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Effect of NAA and Zinc Sulphate on Marketable Yield and Physical Parameters of Litchi (*Litchi chinensis* Sonn.) cv. Rose Scented

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

An experiment was conducted in the Garden, Department of Fruit Science at C.S. Azad University of Agriculture and Technology, Kanpur (U.P.) during two continuous years *i.e.,* 2022 and 2023 to assess the effect of NAA (Naphthalene acetic acid) and zinc sulphate on marketable yield and physical parameters of litchi (*Litchi chinensis* Sonn.) cv. Rose Scented. For this experiment, sixteen treatments including four levels of each NAA (0, 25, 50, and 75 ppm) and zinc sulphate (0, 0.2, 0.4 and 0.6%), and their combinations were applied in Factorial-CRD with three replications. The foliar application of these treatments was done on January 28 and March 16' 2022 and 2023, before flowering and again during fruit setting (pea stage). A carboxymethyl group substituted NAA (Naphthalene acetic acid) at position 1. It has a role as a synthetic auxin. It is a conjugate acid of a

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1-naphthaleneacetate. 1-Naphthylacetic acid is a natural product found in *Humulus lupulus*, *Rehmannia glutinosa*, and other organisms. The results of the experiment clearly show that plants treated with NAA @ 50ppm and zinc sulphate @ 0.4% significantly increased yield of marketable fruits of 79.11 and 83.17 kg/plant, respectively during both years of investigations. Simultaneously, the highest fruit length (3.57 and 3.60 cm), fruit diameter (3.22 and 3.20 cm) and fruit weight (19.99 and 20.54 g) were also recorded which were produced from the plants treated with the combination of NAA @ 50 ppm and $ZnSO_4$ @ 0.4%. This treatment (NAA @ 50 pm and $ZnSO_4$ @ 0.4%) also gave blend results in respect to seed physiology with decreasing seed length (1.17 and 1.30 cm), seed diameter (1.23 and 1.25 cm) and produced minimum seed weight (3.34 and 3.37 g). The same treatment also showed a simultaneous increase in pulp weight (13.45 and 13.98 g) and pulp: seed ratio (4.02 and 4.08) with reduced rind weight (3.20 and 3.19 g) in litchi fruits in the north Indian plains.

Keywords: Litchi; NAA; Zinc sulphate; marketable yield; physical parameters.

1. INTRODUCTION

In India, litchi was introduced through Burma in the 18th century and quickly spread to other countries. 91% of the world's litchi production is produced in India and China, however it is primarily sold locally. In India, it is grown in 98000 ha of an area with a production of 724000 MT [1].

The litchi (*Litchi chinensis* Sonn.) is one of the most important sub-tropical evergreen tree which is a member of the family Sapindaceae. Botanically, the mature fruit of the litchi is a nut and the edible part is its juicy aril. It is sour and quite sweet when dried. It is a good source of minerals like magnesium, iron, calcium, copper, phosphorous and potassium as well as carbohydrates, vitamins and other nutrients. It can be transformed into various value-added products such as juice, wine, pickles, jam, jelly, ice cream and yogurt. It is available in the market from May through June when there are many other fresh fruits available. However, despite the availability of different other fruits in the market, the demand for fresh litchi is still very high due to its unique taste, flavour and colour.

Over the years, plant growth regulators (PGRs) and micronutrients have been systematically used to increase the maximum and long-term economic benefits of litchi production by modifying the behaviour of fruit or fruiting trees. The yield and quality of litchi fruit are positively influenced by the use of plant growth regulators and micronutrients. PGR application leads to increased flowering, fruit set and fruit retention. The cell sap supply pathway to the fruit is severed by the formation of the dermis and the thin cork cells gradually separate, resulting in increased fruit drop. Early researchers reported that gibberellin affects both cell division and expansion [2]. Adjuvants such as naphthalene acetic acid (NAA) greatly influence plant growth; however, their effectiveness depends on application, time and concentrations used.

Micronutrients perform an important function in improving the growth, yield and quality of litchi. Zinc inadequacy adversely affects flowering, fruit size, weight and quality. The metabolic activities of plants are highly dependent on zinc. Zinc principally acts as a metal activator of enzymes such as dehydrogenase (pyridine nucleotide, glucose-6 phosphodiesterase, carbonic anhydrase, etc.). Tryptophan, a precursor of IAA, is highly dependent on zinc for its synthesis and is involved in the absorption and retention of water in the plant body. So, for the production of more marketable fruits having better quality is the prime objective during this experimentation period.

2. MATERIALS AND METHODS

The well-established healthy and uniform litchi cultivar Rose Scented trees, about 63 years old but properly maintained, located in the Garden, Department of Fruit Science, Chandra Shekhar Azad University of Agriculture & Technology Kanpur, were selected for the present investigations during two subsequent years *i.e.,* 2022 and 2023. During the entire duration of the investigation, the whole orchard was kept under clean cultivation, and uniform practices were applied to all plants. Factorial Completely Randomized Design was used with three replications and sixteen treatments *viz.,* four levels each of NAA (0, 25, 50, and 75 ppm), zinc sulphate (0, 0.2, 0.4 and 0.6%) and their combinations were sprayed twice *i.e.,* before flowering (28 January) and at pea stage (16

March) during both the years. Three branches in uniform growth and vigour were selected on each tree for the recorded of various observations.

The marketable yield was recorded at harvesting stage and length and diameter of fruits as well as seeds were determined with the help of vernier callipers and the fruit weight, pulp weight, seed weight, and rind weight of fruits were recorded with the help of an electronic balance/ weighing machine in a standard way.

3. RESULTS AND DISCUSSION

3.1 Marketable Yield

All the cracked and other blemished fruits were isolated from the overall yield of litchi fruits to calculate the yield of marketable fruits. Plants treated with NAA@ 50ppm produced a significant maximum yield of marketable fruits (75.60 and 79.68kg) per plant closely followed by plants treated with 75ppm of NAA with 67.61 and 69.36kg per plant yield of marketable fruits as compared to control treatment with minimum (47.09 and 49.64kg) yield of marketable fruits per plant (Fig. 1). The benefit caused by NAA application may be related to its physiological actions in the plants, which may have prevented fruit drop, reduced cracking, and significantly decreased the number of imperfect fruits, improving production thus increased in the production of marketable fruits yield.

The foliar spray of zinc sulphate considerably increased the production of marketable fruits with a significant maximum marketable fruits yield (64.98 and 67.97kg) per plant was documented in plants treated with 0.6 % zinc sulphate followed by 64.65 and 66.37kg per plant under 0.4% of zinc sulphate treated plants, whereas the lowest yield of marketable fruits (58.19 and 60.39kg) per plant was obtained under control plants (Fig. 1). The production of more fruits per tree in this treatment could be due to the facts that zinc acts as a catalyst in the oxidation and reduction process and is also of great importance in the sugar metabolism thus increasing the yield per tree. The above findings are in line with the reports of Tiwari et al. [3], Tripathi and Viveka Nand [4] in aonla, Kumar et al. [5] in Phalsa; and Babu and Tripathi [6] in guava. The interactive influence of NAA and zinc sulphate was found to be non-significant for the yield of marketable fruits during both years of experiments.

3.2 Fruit Size

Perusal of data from Table 1 shows that during the present investigation, fruit size (length and diameter) was significantly increased with the foliar application of NAA and zinc sulphate. Maximum length (3.52 and 3.49cm) and diameter of fruit (3.18 and 3.08cm) were documented in fruits that were produced from the plant treated with NAA @ 50ppm, closely followed by 3.38 and 3.17cm of fruit length and 3.02 and 2.91cm of diameter from fruits produced in NAA @ 75ppm treated plants. The minimum fruit length (2.76 and 2.77cm) and diameter (2.45 and 2.57cm) were noted in the fruits produced from the plants kept under control or without any treatment application (Table 1). The results are per the findings of Kumar et al. [7] in mango; Tripathi et al. [8] and Tiwari et al. [3] in aonla; Lal et al. [9] in kinnow mandarin; Tripathi et al. [10], Verma et al. [11] in strawberry, Badal and Tripathi [12] in guava; Maurya et al. [13] in mango; and Shahay et al. [14] in litchi.

When the effect of zinc sulphate application is studied, the maximum length (3.30 and 3.20cm) and diameter of fruit (2.92 and 2.88cm) were noted in fruits that were produced from the plants treated with zinc sulphate @ 0.6%, closely followed by (3.27 and 3.16cm) of fruit length and diameter (2.90 and 2.88cm) from zinc sulphate @ 0.4% treated plants. The minimum fruit length (3.10 and 3.01cm) and diameter (2.74 and 2.74cm) were recorded in the fruits which were produced from the plants kept under control or without any treatment application (Table 1). As a micronutrient, zinc sulphate may have a substantial impact on fruit size enhancement due to its participation in promoting cell elongation and expansion, which led to a desired increase in the size of litchi fruits. The results are under the findings of Kumar et al. [7] and Maurya et al. [13] in mango; Singh et al. [15] and Tripathi et al. [8] in Indian gooseberry; Lal et al. [9] in kinnow mandarin; and Tripathi et al. [10] in strawberry.

The interaction effect for the combined application of NAA and zinc sulphate (Table 1), maximum length of fruit (3.57 and 3.60cm) and diameter (3.22 and 3.20cm) was recorded in fruits which were produced from the plants treated with the application of NAA @ 50ppm + zinc sulphate @ 0.4%, while the fruits in plants kept under control results in minimum fruit length (2.54 and 2.62cm) and diameter (27.67 and 27.53cm), respectively, during both the years of experimentation. It is also notable that with the reduction in plant bioregulator and micronutrient concentration, fruit size gets reduced significantly. This increase in the size of fruits might be attributed to the greater mobilization of water into fruits, and food materials from the site of their production to the storage organs under the influence of applied zinc sulphate and NAA. The results are per the findings of Kumar et al. [7] in mango; Singh and Singh [15]; Tiwari et al. [3] and Tripathi et al. [8] in Aonla, Lal et al. [9] in Kinnow Mandarin; and Tripathi et al. [10] in strawberry; Maurya et al. [13] in mango.

3.3 Fruit Weight

Fruits with higher weight (19.85 and 22.01g) were documented, which were produced from the plants treated NAA @ 50ppm, closely followed by 19.22 and 21.38g, from NAA @ 75ppm treated plants. The minimum fruit weight (17.30 and 19.59g) was found in fruits that were produced from the control treatment (Table 1). This increase in fruit weight with NAA application might be due to the accumulation of more food materials in fruit trees which ultimately transferred to the fruits during their growth and developmental stage which also increased their size. These results are by the findings of Singh and Singh [15], Tiwari et al. [3] in aonla and Tripathi et al. [16], Tripathi et al. [17] in strawberry and Gupta et al. [18] in litchi.

When the influence of zinc sulphate application is studied, it was found that fruit having maximum weight (18.97 and 21.19g) was produced from zinc sulphate @ 0.6% treated plants, closely followed by 18.80 and 21.02g fruit weight from zinc sulphate @ 0.4% treated plants. Fruits having minimum weight (18.37 and 20.59g) was documented under control-treated plants (Table 1). This significant increase in fruit weight might be due to the result of cell division and cell elongation with zinc treatments which helps in the synthesis of more photosynthates in the plants which later on transferred to the developing fruits, which ultimately result in increased weight of fruits. These results are in accordance with the findings of Tiwari et al. [3] in aonla and Tripathi et al. [16]; Tripathi et al. [17] in strawberry and Gupta et al. [18], Viveka Nand et al. [2] in litchi.

The interaction effect for the combined use of NAA and zinc sulphate significantly affected fruits weight and fruit with maximum weight (20.12 and 22.28g) was documented under the combination of NAA @ 50ppm + zinc sulphate @ 0.4%, while the plants kept under control produce fruits having minimum weight (16.92 and 19.21g) during both the years of experimentation (Table 1). This increase in the weight of fruits might be due to the better supply of nutrients which results in the production of more amount photosynthates in plants treated with the foliar application of zinc and NAA which results in the rapid synthesis of metabolites particularly carbohydrates along with their fast translocation to the fruits from the site of synthesis causing relatively greater pulp content. The results of the experiment are under the findings of Singh and Singh [15], Tiwari et al. [3] in aonla and Tripathi et al. [16], Tripathi et al. [17] in strawberry and Gupta et al. [18], Viveka Nand et al. [2] in litchi.

3.4 Seed Size

The minimum length (1.25 and 1.35cm) and diameter of seed (1.29 and 1.30cm) was found in fruits which are produced from the plants treated NAA @ 50ppm, closely followed by 1.45 and 1.48cm seed length and seed diameter (1.43 and 1.35cm) from fruits which are produced under NAA@75ppm treated plants (Table 2). The minimum seed length (1.73 and 1.66cm) and seed diameter (1.64 and 1.49cm) were recorded in fruits which were produced from the plant kept under control treatment. The superiority in the length of fruits as indicated in NAA treatments might be due to its involvement in cell division, cell elongation and decreased volume of intracellular space in the monocarpic cells which could have boosted plant health thereby producing healthy and larger fruits NAA treatment also resulted in an increase in the growth rate of fruits which results in bigger fruit size along with small size of stone. These findings are in line with the reports of Meena et al. [19], Bal et al. [20], Ram et al. [21], Tripathi et al. [22], Arora et al. [23], Kumar et al. [24] in ber, Rathod et al. [25] in aonla, Patil et al. [26] in mango, Kumar et al. [27] in guava.

When the influence of zinc sulphate application, the minimum length (1.45 and 1.48cm) and diameter (1.47 and 1.37cm) of seed were noted under zinc sulphate @ 0.6% treatments, closely followed by 1.48 and 1.49cm of seed length and 1.47 and 1.37cm of seed diameter from zinc sulphate @ 0.4% treated plants, whereas the minimum seed length (1.57 and 1.56cm) and seed diameter (1.49 and

Table 1. Effect of foliar sprays of NAA, Zinc sulphate and their interactions on fruit length, diameter and weight

Parameters	Doses	Zinc % (Z)									
	NAA ppm	2022					2023				
	(N)	Z_0 Control	Z_1 0.2	Z_2 0.4	Z_3 0.6	Mean N	Z_0 Control	Z_1 0.2	Z_2 0.4	Z_3 0.6	Mean N
Fruit length	N_0 Control	2.54	2.68	2.87	2.95	2.76	2.62	2.74	2.83	2.89	2.77
	N_1 25	3.08	3.18	3.25	3.28	3.19	2.94	2.98	3.05	3.07	3.01
	N_2 50	3.47	3.51	3.57	3.54	3.52	3.42	3.44	3.60	3.52	3.49
	N_3 75	3.33	3.35	3.41	3.44	3.38	3.08	3.11	3.18	3.33	3.17
	Mean Z	3.10	3.18	3.27	3.30		3.01	3.07	3.16	3.20	
	Factors	**C.D. at 5%**	**S.E.(d)±**	**S.E.(m)±**			**C.D. at 5%**	**S.E.(d)±**	**S.E.(m)±**		
	N	0.07	0.03	0.02			0.06	0.03	0.02		
	Z	0.07	0.03	0.02			0.06	0.03	0.02		
	N × Z	NS	0.07	0.05			NS	0.06	0.04		
Fruit diameter	N_0 Control	2.28	2.46	2.52	2.54	2.45	2.40	2.56	2.65	2.67	2.57
	N_1 25	2.63	2.75	2.82	2.85	2.76	2.70	2.72	2.73	2.79	2.73
	N_2 50	3.14	3.16	3.22	3.20	3.18	3.02	3.05	3.20	3.08	3.08
	N_3 75	2.94	3.02	3.04	3.10	3.02	2.87	2.87	2.95	2.97	2.91
	Mean Z	2.74	2.84	2.90	2.92		2.74	2.80	2.88	2.88	
	Factors	**C.D. at 5%**	**S.E.(d)±**	**S.E.(m)±**			**C.D. at 5%**	**S.E.(d)±**	**S.E.(m)±**		
	N	0.06	0.03	0.02			0.06	0.03	0.02		
	Z	0.06	0.03	0.02			0.06	0.03	0.02		
	N × Z	NS	0.06	0.04			NS	0.06	0.04		
Fruit weight	N_0 Control	16.92	17.18	17.38	17.75	17.30	19.21	19.47	19.67	20.04	19.59
	N_1 25	17.96	18.26	18.46	18.78	18.36	20.25	20.55	20.75	21.07	20.65
	N_2 50	19.65	19.78	20.12	19.87	19.85	21.81	21.94	22.28	22.03	22.01
	N_3 75	18.96	19.22	19.24	19.48	19.22	21.12	21.38	21.41	21.64	21.38
	Mean Z	18.37	18.61	18.80	18.97		20.59	20.83	21.02	21.19	
	Factors	**C.D. at 5%**	**S.E.(d)±**	**S.E.(m)±**			**C.D. at 5%**	**S.E.(d)±**	**S.E.(m)±**		
	N	0.37	0.18	0.12			0.38	0.18	0.13		
	Z	0.37	0.18	0.12			0.38	0.18	0.13		
	N × Z	NS	0.36	0.25			NS	0.37	0.26		

Table 2. Effect of foliar sprays of NAA, Zinc sulphate and their interactions on seed length, diameter and weight

Parameters	Doses	Zinc % (Z)									
	NAA ppm (N)	2022					2023				
		Z_0 Control	Z_1 0.2	Z_2 0.4	Z_3 0.6	Mean N	Z_0 Control	Z_1 0.2	Z_2 0.4	Z_3 0.6	Mean N
Seed length	N_0 Control	1.78	1.75	1.72	1.67	1.73	1.67	1.67	1.65	1.64	1.66
	N_1 25	1.65	1.61	1.59	1.55	1.60	1.62	1.60	1.58	1.55	1.58
	N_2 50	1.33	1.27	1.17	1.22	1.25	1.44	1.38	1.30	1.31	1.35
	N_3 75	1.52	1.47	1.45	1.38	1.45	1.54	1.50	1.45	1.45	1.48
	Mean Z	1.57	1.52	1.48	1.45		1.56	1.53	1.49	1.48	
	Factors	**C.D. at 5%**	**S.E.(d)±**	**S.E.(m)±**			**C.D. at 5%**	**S.E.(d)±**	**S.E.(m)±**		
	N	0.03	0.01	0.01			0.03	0.01	0.01		
	Z	0.03	0.01	0.01			0.03	0.01	0.01		
	N × Z	NS	0.03	0.02			NS	0.03	0.02		
Seed diameter	N_0 Control	1.68	1.65	1.63	1.61	1.64	1.51	1.49	1.48	1.47	1.49
	N_1 25	1.57	1.57	1.54	1.52	1.55	1.45	1.42	1.41	1.39	1.41
	N_2 50	1.35	1.31	1.23	1.27	1.29	1.33	1.32	1.25	1.29	1.29
	N_3 75	1.38	1.42	1.45	1.49	1.43	1.37	1.36	1.35	1.34	1.35
	Mean Z	1.49	1.49	1.47	1.47		1.41	1.39	1.37	1.37	
	Factors	**C.D. at 5%**	**S.E.(d)±**	**S.E.(m)±**			**C.D. at 5%**	**S.E.(d)±**	**S.E.(m)±**		
	N	0.03	0.01	0.01			0.03	0.01	0.01		
	Z	NS	0.01	0.01			0.03	0.01	0.01		
	N × Z	0.06	0.03	0.02			NS	0.02	0.02		
Seed weight	N_0 Control	3.95	3.93	3.90	3.87	3.91	3.99	3.97	3.94	3.91	3.95
	N_1 25	3.85	3.82	3.78	3.76	3.80	3.89	3.86	3.82	3.80	3.84
	N_2 50	3.56	3.45	3.34	3.38	3.43	3.60	3.48	3.37	3.41	3.46
	N_3 75	3.73	3.69	3.66	3.63	3.67	3.76	3.72	3.69	3.66	3.70
	Mean Z	3.77	3.72	3.67	3.66		3.81	3.75	3.70	3.69	
	Factors	**C.D. at 5%**	**S.E.(d) ±**	**S.E.(m) ±**			**C.D. at 5%**	**S.E.(d) ±**	**S.E.(m) ±**		
	N	0.06	0.03	0.02			0.08	0.04	0.02		
	Z	0.06	0.03	0.02			0.08	0.04	0.02		
	N × Z	NS	0.06	0.04			NS	0.08	0.05		

Table 3. Effect of foliar sprays of NAA, Zinc sulphate and their interactions on pulp weight, rind weight and pulp: seed ratio

Parameters	Doses	Zinc % (Z)									
	NAA ppm (N)	2022					2023				
		Z_0 Control	Z_1 0.2	Z_2 0.4	Z_3 0.6	Mean N	Z_0 Control	Z_1 0.2	Z_2 0.4	Z_3 0.6	Mean N
Pulp weight	N_0 Control	10.34	10.56	10.87	11.25	10.75	10.78	11.56	11.87	12.06	11.56
	N_1 25	11.45	11.67	11.84	12.05	11.75	12.12	12.16	12.29	12.35	12.23
	N_2 50	12.94	13.12	13.45	13.23	13.18	13.32	13.68	13.98	13.72	13.67
	N_3 75	12.16	12.44	12.65	12.88	12.53	12.57	12.95	13.23	13.26	13.00
	Mean Z	11.72	11.94	12.20	12.35		12.19	12.58	12.84	12.84	
	Factors	**C.D. at 5%**	**S.E.(d)±**	**S.E.(m)±**			**C.D. at 5%**	**S.E.(d)±**	**S.E.(m)±**		
	N	0.27	0.13	0.09			0.29	0.14	0.10		
	Z	0.27	0.13	0.09			0.29	0.14	0.10		
	N × Z	NS	0.26	0.18			NS	0.28	0.20		
Rind weight	N_0 Control	3.42	3.40	3.39	3.37	3.39	3.40	3.38	3.37	3.35	3.37
	N_1 25	3.36	3.34	3.33	3.31	3.33	3.34	3.32	3.31	3.29	3.31
	N_2 50	3.24	3.21	3.20	3.20	3.21	3.23	3.20	3.19	3.19	3.20
	N_3 75	3.30	3.29	2.28	3.26	3.03	3.29	3.28	2.27	3.25	3.02
	Mean Z	3.33	3.31	3.28	3.05		3.31	3.29	3.27	3.03	
	Factors	**C.D. at 5%**	**S.E.(d)±**	**S.E.(m)±**			**C.D. at 5%**	**S.E.(d)±**	**S.E.(m)±**		
	N	0.05	0.02	0.02			0.06	0.03	0.02		
	Z	0.05	0.02	0.02			0.06	0.03	0.02		
	N × Z	0.11	0.05	0.03			0.12	0.05	0.04		
Pulp: seed ratio	N_0 Control	2.61	2.67	2.78	2.90	2.74	2.72	2.96	2.98	3.14	2.95
	N_1 25	2.97	3.04	3.13	3.20	3.08	3.17	3.23	3.39	3.44	3.30
	N_2 50	3.62	3.80	4.02	3.91	3.83	3.84	3.93	4.08	3.98	3.96
	N_3 75	3.26	3.37	3.45	3.54	3.40	3.50	3.68	3.80	3.82	3.70
	Mean Z	3.11	3.22	3.34	3.38		3.31	3.45	3.56	3.59	
	Factors	**C.D. at 5%**	**S.E.(d)±**	**S.E.(m)±**			**C.D. at 5%**	**S.E.(d)±**	**S.E.(m)±**		
	N	0.05	0.02	0.02			0.07	0.03	0.02		
	Z	0.05	0.02	0.02			0.07	0.03	0.02		
	N × Z	NS	0.05	0.04			NS	0.07	0.05		

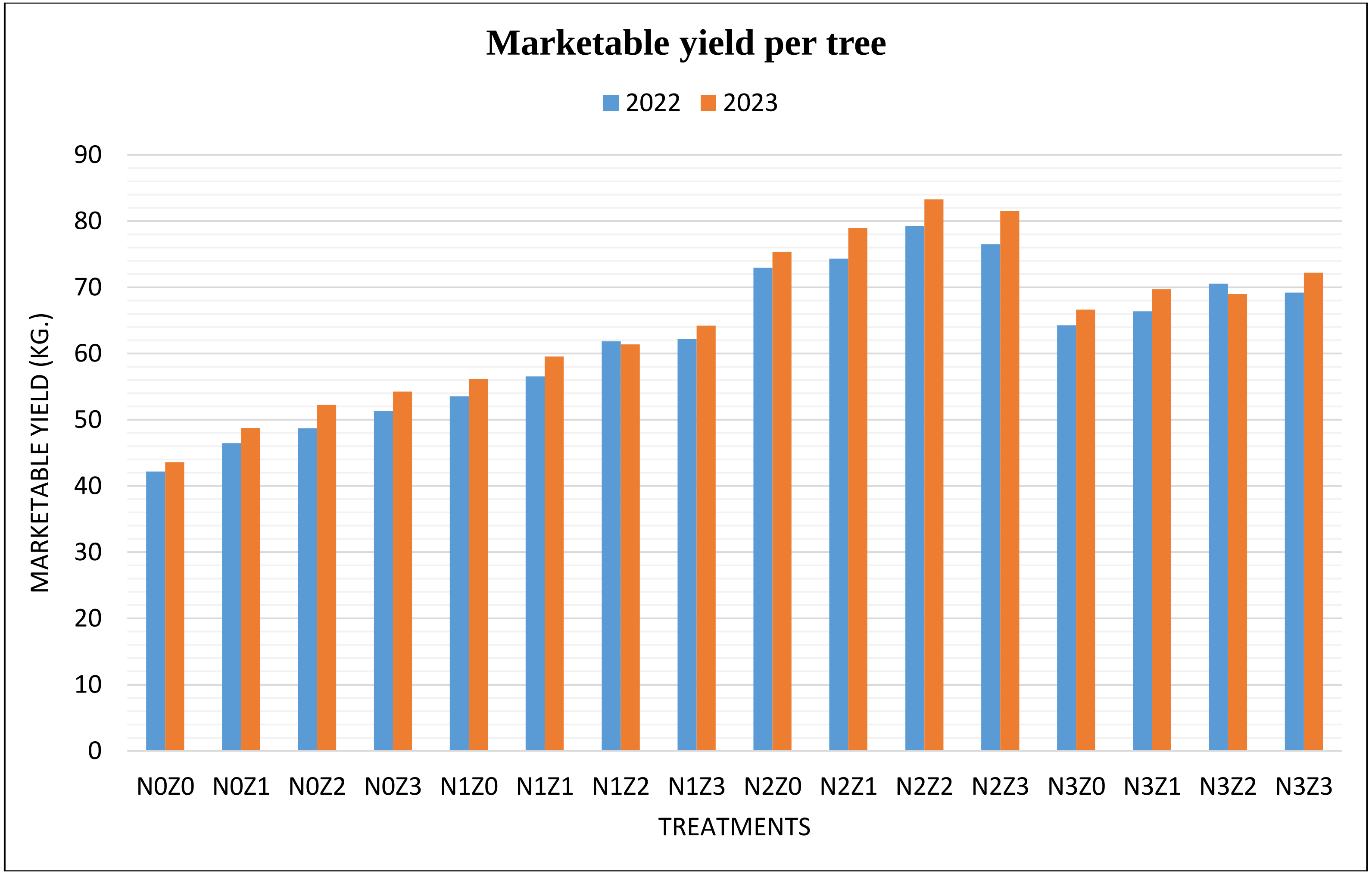

Fig. 1. Effect of foliar sprays of NAA, Zinc sulphate and their interactions on marketable yield per tree

1.41cm) was recorded in plants kept under control treatment (Table 2). The increase in the size of fruits with an application of zinc might be due to the significant increase in cell division and cell elongation associated with active performance in photosynthesis in the plants and photosynthates were translocated to the fruits which possibly caused an increase in fruit size and decrease in stone size. This outcome might be linked to the plant's active photosynthesis, which allowed the pigments to be transferred to the stone and increase in size.

When the interaction effect among various concentrations of NAA and zinc sulphate was studied, it was reported that the minimum length (1.18 and 1.30cm) and diameter of seed (1.23 and 1.25cm) produced in fruits which were harvested from the plant treated with the combination of NAA @ 50ppm + zinc sulphate @ 0.4%, while the fruits produced from control plants results in maximum values of seed length (1.78 and 1.68cm) and diameter (1.68 and 1.51cm), respectively, during both the years of experimentation (Table 2). The increased fruit length that results from NAA and zinc sulphate may be attributable to the compound's role in cell proliferation, elongation, and reduction of intracellular space in monocarpic cells. These processes may have improved plant health and led to the production of larger and healthier fruits. NAA speeds up fruit growth, resulting in larger fruits, which may result in smaller stones. This outcome might be linked to the plant's active photosynthesis, which allows the pigments to be transferred to the fruit causing an increase in size. These findings aligned with reports of Arora et al. [23], Bal et al. [20], Ram et al. [21], Tripathi et al. [22], Meena et al. [19] in ber, Rathod et al. [25] in aonla, and Kumar et al. [27] in guava.

3.5 Seed Weight

The minimum seed weight (3.43 and 3.46g) was found in fruits which were produced from the plants treated with NAA @ 50ppm closely followed by 3.67 and 3.70g from NAA @ 75ppm treated plants (Table 3). The minimum fruit weight (3.91 and 3.95g) were harvested from the plant which were kept under control or without application of any treatment. Application of NAA enhanced metabolism which reduces stone size. Increased cell flexibility and plasticity brought about by NAA encouraged cell wall stretching and increased water uptake, both of which may have increased pulp weight while decreasing seed weight. These results are in close conformity with the findings of Kaur [28], Saraswat et al. [29], Kumar et al. [30], Priyadarshi et al. [31] in Litchi and Vijendla et al. [32] in mango.

In zinc sulphate treated plants, the minimum seed weight (3.66 and 3.69g) was noted in fruits that were harvested from the plants treated with zinc sulphate @ 0.6% closely followed by 3.67 and 3.70g of seed weight produced from the plants treated with zinc sulphate @ 0.4%, whereas, the minimum seed weight (3.77 and 3.81g) was recorded under control plants (Table 3). Zinc application increased the pulp content in litchi fruit, which may have led to a reduction in the weight of the seeds in the litchi fruits. These results were close conformity with the findings of Singh et al. [32] in aonla and Saraswat et al. [29], Priyadarshi et al. [31], Kumar et al. [30] in litchi.

The interaction effect among various concentrations of NAA and zinc sulphate, the minimum seed weight (3.34 and 3.37g) was recorded in fruits, which were harvested from the plants kept treated with the combination of NAA @ 50ppm + zinc sulphate @ 0.4%, while the plants kept under control, produced fruits with maximum values of seed weight (3.95 and 3.99g) during both the years of experimentation (Table 3). Application of NAA enhances metabolism which reduces stone size. The decrease in stone weight may be due to the fact that auxins induced parthenocarpy effect to some extent thereby resulting in lesser stone weight. Zinc increased the pulp content in litchi fruit, which may have led to a reduction in the weight of the seeds in the litchi fruits. These results are in close conformity with the findings of Kaur [28], Saraswat et al. [29], Kumar et al. [30] and Priyadarshi et al. [31] in litchi and Vejendla et al. [32] in mango; Singh et al. [33] in aonla.

3.6 Pulp Weight

Significantly more weight of pulp (13.18 and 13.67g) with minimum rind weight (3.21 and 3.20g) was recorded in fruits which were harvested from the plant treated with NAA @ 50ppm, closely followed by (12.53 and 13.00g of pulp weight and 3.03 and 3.02g of rind weight recorded from NAA @ 75ppm treated plants (Table 3). The minimum pulp weight (10.75 and 11.56g) and maximum rind weight (3.39 and 3.37g) were recorded in fruits which were produced from the plants kept under control treatment. This increase in pulp with the reduction in rind weight might be due to more absorption of water due to the influence of plant bio-regulators and micronutrients which increase the volume of inter-cellular spaces in the pulp causes an increase in pulp weight. The similar findings of reported by Kumar et al. [7], and Maurya et al. [13] in mango.

Plants treated with zinc sulphate at 0.6% produced fruits having maximum pulp weight (12.35 and 12.84g) and minimum rind weight (3.05 and 3.03g), closely followed by 12.20 and 12.84g of fruit weight and 3.28 and 3.27g of rind weight from zinc sulphate @ 0.4% treated plants (Table 3). The minimum pulp weight (11.72 and 12.19g) and maximum rind weight (3.33 and 3.31g) was recorded under control treatment. The similar results supported by Anushi et al. [34], Kumar et al. [7], Moazzam et al. [35], and Maurya et al. [13] in mango; and Meena et al. [36] in ber.

Further investigation for the interaction effect among various combinations of NAA and zinc sulphate shows that the maximum pulp weight (3.20 and 3.19g) and minimum rind weight (3.20 and 3.19g) were recorded with application of NAA @ 50ppm + zinc sulphate @ 0.4%, while the plants under control results fruits with minimum pulp weight (27.67 and 27.53g) and maximum rind weight (27.67 and 27.53g) during both the years of experimentation (Table 3). Auxin cell wall is one source of evidence, which enhanced its elasticity and flexibility. As a result, the cell size increased and the cell wall would be able to flex, which would ultimately increase pulp weight in the litchi fruits. The results are the following the findings Yadav et al. [37] in ber; Vejendla et al. [32], and Moazzam et al. [35] in mango; Saraswat et al. [29], Kaur [28], Priyadarshi et al. [31], Kumar et al. [30], and Radha et al. [38] in litchi.

3.7 Pulp: Stone Ratio

The significant maximum pulp: stone ratio (3.83 and 3.96) was found with the application of NAA @ 50ppm in comparison to various other concentrations, closely followed by of 3.40 and 3.70 from NAA @ 75ppm, whereas, the minimum pulp: stone ratio (2.74 and 2.95) was recorded in fruits which were harvested from the plants kept under control without any application (Table 3). This increase in pulp/stone ratio might be due to an increase in the amount of pulp per cent, volume of inter-cellular spaces and decrease in stone size. The results are in support with the findings of Anushi et al. [34] Kumar et al. [7] in mango, Meena et al. [19] in Ber; and Tiwari et al. [3], Tripathi et al. [12], and Bhadauria et al. [39] in aonla.

In the case of zinc sulphate application, the maximum pulp: stone ratio (3.38 and 3.59) was noted under zinc sulphate @ 0.6% treated plants, closely followed by 3.34 and 3.56 from NAA @ 75ppm treated plants (Table 3). The minimum pulp: stone ratio (3.11 and 3.31) was recorded under control plants.

The interaction effect among various concentrations of NAA and zinc sulphate reveals thar the maximum pulp: stone ratio (4.02 and 4.08) was recorded in fruits which are harvested from the plants treated with the combination of NAA @ 50ppm + zinc sulphate @ 0.4%, while the plants under control produced fruits with minimum values (2.61 and 2.72) during both the years of experimentation (Table 3). This improvement in pulp: stone ratio may be due to more accumulation of food substances in elongated cells and intercellular space of the mesocarp. The results are in support with the findings of Anushi et al. [34] Kumar et al. [7] in mango, Meena et al. [36]; Pratap et al. [40] in ber and Tiwari et al. [3] Tripathi et al. [12], Bhadauria et al. [39] in aonla [41,42].

4. CONCLUSION

Based on the results acquired in the present experiment it could be presumed that NAA @ 50 ppm with zinc sulphate @0.4% performed better in producing high marketable yield and physical parameters of litchi credited characters such as length, diameter and weight of fruit with reduced seed length, diameter and weight, which increase the marketable yield per tree with NAA @ 50ppm and zinc sulphate @ 0.4% application. This treatment inversely reduced fruit cracking which enhanced a greater number of marketable fruits and affected seed physiology by decreased the length, diameter and weight of seed in litchi fruit. The application of plant bio-regulators (NAA) and micronutrients ($ZnSO_4$) played a significant role in enhancing pulp weight. Thus, given the above results 50ppm of NAA in combination with 0.4% of zinc sulphate is recommended to the litchi growers for increasing the yield and physical quality parameters of litchi fruits under the plains of North India.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declares that no generative AI technologies such as Large Language Models

(ChatGPT, COPILOT, *etc*.) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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