming reagent and two copper reagents "A" and "B". The non-reducing sugars were estimated by subtracting reducing sugars from the total sugars.

Data obtained on various characters were analyzed statistically according to the analysis of variance techniques as suggested by Panse and Sukhatme, (1985) [12]. The critical difference (CD) was calculated to access the significance or non-significance of difference between treatment means at 5 per cent level of significance.

Results and Discussion

In the present study, we found that soil and foliar application of $ZnSO_4$, $FeSO_4$, $MgSO_4$ and Boric acid alone or in conjunction resulted significant effect on physicochemical attributes of pomegranate cultivar Bhagwa (Table 1). The highest fruit TSS (18.29 ^oBrix) was recorded in treatment T_{12} i.e., combination of soil and foliar application of $ZnSO_4$ @ 50 g + $FeSO_4$ @ 50 g + $MgSO_4$ @ 50 g + Boric acid @ 25g + $ZnSO_4$ @ 0.2% +$FeSO_4$ @ 0.2% + $MgSO_4$ @ 0.2% + Boric acid @ 0.1% which showed 6.77% increase in TSS as compared to control (17.13 ^{o}Brix). Similarly, the enhancement of fruit TSS with the use of nutrients also has been demonstrated by Hamouda *et al.* (2016) [6] and Ram and Bose (2000) [13]. Improvement in TSS might be due to the regulatory role of zinc which is mediated through auxin induced cell enlargement, accumulation of water and solutes in the vacuole and; the influence of boron in translocation of sugars. Micronutrients are believed to stimulate the function of numbers of enzymes and accumulation of carbohydrates from photosynthesis process where boron is believed to smooth out the sugar transport within the plant. The minimum acidity (0.54%) was observed in treatment T_{12} i.e., combination of soil and foliar application of $ZnSO_4$ @ 50 g + $FeSO_4$ @ 50 g + $MgSO_4$ @ 50 g + Boric acid @ 25g + $ZnSO_4$ @ 0.2% +$FeSO_4$ @ 0.2% + $MgSO_4$ @ 0.2% + Boric acid @ 0.1% however the maximum acidity (0.64%) was recorded in control on pooled basis. As per the data, the maximum 15.62 percent reduction in acidity was recorded under treatment T_{12} over the control. Similarly the TSS: acid ratio (33.69) was recorded in treatment T_{12} i.e., combination of soil and foliar application of $ZnSO_4$ @ 50 g + $FeSO_4$ @ 50 g + $MgSO_4$ @ 50 g + Boric acid @ 25g + $ZnSO_4$ @ 0.2% +$FeSO_4$ @ 0.2% + $MgSO_4$ @ 0.2% + Boric acid @ 0.1% shows maximum 25.70 percent increment in TSS: acid ratio compared to control.

We also noticed that foliar and soil application of $ZnSO_4$, $FeSO_4$, $MgSO_4$ and Boric acid significantly increased reducing, non-reducing sugar and total sugar concentration in fruit juice (Table 2). Among the different treatments T12 ($ZnSO_4$ @ 50 g + $FeSO_4$ @ 50 g + $MgSO_4$ @ 50 g + Boric acid @ 25g + $ZnSO_4$ @ 0.2% +$FeSO_4$ @ 0.2% + $MgSO_4$ @ 0.2% + Boric acid @ 0.1%) recorded the highest reducing (11.65%), non-reducing (1.14%) and total sugar (12.79%) concentration in fruit. These findings are in agreement with the increase in sugar concentration reported in papaya, mandarin, mango and pomegranate fruits upon nutrient treatment (Sing *et al*., 2005; Babu & Yadav, 2005; Anees, 2012; Davarpanah *et al*., 2016) [16, 2, 1, 4]. The effect of nutrients on sugar concentration could be attributed to there role in accumulation of carbohydrates through photosynthesis, specifically boron facilitate sugar transport within the plant (Yadav *et al*., 2013; Hamouda *et al*., 2016) [18, 6]. Zinc is necessary for enzymatic reactions involved in hexokinase creation, carbohydrate synthesis, and protein synthesis (Pamila *et al*., 1992) [11]. Iron plays a crucial role in enhancing photosynthetic efficiency, resulting in a better photosynthetic rate, while boron facilitates sugar transport through the boron-sugar complex and enhances the hydrolysis of saccharides into simple sugars (Shanmugavelu *et al*., 1973) [15]. Similarly, magnesium (Mg) contributes to the formation of compounds such as sugars and proteins, regulates the uptake of other plant nutrients, and is involved in carbohydrate metabolism and translocation (Kiss, 1989) [8]. Since sugar is the primary product of photosynthesis, increased photosynthesis leads to more sugar molecules and soluble solids in fruit juice.

Table 1: Effect of soil and foliar application of nutrients on TSS, TA and TSS: TA ratio of pomegranate cv. Bhagwa.

Treatments	TSS (ºBrix)			TA (%)			TSS:TA		
	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
T_1	17.07	17.18	17.13	0.64	0.64	0.64	26.55	27.05	26.80
T_2	17.25	17.36	17.31	0.63	0.61	0.62	27.39	28.63	28.01
T_3	17.42	17.48	17.45	0.59	0.58	0.58	28.25	29.31	28.78
T_4	17.47	17.50	17.48	0.59	0.60	0.60	29.46	29.19	29.32
T_5	17.95	17.66	17.81	0.62	0.60	0.61	29.87	30.64	30.25
T_6	17.50	17.64	17.57	0.61	0.61	0.61	28.71	28.94	28.83
T_7	17.45	17.79	17.62	0.59	0.60	0.60	29.41	29.81	29.61
T_8	17.92	18.00	17.96	0.60	0.60	0.60	29.71	30.18	29.95
T_9	17.70	17.77	17.74	0.60	0.59	0.59	29.71	30.16	29.94
T_{10}	18.16	18.19	18.18	0.59	0.57	0.58	30.97	31.94	31.46
T_{11}	18.20	18.30	18.25	0.57	0.56	0.57	31.78	32.73	32.25
T_{12}	18.26	18.33	18.29	0.55	0.54	0.54	33.42	33.95	33.69
S.Em+_	0.13	0.17	0.11	0.01	0.01	0.01	0.55	0.62	0.41
CD (5%)	0.37	0.51	0.30	0.03	0.03	0.02	1.61	1.80	1.17

Where T_1 Control (RDF), T_2 RDF + Soil application of $ZnSO_4$ @ 100 g, T_3 RDF + Soil application of $FeSO_4$ @ 100 g, T_4 RDF + Soil application of $MgSO_4$ @ 100 g, T_5 RDF + Soil application of Boric acid @ 50 g, T_6 RDF + Foliar spray of $ZnSO_4$ @ 0.4%, T_7 RDF + Foliar spray of $FeSO_4$ @ 0.4%, T_8 RDF + Foliar spray of $MgSO_4$ @ 0.4%, T_9 RDF + Foliar spray of Boric acid @ 0.2%, T_{10} RDF + Soil application of $ZnSO_4$ @ 100 g + $FeSO_4$ @ 100 g + $MgSO_4$ @ 100 g + Boric acid @ 50 g, T_{11} RDF + Foliar spray of $ZnSO_4$ @ 0.4% + $FeSO_4$ @ 0.4% + $MgSO_4$ @ 0.4% + Boric acid @ 0.2%, T_{12} RDF + Soil application of $ZnSO_4$ @ 50 g + $FeSO_4$ @ 50 g + $MgSO_4$ @ 50 g + Boric acid @ 25 g + Foliar spray of $ZnSO_4$ @ 0.2% +$FeSO_4$ @ 0.2% + $MgSO_4$ @ 0.2% + Boric acid @ 0.1%

Table 2: Effect of soil and foliar application of nutrients on total sugar, reducing sugar and non-reducing sugar of pomegranate cv. Bhagwa.

Treatments	Total sugar (%)			Reducing sugar (%)			Non-reducing sugar (%)		
	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
T_1	11.28	11.42	11.35	10.43	10.50	10.46	0.85	0.91	0.88
T_2	11.65	11.86	11.75	10.75	10.85	10.80	0.91	1.01	0.96
T_3	11.92	12.10	12.01	10.93	11.06	11.00	1.00	1.03	1.02
T_4	12.08	12.14	12.11	11.07	11.08	11.08	1.02	1.05	1.04
T_5	12.17	12.27	12.22	11.12	11.18	11.15	1.05	1.08	1.07
T_6	11.91	11.91	11.91	10.85	10.84	10.85	1.06	1.07	1.06
T_7	12.09	12.16	12.13	11.02	11.05	11.04	1.07	1.11	1.09
T_8	12.13	12.18	12.15	11.05	11.09	11.07	1.08	1.08	1.08
T_9	12.28	12.35	12.32	11.19	11.24	11.22	1.09	1.10	1.10
T_{10}	12.40	12.46	12.43	11.29	11.35	11.32	1.11	1.12	1.12
T_{11}	12.61	12.64	12.63	11.49	11.50	11.50	1.12	1.13	1.13
T_{12}	12.74	12.84	12.79	11.61	11.69	11.65	1.14	1.15	1.14
S.Em+_	0.17	0.23	0.12	0.08	0.13	0.07	0.03	0.03	0.02
CD (5%)	0.49	0.68	0.35	0.22	0.39	0.19	0.08	0.09	0.05

Where T_1 Control (RDF), T_2 RDF + Soil application of $ZnSO_4$ @ 100 g, T_3 RDF + Soil application of $FeSO_4$ @ 100 g, T_4 RDF + Soil application of $MgSO_4$ @ 100 g, T_5 RDF + Soil application of Boric acid @ 50 g, T_6 RDF + Foliar spray of $ZnSO_4$ @ 0.4%, T_7 RDF + Foliar spray of $FeSO_4$ @ 0.4%, T_8 RDF + Foliar spray of $MgSO_4$ @ 0.4%, T_9 RDF + Foliar spray of Boric acid @ 0.2%, T_{10} RDF + Soil application of $ZnSO_4$ @ 100 g + $FeSO_4$ @ 100 g + $MgSO_4$ @ 100 g + Boric acid @ 50 g, T_{11} RDF + Foliar spray of $ZnSO_4$ @ 0.4% + $FeSO_4$ @ 0.4% + $MgSO_4$ @ 0.4% + Boric acid @ 0.2%, T_{12} RDF + Soil application of $ZnSO_4$ @ 50 g + $FeSO_4$ @ 50 g + $MgSO_4$ @ 50 g + Boric acid @ 25 g + Foliar spray of $ZnSO_4$ @ 0.2% +$FeSO_4$ @ 0.2% + $MgSO_4$ @ 0.2% + Boric acid @ 0.1%

Conclusion

In the arid climate of Rajasthan, where pomegranate cultivation has become a vital horticultural pursuit, our study highlights the crucial role of nutrient management in shaping the physicochemical attributes of pomegranate fruit. Through a comprehensive two-year experiment, it became evident that the application of Zinc, Iron, magnesium and Boric acid significantly influences various aspects of pomegranate fruit quality. The combination of soil and foliar nutrient applications (T_{12} $ZnSO_4$ @ 50 g + $FeSO_4$ @ 50 g + $MgSO_4$ @ 50 g + Boric acid @ 25 g + $ZnSO_4$ @ 0.2% +$FeSO_4$ @ 0.2% + $MgSO_4$ @ 0.2% + Boric acid @ 0.1%) emerged as the most effective approach, demonstrating higher total soluble solids, better TSS/TA ratios, and enhanced sugar content. These findings hold significant implications for pomegranate growers in arid regions, such as Rajasthan, providing insights into optimizing nutrient management strategies to enhance fruit quality. As pomegranate continues to play a vital role in the agricultural and economic landscape of this region, the study underscores the importance of sustainable practices and tailored nutrient management for the continued success of pomegranate cultivation.

Acknowledgement
The authors would like to extend their sincere appreciation to the Department of Horticulture at Swami Keshwanand Rajasthan Agricultural University, Bikaner, Rajasthan, India, for generously providing the essential facilities and support that enabled the successful execution of this experiment.

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