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Effect of Foliar Feeding with Nutrients and Bioregulators on Yield and Quality Attributes of Litchi cv. Bombai

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Abstract: Litchi (*Litchi chinensis* Sonn.) is considered one of the most important sub-tropical fruits of the world. In the western part of Odisha, India, litchi growers are facing problems of unstable and lower marketable yield and inferior quality due to a higher incidence of fruit cracking, fruit drop, low sugar content, and higher fruit acidity. Keeping in mind the positive effects of nutrients and bioregulators, the current study was conducted to elucidate their impact on fruit yield and quality in the farmers' field of Jamankira block in Sambalpur district of Odisha, which is under the care of Odisha University of Agriculture and Technology, India. For this study, eight-year-old litchi trees were selected. With 12 treatments, the experiment was set up in a Randomized Block Design replicated thrice, as follows: T_1: spray treatment with Borax—0.5%; T_2: spray treatment with Borax—0.3%; T_3: spray treatment with $ZnSO_4$—0.75%; T_4: spray treatment with $ZnSO_4$—0.5%; T_5: spray treatment with $CaCl_2$—0.5%; T_6: spray treatment with $CaCl_2$—0.1%; T_7: spray treatment with humic acid—1.5%; T_8: spray treatment with humic acid—1%; T_9: spray treatment with seaweed extract—0.5%; T_{10}: spray treatment with seaweed extract—0.1%; T_{11}: foliar spray with NAA—20 ppm; and T_{12}: control (Water Spray). The current study compared foliar feeding treatments comprising different nutrient and bioregulators, which were applied during the first week of December, just after the completed formation of new leaves and the untreated control. The highest total number of fruits per plant was recorded in plants sprayed with 0.5% $ZnSO_4$ (T_4) followed by those treated with 1% humic acid (T_8). The highest total fruit yield was recorded in plants subjected to foliar feeding with 0.3% Borax (T_2) which was found to be statistically similar to plants treated with 0.1% seaweed extract (T_{10}) and 0.5% seaweed extract (T_9). Among the treatments, a better response, i.e., a higher number of marketable fruits and marketable yield, was recorded in litchi plants treated with 0.3% Borax (T_2) followed by 0.5% zinc sulphate (T_4), 1% humic acid (T_8), and 0.1% $CaCl_2$ (T_6). The application of 1% humic acid (T_8) followed by 1.5% humic acid (T_9) enhanced fruit setting (%) and fruit retention rates (%) and reduced the fruit drop rate (%). The enhanced fruit size (fruit length and fruit width) and higher fruit weight was obtained in litchi plants treated with 0.3% Borax. The foliar application of 0.3% Borax (T_2) also resulted in a higher TSS, total sugars, reducing sugar content, lower acidity, the highest aril weight, and lower seed weight in litchi cv. Bombai. In this research, among the five principal components, only PC1 demonstrated approximately 45.14% variability within the influential axes. PC1 contributed the highest proportion (48.9%) to the overall variability, followed by PC2 with 29.1%, PC3 with 11.9%, PC4 with 0.59%, and PC5 with 0.20%. Consequently, the outcomes of the principal component analysis indicate the presence of extensive variability among treatments.

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1. Introduction

Litchi is a member of the subfamily Nepheleae of the family Sapindaceae, which comprises 2000 species and 150 genera [1], and is native to Southern China. It is regarded as the queen of fruits because of its superb quality, juicy fruit, superb balance of sugar and acid, unique and pleasant flavor, appealing color, and high nutrient content [2]. Its delightful flavor, superb taste, nice aroma, appealing look, and high nutritional content have made it popular throughout the world, creating new opportunities for faster export growth [3]. Litchi fruits primarily consist of organic acids, carbohydrates, protein, fat, pigments, vitamins, and organic acids [4–6]. This fruit contains 83.6 g of moisture, 0.7 g of protein, 0.1 g of fat, 15.0 g of carbohydrates, 4.0 mg of calcium, 32.0 mg of phosphorus, 0.7 mg of iron, 0.02 mg of thiamine, 0.07 mg of riboflavin, 1.1 mg of niacin, and 15.0 mg of ascorbic acid [4]. The fruit is highly appreciated as a table fruit as well as when consumed both in dried and canned forms. Jam, jelly, squash, and cordial can also be prepared from this fruit. In general, the reddening of the epicarp and the flattening of the tubercles are regarded as the signs of fruit maturity [7].

The yield and quality of plants are enhanced by the foliar application of nutrients and bioregulators during key developmental and critical stages [8,9]. The application of nutrients and plant growth regulators has been proven to have a beneficial impact on litchi fruit yield and quality [9]. Zinc and boron deficiencies result in decreased flower induction and fruit setting, which diminishes fruit quality [10]. Calcium primarily affects fruit quality through the synthesis of calcium pectate, which is linked to an increase in the strength of the middle lamella and cell wall [11]. When micronutrients are given in the right quantities, plants develop more quickly, which improves flowering and increases fruit setting, both of which increase yield [12]. Zinc and boron play an important role in a number of enzymatic processes and aid in the buildup of sugar in fruit obtained from source organs to sinks [13]. Since the foliar application of micronutrients is an established means of completing as well as improving plant nutrition, it is a frequently used method [12,13]. When a plant is subjected to stress or unfavorable soil conditions, the absorption of nutrients from the soil by the plant is restricted. Under this circumstance, a foliar spray can be used to meet nutritional needs of the plant [8]. Plant bioregulators encourage increased fruit retention, flowering, and fruiting. Boron is unique among the micronutrients in that it is linked to the reproductive system and carbohydrate chemistry of plants, in addition to being directly related to photosynthesis and enzyme performance.

Bioregulators are naturally occurring organic products that encourage plants to reach their full growth and yield potentials [7]. Humic acid is extremely useful in releasing nutrients from the soil, making them available to the plant when needed. Humic acids have multiple significant functions, including improving the physical and biochemical activities of soil by enhancing its structure, texture, water-holding capacity, and microbial population [14]. They also increase the availability of soil nutrients, particularly micronutrients, by chelating and co-transporting them to plants [15].

Seaweeds have been shown to be beneficial when employed as biofertilizers not only because they have a biological impact but also owing to their biocompatibility, contributing biological molecules that are common with plants. Seaweeds are multicellular, macroscopic organisms that inhabit coastal and marine environments. They are abundant in polysaccharides, polyunsaturated fatty acids, and enzymes [16,17]. Seaweed extracts are considered bio-stimulants because they include a variety of macronutrients (Ca, P, and K), micronutrients (Fe, Cu, Zn, B, Mn, Co, and Mo), and growth regulators (cytokinin, auxins, and gibberellins) that are essential for plant growth and development [18,19]. The most common method for boosting yields of a number of commercial crops is by the foliar spraying of seaweed extract [19]. Seaweed extracts have been found to contain a variety of growth regulators, including gibberellins, auxins, and cytokinins [20]. Because seaweed extracts can promote the rapid development and yield of horticultural plants like vegetable, fruit, and cereals, they have recently acquired a great deal of attention [21]. Despite its distinct and appealing qualities, poor fruit setting [22], excessive fruit drop [9,23], fruit cracking [23], and poor fruit quality [24] are the main obstacles in litchi production, which result in poor yield and profitability. Fruit drop in litchi has been linked to endogenous hormonal disruption [18,25], internal factors such as high temperatures, low humidity and strong winds [26], as well as, embryo abortion, internal nutrition, and hormonal imbalance [22,23,27]. Fruit cracking in growing fruits is a global issue in the cultivation of litchi. Because of the aforementioned limitations, there is a huge discrepancy between the supply and demand for litchi, raising its price on the market. Many nutrients and bioregulators are applied in addition to the recommended irrigation practices in order to reduce this gap. Many research investigations have documented the various advantages of seaweed extracts on the growth, development and higher yield of many crops [28,29]. Growers are using nutrients and bioregulators to improve yield-related attributes in litchi, thereby boosting the yield. It is established that nutrients increase both the quantity and quality of litchi fruit, but the beneficial effects of combining nutrients with bioregulators have not yet been thoroughly investigated. After China, India is the world's second-largest producer of litchi. It is mostly cultivated in Eastern Indian states like Bihar, West Bengal, Odisha, etc. During 2022–2023, according to the data released from the Directorate of Horticulture, Krushi Bhawan, Bhubaneswar, the total area of land used for litchi cultivation in Odisha was 4380 ha with a production of 24,220 metric tonnes of fruit. Of this, more than half of the total area of land used for litchi cultivation is found in the western region of Odisha, which includes districts like Sundergarh, Sambalpur, Angual, Deogarh, Kandhmal, and Kalahandi. Due to lower fruit setting, fruit drop, and sugar content, and increased fruit cracking, acidity, and other factors, the growers of litchi in the western region of Odisha, India, have been facing problems with the inconsistent of the yield, the marketable of the fruit, and their inferior quality. Due to the abovementioned constraints, the actual productivity realized by the farmers of the western part of Odisha (6.6 t/ha) is comparatively less than that of major litchi-producing states in India like Bihar (8.0 t/ha) and West Bengal (10.5 t/ha). The other factors that may contribute towards the low yield of poor-quality litchi fruits include the low organic matter content in the soil, low soil pH, and improper management techniques employed by the farmers. However, according to many researchers, using nutrients and bioregulators like humic acids and seaweed extracts improved the quantity and quality of litchi.

A set of possibly correlated variables can be reduced to a smaller set of uncorrelated variables known as principal components using a mathematical technique called principal component analysis (PCA). This statistical technique is important for plant breeding programs because it makes it possible to identify important polygenic features. By lowering the dimensionality of a complicated dataset, PCA provides a way to simplify it and reveal hidden structures inside it. The degree of trait variation explained by a particular main component is indicated by the eigenvalue linked to that component. The breeding program's later stages can be effectively guided by this knowledge. Studies on the impact of nutrients and bioregulators on litchi have not yet been carried out in western part of Odisha in India. Hence, an experiment was carried out in this region based on this background to evaluate the impact of nutrients and bioregulators on the yield and fruit quality of Litchi cv. Bombai.

2. Materials and Methods

2.1. Experimental Material

Eight-year-old Litchi trees (*Litchi chinensis* Sonn.) cv. Bombai were used as experimental material.The plants were produced by layering and planted in July 2012. The plants were planted in a square system with a spacing of 8 m × 8 m.

2.2. Experimental Site & Design

The present investigation was conducted in a farmer's field at Jamankira block (21°54′ N latitude, 84°39′ longitude, and altitude 171 m above the mean sea level), Sambalpur district, Odisha, India, during the years of 2020–2022 in a Randomized Block Design (RBD) with 12 treatments (Table 1) replicated thrice.

Table 1. Treatment details.

Sl. No.	Treatments	Details of Treatments
1.	T_1	Borax—0.5%
2.	T_2	Borax—0.3%
3.	T_3	$ZnSO_4$—0.75%
4.	T_4	$ZnSO_4$—0.5%
5.	T_5	$CaCl_2$—0.5%
6.	T_6	$CaCl_2$—0.1%
7.	T_7	Humic acid—1.5%
8.	T_8	Humic acid—1%
9.	T_9	Seaweed extract—0.5%
10.	T_{10}	Seaweed extract—0.1%
11.	T_{11}	NAA—20 ppm
12.	T_{12}	Control (Water Spray)

In the first week of December, just after the completed production of new leaves, the nutrients and bioregulators were applied. The climate of the experimental site was warm and semi-dry, with hot, dry summers and mild winters. The meteorological information gathered between 2020 and 2022 at the Regional Research and Technology Transfer Station (RRTTS), Chiplima, during the meteorological observational period is shown in Figures 1–4.

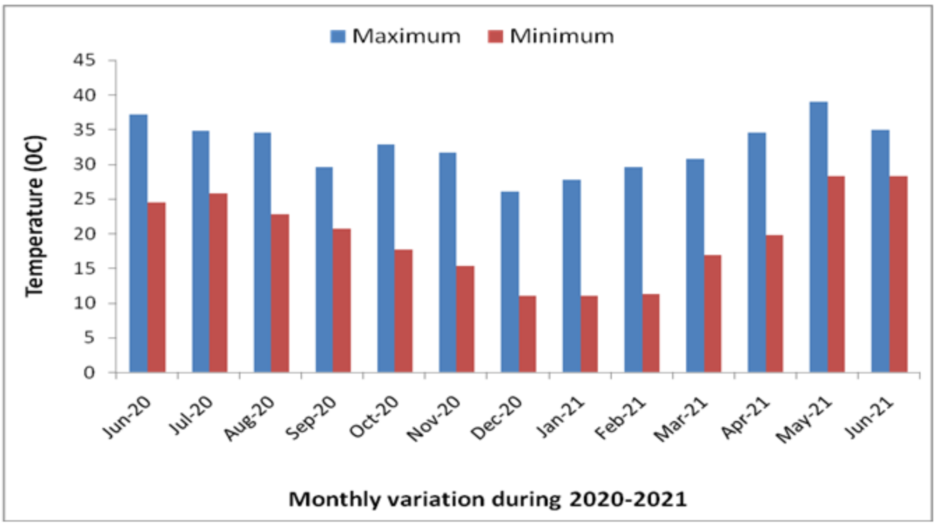


Figure 1. Monthly variation in temperature during 2020–2021.

2.3. Trait Measurement

The fruits were harvested when their color turned red. They were analyzed for yield parameters, which included total number of fruits, total number of marketable fruits, total yield, and total marketable yield. Physico-chemical parameters included fruit weight, aril weight, seed weight, pericarp weight, fruit length and width, and nut length and width, while biochemical parameters included total sugars, titratable acidity, total sugars, reducing sugar content, non-reducing sugar content, TSS/acid ratio, and ascorbic acid content.

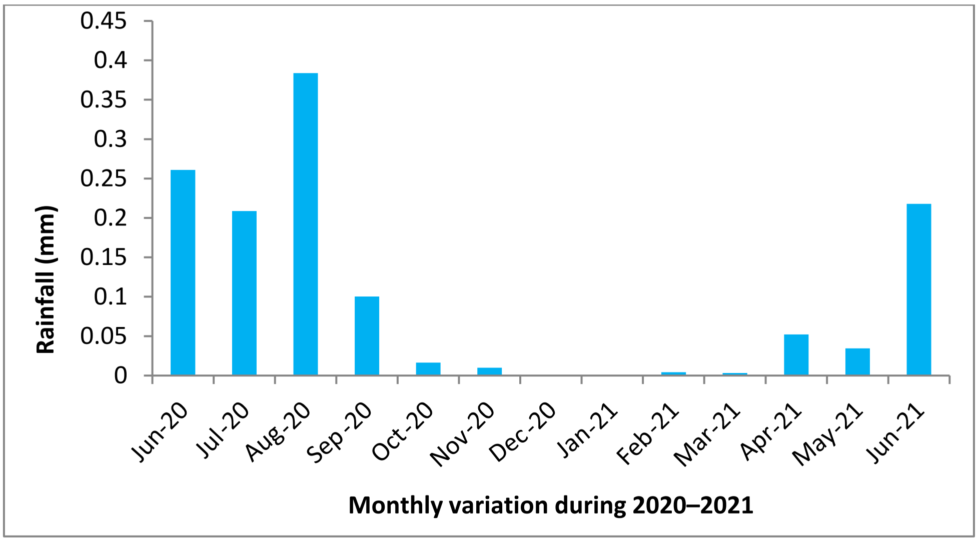


Figure 2. Monthly variation in rainfall (mm) during 2020–2021.

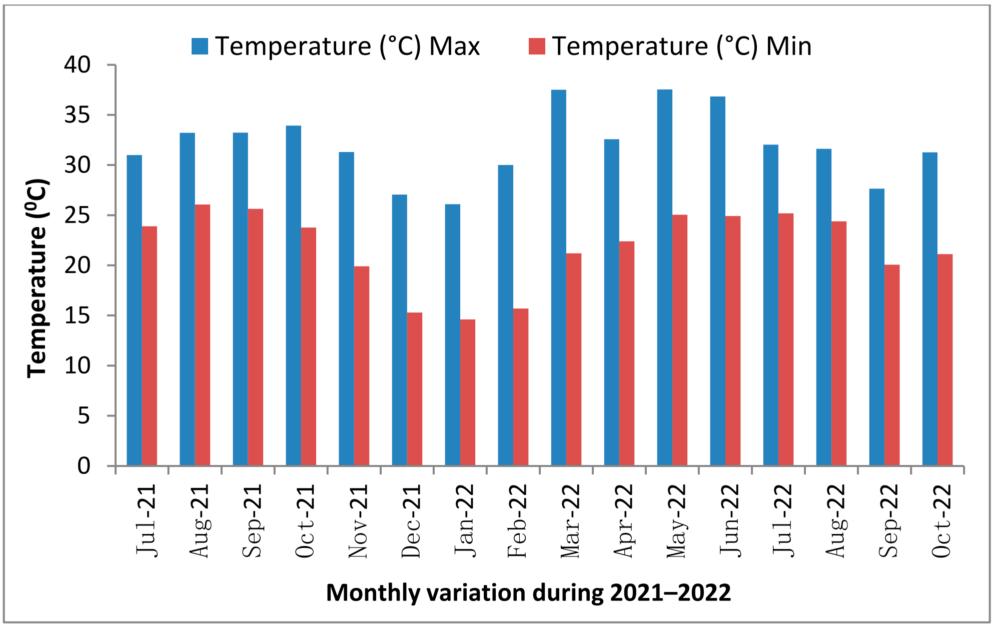


Figure 3. Monthly variation in temperature during 2021–2022.

2.3.1. Determination of Fruit and Aril Weight

The average fruit weight, aril weight, seed weight, and pericarp weight of 10 samples from each replication were analyzed by using an electronic weighing balance, and their average weight was determined and expressed in grams (g).

2.3.2. Determination of Fruit and Nut Size

The length and breadth of fruit and nut were measured by using a digital slide caliper, and the mean was expressed in centimeter (cm).

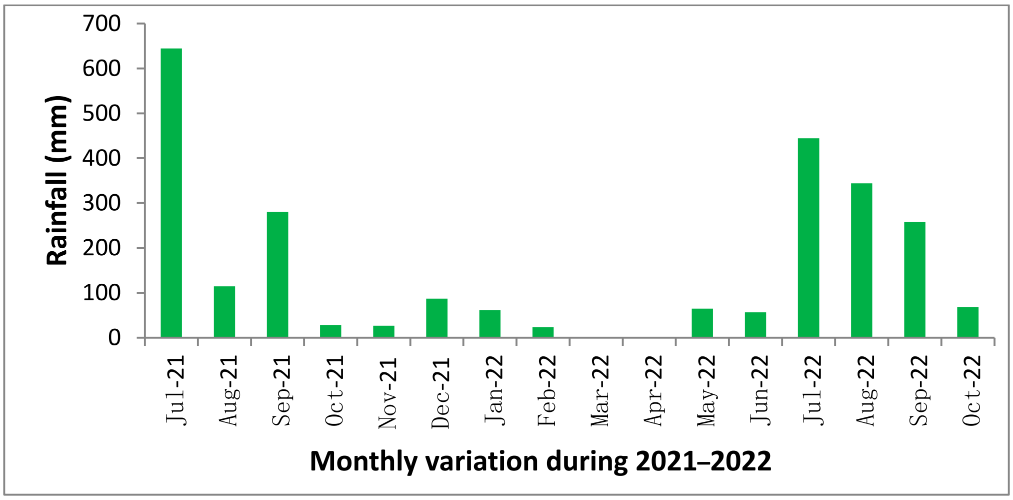


Figure 4. Monthly variation in rainfall (mm) during 2021–2022.

2.3.3. Biochemical Parameters

Determination of Total Soluble Solids (^{0}Brix)

TSS is generally measured using digital refractometer (0–32^{0}Brix). TSS stands for total soluble solids which include sugar, vitamins, amino acids, acids, and other soluble solids present in the juice. To measure the TSS of litchi fruit, two to three drops of juice were placed on the prism of the refractometer, and observations were recorded. Before and after taking the reading, the refractometer was properly washed. The reading of refractometer is expressed as a percentage or in ^{0}Brix.

Determination of Titratable Acidity (%)

A known volume of aqueous extract was titrated against an alkali solution with known normality to determine the total acidity of the fruit. It is measured against an equivalent volume of any organic acid, such as citric or malic acid [30]. The titratable acidity is calculated in terms of malic acid, as shown in Equation (1), and expressed in percentage [31].

$$\text{Total acidity (\%)} = \text{TA} = [(\text{T} \times \text{N} \times \text{V} \times \text{W}_\text{E})/(\text{V}_\text{A} \times \text{V}_\text{s} \times 1000)] \times 100 \quad (1)$$

where, TA = Total titratable acidity (%); T = Titrated value; N = Normality of NAOH; V = Volume made up; W_E = Equivalent weight of acidity (66); V_A = Volume of aliquote taken; V_s = Volume of sample taken

Determination of Total Sugar (%)

By utilizing Fehling's A and Fehling's B solutions and the method outlined by [32], the total sugar content of the fruit aril was calculated. It was titrated against the sample in a burette until a bright red color appeared, which indicates the endpoint. The total sugar content was calculated using the following formula shown in Equation (2):

$$\text{Total Sugar (\%)} = [(\text{Dilution factor } (0.05) \times \text{Dilution } (100))/(\text{Titrate value} \times \text{volume of sample taken})] \times 100 \quad (2)$$

Determination of Reducing Sugar Content (%)

The method described by [33] was used to calculate the reducing sugar content, which was computed using Equation (3):

$$\text{Reducing Sugar (\%)} = [(\text{Dilution factor } (0.05) \times \text{Dilution } (100))/(\text{Titrate value} \times \text{volume of sample taken})] \times 100 \quad (3)$$

Determination of Non-Reducing Sugar Content (%)

By subtracting the reducing sugar content from the total carbohydrates and multiplying the outcome by 0.95, the amount of non-reducing sugar was determined.

Determination of TSS/Acid Ratio

By dividing the TSS value by the titratable acidity, the TSS/Acid ratio was calculated computationally, and the outcome of that calculation was expressed as the TSS/acid ratio.

$$\text{TSS/acid ratio} = \text{TSS/titratable acidity}$$

Determination of Ascorbic Acid Content (mg/100 g)

The 2,6-dichlorophenol indophenol visual titration method described by [32] was used to determine the ascorbic content of the litchi fruit. This was expressed in terms of mg ascorbic acid per 100 g of fruit aril and was calculated by using following formula shown in Equation (4).

$$\text{Ascorbic acid (mg/100g)} = (\text{titrate reading} \times \text{dye factor} \times \text{dilution} \times 100)/(\text{Aliquat of extract} \times \text{weight of sample taken}) \quad (4)$$

2.3.4. Statistical Analysis

The data were analyzed according to the method of analysis suggested by [33] for a Randomized Block Design. The significant variation among the treatments was observed by applying the "F" test and Critical Difference (CD) at a 5% level of significance which was calculated to compare the mean values of the treatments for all the characters. Duncan's Multiple Range (DMR) test was performed to compare the treatment means.

2.3.5. Principal Component Analysis (PCA)

The principal component analysis decreases the dimensions of multivariate data to a few principal axes, generates an eigenvector for each axis, and produces component scores for the characteristics [34,35]. A PCA analysis is employed to condense the dimensions of multivariate data into a small set of principal axes, each associated with an eigenvector. Component scores are then generated for each individual characteristics. In this study, a graph was plotted based on PC1 and PC2. The statistical analysis and graphical representations were conducted using Minitab 19, a statistical software package.

3. Results

3.1. Fruit Setting

The results regarding the percentage of fruit setting in litchi influenced by different nutrients and bioregulators applications are given in Table 2. The obtained data revealed that the highest fruit setting rate (59.76%) was recorded with T_7, i.e.,1.5%-humic-acid-treated trees which was statistically similar to that of plants treated with 1% humic acid, i.e., T_8, (58.17%) while the minimum fruit setting rate (46.49%) was observed in T_{12} (control) which was found to be statistically inferior compared to the rest of treatments and was followed by T_9 (53.53%), T_2 (53.11%), and T_1 (53.07%).

3.2. Fruit Drop

It is evident from the pooled data presented in Table 2 and Table S10, that the fruit drop rate varied from 65.94 to 80.91 percent. The minimum fruit drop (65.94%) was recorded in plants in the T_8 treatment (humic acid—1%) which was followed by the statistically similar T_7 treatment (70.19%), while the maximum fruit drop rate (80.91%) was recorded in the T_{12} treatment (control) which was followed by the statistically similar T_3 (79.59%) and T_4 (80.01%) treatments. The pooled data further indicated that the mean value of all the concentrations of humic acid had the lowest value (65.94% in T_8 and 70.19% in T_7) followed by the seaweed extracts (73.72% in T_9 and 74.18% in T_{10}).

Table 2. Influence of foliar feeding with nutrients and bioregulators on fruit setting, fruit drop, fruit retention, and fruit cracking percentage in Litchi cv. Bombai.

Treatment	Treatment Details	Fruit Setting (%)	Fruit Drop (%)	Fruit Retention (%)	Fruit Cracking (%)
T_1	Borax—0.5%	53.07 cde	74.47 fg	25.53 bcde	8.73 e
T_2	Borax—0.3%	53.11 cd	74.69 ef	25.32 bcdef	8.46 e
T_3	$ZnSO_4$—0.75%	52.10 cdefg	79.59 abc	20.41 ghi	17.25 d
T_4	$ZnSO_4$—0.5%	51.88 cdefgh	80.01 ab	19.99 ghij	17.27 d
T_5	$CaCl_2$—0.5%	51.84 cdefghi	76.70 de	23.30 bcdefg	12.36
T_6	$CaCl_2$—0.1%	51.76 cdefghij	78.53 bcd	21.47 bcdefgh	14.99
T_7	Humic Acid—1.5%	59.76 a	70.19	29.81 a	20.07 c
T_8	Humic Acid—1%	58.17 ab	65.94	34.07 a	19.40 c
T_9	Seaweed extract—0.5%	51.60 cdefghij	73.72 f	26.28 b	22.54 a
T_{10}	Seaweed extract—0.1%	52.73 cdef	74.18 fghi	25.82 abc	22.18 ab
T_{11}	NAA (20 ppm)	53.53 c	74.29 fgh	25.71 bcd	24.31
T_{12}	Control (Water Spray)	46.49 e	80.91 a	19.10 ghij	30.36
	SE m (±)	1.03	0.67	1.58	0.39
	CD (0.05)	2.08	1.36	3.18	0.78
	CV (%)	3.37	1.55	11.06	3.70

SE m (±)—Standard Error of means; CD (0.05)—Critical Difference at 5% level of Significance; CV (%)—Coefficient of variation. abcdefghijk—represents the non-significant group at 5% level of significance.

3.3. Fruit Retention

The T_8 treatment group (humic acid—1%) showed the highest fruit retention rate (34.07%) and was statistically superior to all other treatments; it was followed (29.81%) byT_7 (humic acid—1.5%). The control plants (T_{12}) had the lowest fruit retention rate (19.10%), which was found to be statistically different and less than that of the other treatments (Tables 2 and S10). When compared to the control, all other treatments significantly improved fruit retention in litchi.

3.4. Fruit Cracking

From the combined data shown in Tables 2 and S10, it becomes apparent that foliar feeding with different nutrients and bioregulators significantly reduced the fruit cracking percentage in litchi cv. Bombai, and that the values ranged from 8.46% in T_2 to 30.36% in the control (T_{12}). The pooled data clearly show that the T_2 treatment (Borax—0.3%) produced the lowest percentage of fruit cracking (8.46%), which was found to be statistically equivalent to T_1 (8.73%), and that all other treatments recorded more cracking than T_2, while the highest fruit cracking rate (30.36%) was recorded in the untreated control trees (T_{12}).

3.5. Total Number of Fruits per Plant

The number of fruits per plant varied significantly due to different treatments, as shown in Table 3 and Figure 5. The highest total number of fruits per plant (1972.08) was obtained in T_4 ($ZnSO_4$—0.5%) and was found to be statistically equal to T_8 (humic acid—1%), T_2 (Borax—0.3%), and T_{10} (seaweed extract—0.1%), recording 1864.91, 1858.03, and 1836.79 fruits per plant, respectively. The control plants (T_{12}) produced the lowest number of fruits per plant (1627.77).

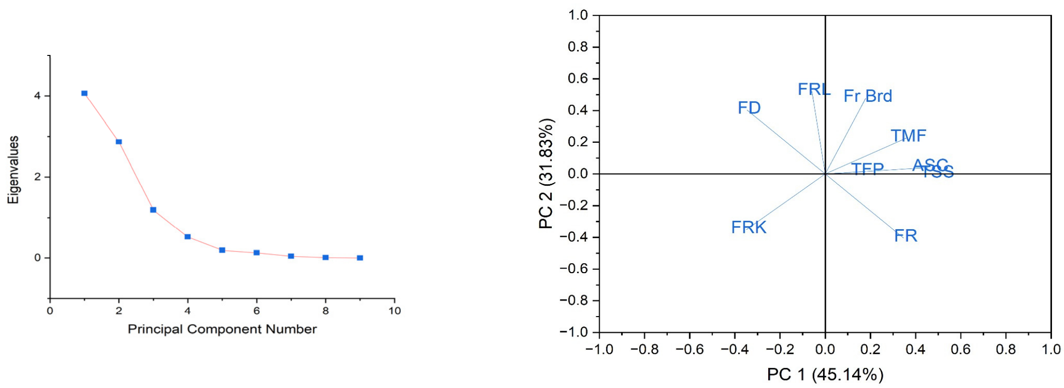
3.6. Total Number of Marketable Fruits per Plant

The pooled data presented in Tables 3 and S11, show that the maximum number of marketable fruits (1698.46) was observed in plants under the T_2 treatment (Borax—0.3%), which has been shown to be superior to all other treatments. It was statistically equivalent (1632.43) to T_4, while all other treatments recorded higher number of marketable fruits than T_{12} (control). Out of all the treatments, the control plants (T_{12}) had the lowest marketable fruits per plant (144.18), and they were found to be significantly less effective than the other treatments.

Table 3. Influence of foliar feeding with nutrients and bioregulators on number of fruits per plant and yield of Litchi cv. Bombai.

Treatment	Treatment Details	Total Number of Fruit per Plant	Total Number of Marketable Fruits per Plant	Total Yield per Plant (kg)	Total Marketable Yield per Plant (kg)
T_1	Borax—0.5%	1636.31 defghij	1491.91 bcde	30.44 efghijk	28.12 abcde
T_2	Borax—0.3%	1858.03 abc	1695.05 a	38.69 a	35.34
T_3	$ZnSO_4$—0.75%	1717.80 bcdefghi	1416.23 cdefgh	34.73 bcdef	28.68 ab
T_4	$ZnSO_4$—0.5%	1972.08 a	1622.14 ab	35.85 abcd	29.56 a
T_5	$CaCl_2$—0.5%	1625.68 efghijk	1425.05 cdef	31.10 efghij	28.29 abcd
T_6	$CaCl_2$—0.1%	1801.94 abcde	1518.85 abcd	32.97 bcdefg	28.11 abcdef
T_7	Humic Acid—1.5%	1730.42 bcdefgh	1421.51 cdefg	32.10 defghi	26.33 abcdefghi
T_8	Humic Acid—1%	1864.91 ab	1519.29 abc	34.93 abcde	28.39 abc
T_9	Seaweed extract—0.5%	1785.04 bcdef	1373.86 defghij	36.41 abc	26.68 abcdefg
T_{10}	Seaweed extract—0.1%	1836.79 abcd	1297.67 efghijk	36.68 ab	25.92 ghij
T_{11}	NAA (20 ppm)	1735.27 bcdefg	1374.69 defghi	32.79 bcdefg	26.02 abcdefghij
T_{12}	Control (Water Spray)	1627.77 efghijk	1144.18 ijk	29.65 efghijk	20.88
	SE m (±)	69.74	56.57	1.53	1.09
	CD (0.05)	140.56	114.02	3.09	2.20
	CV (%)	6.84	8.80	7.84	6.83

SE m (±)—Standard Error of means; CD (0.05)—Critical Difference at 5% level of Significance; CV (%)—Coefficient of variation. abcdefghijk—represents the non-significant group—5% level of significance.



(**A**) (**B**)

Figure 5. (**A**) Slope declining of the treatments from first treatment to last treatment; (**B**) Scattered graph of Principal Component Analysis for treatments (where, TFP—Total number of fruits per plat; TMF—Total number of marketable fruits; FD—Fruit drop; FRK—Fruit cracking; FR—Fruit retention; TSS—Total soluble solids; FRL—Fruit length; FB—Fruit width, ASC—Ascorbic acid.

3.7. Total Yield per Plant

The litchi plants under the T_2 treatment (Borax—0.3%) produced the highest total fruit yield (38.69 kg per plant), which was found to be statistically equal to T_{10} (36.68 kg/plant), T_9 (36.41 kg/plant), and T_4 (35.85 kg/plant) and was also observed to be superior to all other treatments, whereas the lowest fruit yield (29.65 kg/plant) was found in T_{12} (control). The influence of the treatments (T_2, T_{10}, T_9, and T_4) on the total fruit yield per plant was found to be statistically equivalent between treatments. The pooled data further shows that the mean fruit yield obtained from T_2 (38.69 kg/plant) is 23.3% higher than the control and that there is a 19.16% higher yield in the T_{10} treatment compared to the control (Tables 3 and S11).

3.8. Total Marketable Yield

The maximum marketable yield (35.34 kg/plant) was observed in litchi plants under T_2 (i.e., Borax—0.3%), which was found to be statistically superior to all other treatments, pursuant to the pooled data shown in Tables 3 and S11. There was statistical similarity observed among the T_4 (29.56 kg/plant), T_5 (28.29 kg/plant), T_6 (28.11 kg/plant), and T_8 (28.39 kg/plant) treatments. The T_{12} treatment (control) showed the lowest marketable fruit yield (20.88 kg/plant), and it appeared to be significantly less effective than any other treatment. The pooled mean value of the marketable yield obtained from all the treatments revealed that T_2, T_4, T_5, and T_8 showed a 41.03%, 29.76%, 26.19%, and 25.72% higher marketable fruit yield than the control.

3.9. Physico-Chemical Parameters

3.9.1. Fruit Length

All the plant bioregulators and nutrients significantly increased the fruit length in comparison to the control. The plants under the T_2 treatment (foliar feeding with 0.3% Borax) showed the longest fruit (3.66 cm) based on the pooled data shown in Tables 4 and S12. The following treatments were found to be statistically similar with each other with respect to fruit length in litchi: T_3, i.e., foliar feeding with 0.75% $ZnSO_4$ (3.53 cm); T_5, i.e., foliar feeding with 0.5% $CaCl_2$ (3.56 cm); T_9, i.e., foliar feeding with 0.3% seaweed extract (3.43 cm); and T_{10}, i.e., foliar feeding with 0.1% seaweed extract (3.45 cm). The fruit with the minimum length (2.83 cm) was observed in the T_7 treatment (1% humic acid).

Table 4. Influence of foliar feeding with nutrients and bioregulators on fruit and nut size of Litchi. cv. Bombai.

Treatment	Treatment Details	Fruit Length (cm)	Fruit Width (cm)	Nut Length (cm)	Nut Width (cm)
T_1	Borax—0.5%	3.14 defghi	3.02 abc	2.53 bcd	1.49 bcdefgghijk
T_2	Borax—0.3%	3.66 a	3.12 a	2.49 bcdef	1.70 ab
T_3	$ZnSO_4$—0.75%	3.53 abc	3.01 abcde	2.61 abc	1.58 abcdef
T_4	$ZnSO_4$—0.5%	3.33 abcdefg	2.95 abcdef	2.31 cdefghijk	1.64 abcd
T_5	$CaCl_2$—0.5%	3.56 ab	3.08 ab	2.38 bcdefghi	1.53 bcdefgghij
T_6	$CaCl_2$—0.1%	3.41 abcdef	2.91 abcdefghi	2.43 bcdefgh	1.44 fghijk
T_7	Humic Acid—1.5%	3.03 ghijk	2.95 abcdefg	2.33 cdefghij	1.61 abcde
T_8	Humic Acid—1%	2.83 ijk	2.61 cdefghijk	2.26 defghijk	1.56 abcdefgh
T_9	Seaweed extract—0.5%	3.43 abcde	2.92 abcdefgh	2.48 bcdefg	1.57 abcdefg
T_{10}	Seaweed extract—0.1%	3.45 abcd	3.02 abcd	2.50 bcde	1.65 abc
T_{11}	NAA (20 ppm)	3.05 fghij	2.87 abcdefghij	2.64 ab	1.54 bcdefgghi
T_{12}	Control (Water Spray)	3.27 bcdefgh	2.66 abcdefghijk	2.85 a	1.73 a
	SE m (±)	0.12	0.12	0.14	0.06
	CD (0.05)	0.24	0.25	0.28	0.12
	CV (%)	6.36	7.28	9.86	6.41

SE m (±)—Standard Error of means; CD (0.05)—Critical Difference at 5% level of Significance; CV (%)—Coefficient of variation. abcdefghijk—represents the non-significant group—5% level of significance.

3.9.2. Fruit Width

It is apparent from the data shown in Tables 4 and S12 that the fruit width of litchi was not significantly influenced by the various foliar treatments. From the pooled data, it can be seen that the foliar application of 0.3% Borax (T_2) resulted in the highest fruit width

(3.12 cm) followed by plants in T_5 (3.08 cm) and T_{10} (3.02 cm).The plants in T_8 produced the lowest fruits width (2.61 cm).

3.9.3. Nut Length

The average length of the nut was not found to be statistically significant between the different treatments in litchi (Tables 4 and S12). The T_{12} treatment (control) showed the highest average nut length (2.85 cm), while T_4 ($ZnSO_4$—0.5%) recorded the lowest (2.31 cm) nut length.

3.9.4. Nut Width

The nut width of litchi cv. Bombai did not show any significant variation among the different foliar treatments, and in the pooled data (Tables 4 and S12), it ranged from a maximum of 1.73 cm in T_{12} (control) to a minimum of 1.44 cm in T_6 ($CaCl_2$—0.1%).

3.9.5. Fruit Weight

During the study period, there was a significant variation in the average fruit weight of litchi fruit due to influence of different treatments. The pooled data presented in Tables 5 and S13, clearly show that the plants treated with 0.3% Borax (T_2) had the highest fruit weight (20.85 g), which was statistically found to be equal to the T_3 (20.39 g), T_{10} (20.02 g), and T_5 (19.81 g) treatment. The lowest fruit weight (18.26 g) was obtained in the control plants (T_{12}) which was found to be statistically similar with the T_4 (18.30 g), T_6 (18.59 g), T_7 (18.63 g), T_8 (18.84 g), and T_1 (18.91 g) treatments.

Table 5. Influence of foliar feeding with nutrients and bioregulators on fruit weight, aril weight, seed weight, and pericarp weight of Litchi cv. Bombai.

Treatment	Treatment Details	Fruit Weight (g)	Aril Weight (g)	Seed Weight (g)	Pericarp Weight (g)	Aril/Seed Ratio	Aril/ Pericarp Ratio
T_1	Borax—0.5%	18.91 bcdefg	14.17 cde	2.65 efgh	2.35	5.35 cde	6.04 cde
T_2	Borax—0.3%	20.85 a	16.01 a	2.19	2.23 bcdefghik	7.31 a	7.18 a
T_3	$ZnSO_4$—0.75%	20.39 ab	14.86 bc	2.45 ghi	2.30 bcdefghi	6.07 bc	6.45 bc
T_4	$ZnSO_4$—0.5%	18.30 efghijk	13.07 efghijk	2.92 bc	2.28 bcdefghik	4.47 ghij	5.75 cdefgh
T_5	$CaCl_2$—0.5%	19.80 abcd	15.70 ab	2.38 i	2.33 abcdefgh	6.62 ab	6.77 ab
T_6	$CaCl_2$—0.1%	18.59 cdefghij	14.04 cdef	2.81 bcdef	2.35 abcdef	5.07 defg	5.98 cdef
T_7	Humic Acid—1.5%	18.63 cdefghi	13.50 defgh	2.82 bcde	2.43 abcdefg	4.82 efgh	5.56 defghijk
T_8	Humic Acid—1%	18.84 cdefgh	13.86 defg	2.65 efg	2.37 abcde	5.27 cdef	5.84
T_9	Seaweed extract—0.5%	19.48 bcde	13.39 defghij	2.86 bcd	2.40 abcd	4.71 efghi	5.59 defghij
T_{10}	Seaweed extract—0.1%	20.02 abc	14.40 bcd	2.57 fghi	2.30 bcdefghij	5.61 cd	6.26 bcd
T_{11}	NAA (20 ppm)	18.95 Bcdef	13.48 defghi	3.00 ab	2.43 ab	4.49 fghi	5.64 defghi
T_{12}	Control (Water Spray)	18.26 efghijk	12.20 k	3.09 a	2.54 a	3.95 ij	4.81 fghijk
	SE m (±)	0.51	0.35	0.08	0.08	0.27	0.25
	CD (0.05)	1.04	0.71	0.16	0.15	0.54	0.51
	CV (%)	4.63	4.37	5.08	5.58	8.77	7.28

SE m (±)—Standard Error of means; CD (0.05)—Critical Difference at 5% level of Significance; CV (%)—Coefficient of variation. abcdefghijk—represents the non-significant group—5% level of significance.

3.9.6. Aril Weight, Seed Weight, Pericarp Weight, Aril/Seed Ratio, and Aril/Pericarp Ratio

The data recorded with respect to the aril weight in litchi and the effects of foliar feeding with nutrient and bioregulator treatments are presented in Tables 5 and S13. The pooled data exhibited a significant variation among the treatments with respect to aril content in litchi cv. Bombai. The highest was recorded in T_2 (16.01 g) followed by T_5 (15.70 g), which were found to be statistically similar to each other. The lowest aril content (12.20 g) was recorded in T_{12} which was found to be statistically different from rest of the treatments (Table 4).

The plants treated with 0.3% Borax (T_2) had the lowest seed weight (2.19 g) and were statistically different from the other treatments, according to the data presented in Table 5. The untreated control plants (T_{12}) had the highest recorded seed weight (3.09 g) among all the treatments. There was a non-significant effect of various treatments on the pericarp weight of litchi cv. Bombai (Tables 5 and S13), yet T_2 showed the lowest pericarp weight, and the control plants had recorded the highest pericarp weight. From the pooled data, the minimum value was obtained (2.23 g) in T_2, and the maximum value (2.54 g) was obtained in T_{12} (control). Assessing the data set displayed in Tables 5 and S13, it was found that plants subjected to foliar feeding with 0.3% Borax (T_2) had the highest aril/seed ratio (7.31) compared to the other treatments. On the other hand, the lowest aril/seed ratio (3.95) was found in T_{12} (control) which was observed to be statistically similar to the T_4 (4.47), T_7 (4.82), T_9 (4.71), and T_{11} (4.49) treatments. It is evident from the pooled data that maximum aril/pericarp ratio (7.18) was found in T_2, whereas the lowest was recorded in the control (T_{12}) plants (4.81) (Tables 5 and S13). The aril/pericarp ratio was found to be significantly superior in all the treatments in reference to the control.

3.9.7. Chemical Analysis

Total Soluble Solids

The treatments had significant effects on the total soluble solids (TSS) content of the litchi fruit (Tables 6 and S14). Based on the pooled data, it was determined that the highest TSS was recorded in T_2 (14.07^{0}Brix) followed a significantly similar value in T_1 (14.02^{0}Brix), T_8 (13.73^{0}Brix), T_7 (13.42^{0}Brix), and T_{10} (13.22^{0}Brix). However, the lowest TSS was observed in the control, i.e., T_{12}, (9.82^{0}Brix) which was statistically different than the values obtained from the treatments; it was followed by the statistically significant T_3 (11.47^{0}Brix), T_{11} (11.78^{0}Brix), T_4 (11.98^{0}Brix), and T_6 (12.55^{0}Brix) treatments.

Titratable Acidity

A significant effect for titratable acidity (%) was observed in the fruits treated with various nutrients and bioregulators (Tables 6 and S14). The lowest titratable acidity was obtained in T_2 (0.72%), which was followed by significantly similar T_1 (0.78%), T_8 (0.79%), and T_7 (0.80%) treatments. The control plants, however, had the highest calculated titratable acidity, i.e., T_{12}, (1.00%) followed by statistically equivalent T_{10} (0.91%) and statistically different T_9 (0.88%), T_4 (0.85%), and T_3 (0.85%) treatments.

Total Sugar Content

The treatments had a notable effect on the total sugar content (%) of the litchi fruit (Tables 6 and S14). The pooled data showed that the T_2 treatment had the highest total sugar percentage (10.40%), followed by the statistically similar T_1 treatment (10.12%). These were followed by the statistically different T_8 (9.98%) and T_7 (9.88%) treatments. However, the lowest total sugar content was observed in the control, i.e., T_{12}, (7.85) which was followed by the statistically different T_{11} (8.63%) and T_3 (8.88%) treatments. However, T_{11} and T_3 were statistically similar to each other.

Reducing Sugar Content

The T_2 treatment showed the highest reducing sugar content (8.15%) followed by the statistically identical T_1 (7.93%) treatment, which is evident from the pooled data for the two years studied (Tables 6 and S14). These were followed by the statistically different T_8 (7.88%) and T_7 (7.82%) treatments. However, the lowest reducing sugar content was observed in the control (6.08%), which was followed by the statistically similar T_4 (6.65%) treatment and statistically different T_{11} (6.78%) and T_7 (7.01%) treatments.

Table 6. Influence of foliar feeding with nutrients and bioregulators on total soluble solids, acidity, total sugar content, and reducing and non-reducing sugar content of Litchi cv. Bombai.

Treatment	Treatment Details	TSS (^{0}Brix)	Titratable Acidity (%)	Total Sugar (%)	Reducing Sugar (%)	Non-Reducing Sugar (%)
T_1	Borax—0.5%	14.02 ab	0.78 bcdefghijk	10.12 ab	7.93 ab	2.07 ab
T_2	Borax—0.3%	14.07 a	0.72 defghijk	10.40 a	8.15 a	2.14 a
T_3	$ZnSO_4$—0.75%	11.47 hij	0.85 abcde	8.88 defghi	7.01 bcdefghi	1.78 abcdefgh
T_4	$ZnSO_4$—0.5%	11.98 fgh	0.85 abcdef	8.49 Fghijk	6.65 efghijk	1.75 abcdefghijk
T_5	$CaCl_2$—0.5%	12.70 cdefg	0.82 bcdefg	9.03 bcdefg	7.12 abcdefg	1.82 abcdefg
T_6	$CaCl_2$—0.1%	12.55 cdefg	0.82 bcdefgh	9.02 cdefgh	7.08 bcdefgh	1.84 sbcdefgh
T_7	Humic Acid—1.5%	13.42 abcd	0.80 bcdefghi	9.88 abcd	7.82 abcd	1.96 abcd
T_8	Humic Acid—1%	13.73 abc	0.79 bcdefghij	9.98 abc	7.88 abc	2.00 Abc
T_9	Seaweed extract—0.5%	12.95 cdef	0.88 abcd	9.28 bcdef	7.27 abcdef	1.92 abcdef
T_{10}	Seaweed extract—0.1%	13.22 abcde	0.91 abc	9.53 bcde	7.49 abcde	1.94 abcde
T_{11}	NAA (20 ppm)	11.78 fghi	0.93 ab	8.63 Efghij	6.78 Efghij	1.76 abcdefghij
T_{12}	Control (Water Spray)	9.82 huj	1.00 a	7.85 ijk	6.08 hijk	1.69 abcdefghijk
	SE m (±)	0.43	0.05	0.34	0.31	0.33
	CD (0.05)	0.86	0.09	0.68	0.62	0.66
	CV (%)	5.86	9.41	6.34	7.35	30.07

SE m (±)—Standard Error of means; CD (0.05)—Critical Difference at 5% level of Significance; CV (%)—Coefficient of variation. abcdefghijk—represents the non-significant group—5% level of significance.

Non-Reducing Sugar Content

There was non-significant effect of the treatments on the non-reducing sugar content (%) of the litchi fruit (Tables 6 and S14). In the pooled data of the two years studied, the highest non-reducing sugar content was observed in T_2 (2.14%), which was followed by the statistically similar T_1 (2.07%), T_8 (2.00%), and T_7 (1.96%) treatments. However, the lowest non-reducing sugar was observed in the control (1.69%), which was followed by the statistically similar T_4 (1.75%), T_{11} (1.76%), and T_3 (1.78%) treatments.

TSS/Acidity Ratio

The TSS/acid ratio varied significantly due to different treatments and reflected in Tables 7 and S15. The pooled results showed the highest TSS/acidity ratio. in the T_2 (20.33), which was followed by statistically significant T_1 (18.76) and statistically different T_8 (17.96), T_7 (17.25), and T_5 (16.35). However, the lowest TSS/acidity ratio was observed in the control, i.e., T_{12}, (9.99) which was statistically different than all other treatments. It was followed by T_{11} (12.74), T_3 (14.39), T_4 (14.74), and T_{10} (14.98).

Ascorbic Acid

There was a significant effect of the treatments on the ascorbic content (mg/100 g) of the litchi fruit (Tables 7 and S15).The highest ascorbic acid content was observed in the T_2

treatment (32.22 mg/100 g), which was followed by the statistically similar T_1 treatment (32.06 mg/100 g) as indicated from the pooled data presented in Table 7. This was followed by the statistically different T_7 (30.67 mg per 100 g) and T_8 (30.56 mg per 100 g) treatments. The lowest ascorbic content was observed in the control, i.e., T_{12}, (27.06 mg/100 g) which was followed by the statistically different T_{11} (27.83 mg per 100 g), T_3 (28.11 mg per 100 g), and T_4 (28.50 mg per 100 g) treatments.

Table 7. Influence of foliar feeding with nutrients and bioregulators on TSS/acid ratio and ascorbic acid content of Litchi cv. Bombai.

Treatment	Treatment Details	TSS/Acid Ratio	Ascorbic Acid (mg/100 g)
T_1	Borax—0.5%	18.76 ab	32.06 ab
T_2	Borax—0.3%	20.33 a	32.22 a
T_3	$ZnSO_4$—0.75%	14.39 cdefghij	28.11 ghij
T_4	$ZnSO_4$—0.5%	14.74 bcdefghi	28.50 ghi
T_5	$CaCl_2$—0.5%	16.35 bcde	29.61 cdefg
T_6	$CaCl_2$—0.1%	16.00 bcdef	28.72 gh
T_7	Humic Acid—1.5%	17.25 abcd	30.67 c
T_8	Humic Acid—1%	17.96 abc	30.56 cd
T_9	Seaweed extract—0.5%	15.17 bcdeg	30.00 cdef
T_{10}	Seaweed extract—0.1%	14.98 bcdegh	30.11 cde
T_{11}	NAA (20 ppm)	12.74 efghijk	27.83 hijk
T_{12}	Control (Water Spray)	9.99 k	27.06 ijk
SEm (±)		1.25	0.33
CD (0.05)		2.52	0.67
CV (%)		13.75	1.95

SE m (±)—Standard Error of means; CD (0.05)—Critical Difference at 5% level of Significance; CV (%)—Coefficient of variation. abcdefghijk—represents the non-significant group—5% level of significance.

Principal Component Analysis

Due to the many characteristics studied, including the total number of fruits per plant, total number of marketable fruits, fruit drop, fruit retention, total soluble solids, ascorbic acid, fruit cracking, fruit length, and fruit width, principal component analysis was performed.

The eigen values slowly declined starting from the total number of fruits followed by the total number of marketable fruits and fruit drop, and the remaining characteristics showed negligible responses for the treatments effect. The eigen values corresponding to the variables measuring the total number of fruits per plant (4.06255) suggest a pronounced response to the applied treatments in this investigation, with the fruit drop (1.1867) and fruit retention (0.51802) following in significance. The eigen value is notably low for fruit width and also for fruit length. The overall variance is distributed across ten components, elucidating the impact of treatments on various measured traits in the current study. The principal component analysis (PCA) reveals a transformation in the dimensionality of variables such as fruit cracking and ascorbic acid content, with varying degrees of variance. Notably, PCA1 (45.14%) and PCA2 (31.83%) collectively account for the total variance in this study (Tables S7–S9 in the Supplementary Materials).

4. Discussion

Compared to earlier research, this study delivers more precise information since it supported our hypothesis that applying nutrients and bioregulators topically could enhance the yield and physico-chemical parameters of litchi fruit.

Plants sprayed with 0.5% $ZnSO_4$ had the highest total number of fruits per plant, followed by those treated with 1% humic acid. This result corroborates the findings of the authors of [36], who obtained a considerably high number of fruits per tree by spraying litchi plants with zinc sulphate (0.6%). Similar results were also reported by [37]. Since humic acids can adhere to ionized nutrients and prevent them from leaching away, they could act as a medium for transporting nutrients from the soil to the plant. They provide water and nutrients to plants when they reach the roots. This would have facilitated greater nutrient availability and utilization [38]. In addition to producing plant hormones and enzymes, it has also been demonstrated that the application of humic acid increases the weight of the roots and shoots, chlorophyll content, and the photosynthetic rate [39].

The litchi plants treated with 0.3% Borax by foliar feeding had the highest total number of fruits per plant, which was found to be statistically identical to plants treated with 0.1% and 0.5% seaweed extracts. This result was close to the findings of the authors of [40], who recorded an enhanced total fruit yield over their control due to the application of seaweed extract in kiwi fruit. The essential nutrients contained in seaweed extracts, viz. nitrogen, potassium, phosphorous, calcium, magnesium, sulfur, iron, sodium, zinc, and copper [41], might reduce the production losses caused by cracking without compromising either the quality or the yield of crops. The findings also corroborate the claims of a higher yield per plant when humic acid is applied to peaches [42], apples [43], and pears [44]. The favorable effects of boron, namely boosting the rates of carbohydrate and RNA metabolism [45] and accelerating the passage of photosynthates from the leaves to the developing fruits [46], may contribute to the yield enhancement that results from treatment with boron.

Among the treatments, plants treated with 0.3% Borax and 0.5% zinc sulphate demonstrated the best response in terms of a higher number of marketable fruits and marketable output. The application of 1% humic acid and 0.1% $CaCl_2$ also enhanced the marketable yield of litchi. This result is in line with that of the authors of [47], who found that applying boron to plants increased the yield of marketable fruits per plant. The right dose of boron may contribute significantly to the mechanisms related to flowering and fruiting, nitrogen metabolism, hormone synthesis, and cell division, among other positive functions [48]. It might also facilitate the mobilization of nutrient to the fruits, augmenting the yield of nutritious fruit. Additionally, the results concur with those reported in [49]. Boron is also relevant in the biosynthesis of auxin in the meristem of plants. A boron deficiency leads to decreased levels of bound auxin and a reduction in IAA oxidase activity [50]. The marketable fruits represent the number of fruits excluding cracked and pest- and disease-affected fruit. The results of the authors of [51], who found that applying boron greatly decreased the amount of fruit cracking, provided complete support for the data we gave on fruit cracking in litchi in our experiment. The application of Boron has also been shown to reduce fruit cracking in litchi, according to [52,53]. The presence of boron, zinc, and other micronutrients influences the uptake of water and solutes. In the case of enhanced water uptake, solutes accumulate in the fruits and minimize the pressure on the skin, resulting in less cracking. Auxin stimulation brought about by the use of bioregulators may be the cause of the quicker accumulation of building blocks and the improved source–sink relationship, which results in higher fruit setting, retention, and less cracking.

The application of 1% humic acid followed by 1.5% humic acid improved the percentage of fruit setting and fruit retention in litchi and decreased the fruit drop percentage. Humic acid in the soil acts as a chelating agent, making already present nutrients in the soil available to plants. The findings of this investigation are parallel with those of [54], in which the influence of humic acid on pomegranates was investigated, and it was found that higher amounts of humic acid contributed to higher percentages of fruit setting and fruit retention. Additionally, they observed that with the increased application of humic acid, the percentage of fruit drop decreased. Humic acid has also been shown to have a significant beneficial effect on grapes [55] and pears [56,57].

The litchi plants treated with 0.3% Borax yielded fruits with increased fruit weight and size (both length and width). The application of boron directly accelerates the processes of cell division and elongation, which may be the cause of enhanced fruit size and fruit weight in litchi. Fruits grew larger because of their faster development and increased food material mobilization from the production site to the storage organs as a result of the applied nutrients. A similar result was observed in litchi after boron treatment and has already been reported [58]. The current results further support the findings of the authors of [59], who found no discernible variations in the fruits' vertical diameter, transverse diameter, lateral diameter, and fruit shape index among fruits of all treatments and their control. These results are in conformity with those reported by [60] in guava and by [61,62] in litchi. The increase in fruit weight might be due to the rapid increase in the size of cells, or it may also due the fact that the foliar application of boron eventually increased the fruit weight by maintaining lower levels of auxins in various parts of the fruit which helped in increasing the growth rate of the fruit [62].

The highest aril weight and lowest seed weight was observed in plants treated with 0.3% Borax. The application of boron increased the weight of the aril and decreased the weight of the seed, resulting in a high aril/seed ratio. These results are consistent with those of [61] in litchi and those of [32] in apricot. The aril weight also depends on the fruit and seed size [63] but is also affected by plant nutrition [64]. Boron treatments resulted in the production of fruits with smaller seed. This may be due to involvement of boron in the metabolism of IAA which reduces seed size. The decrease in seed weight may be due to the fact that auxin induced a parthenocarpic effect to some extent, thereby resulting in a reduced seed weight [65].

The ratio between the weight of the aril to the weight of the seed is known as the aril/seed ratio. Fruits collected from boron-treated plants had the highest aril/seed ratio, while fruits that were not treated had the lowest ratio. This is related to the fact that the application of boron enhanced the pulp weight and reduced the stone weight which, as a consequence, resulted in a high pulp/stone ratio [61]. Similar findings were obtained by [25,66] in litchi.

The foliar application of Borax resulted in a higher TSS and lower acidity in litchi cv. Bombai. The application of Borax also improved the total sugar and reducing sugar contents. This is in accordance with the results of the authors of [67], who found that applying boric acid prior to harvest increased the TSS, total sugar content, and reducing sugar content, and decreased the titratable acidity. The data presented on the acidity of litchi was fully supported with the findings of the authors of [68] who observed that foliar spraying with boric acid reduced acid levels in the fruits of litchi. Lower acidity in fruits might be due to increased sugar buildup, improved sugar release into fruit tissues, and the conversion of organic acids to sugars [69]. Another possible cause for limiting the titratable acidity might also be due to fast acid consumption of organic acids during respiration. The higher TSS/acid ratio and ascorbic acid content were obtained in litchi due to the foliar application of 0.3% Borax followed by1.5% humic acid and 1% humic acid to litchi. Similar results were also reported by the authors of [70], who found that spraying litchi fruits with 0.5% or 1% Borax enhanced the TSS and lowered the acidity. It was also discovered that while the acidity was lowest, a 0.4% Borax spray increased the TSS, sugar, and ascorbic acid levels in litchi cv. Purvi [68].

The highest total fruit yield and marketable fruit yield were recorded in plants treated with 0.3% Borax (T_2) among the other nutrient treatments applied to litchi. From a quality point of view, the same treatment, i.e., 0.3% Borax (T_2), was found to be the best, resulting in a higher TSS, lower acidity, higher ascorbic acid content, etc. Regarding the bioregulator treatments, the plants treated with0.1% seaweed extract (T_{10}) and 0.5% seaweed extract (T_9) produced the highest total fruit yield. However, the highest marketable yield was recorded in plants treated with 1% humic acid (T_8).

5. Conclusions

Determining the effectiveness of applying nutrients and bioregulators to enhance fruit yield and quality in litchi was the primary objective of this study. During both the two years studied, all the treatments increased the fruit yield and yield-attributing parameters such as fruit weight, fruit width, and fruit length in litchi when compared to the control. The highest total fruit yield was recorded (38.44 kg/plant) in plants treated with 0.3% Borax (T_2) followed by plants treated with0.1% seaweed extract (T_{10}) with 36.68 kg per plant and0.5% seaweed extract (T_9) with 36.41 kg per plant. However, the highest marketable yield (35.34 kg per plant) was recorded in plants treated with 0.3% Borax (T_2) followed by 0.5% zinc sulphate (T_4) (with 29.56 kg per plan) and 1% humic acid (T_8) with 28.39 kg per plant. The increase in fruit weight and the number of fruits per plant, along with other fruit-related physical attributes, might be responsible for the yield improvement. Additionally, it was discovered that foliar spraying with 0.3% Borax (T_2) was superior in improving certain quality parameters such as total soluble solids (14.07^0Brix), total sugar content (10.40%), and ascorbic acid (32.06 mg per 100 g edible portion). The improvement of fruit quality may be attributed to better growth of plants with different treatments of humic acid which might have favored the production of better-quality fruit. The increase in the fruit yield might also be due to the accumulation of sugars and other soluble solids in the fruits.

On the basis of the above findings, it may be concluded that among the nutrients studied, 0.3% Borax (T_2), 0.1% seaweed extract (T_{10}), and 1% humic acid (T_8) were found to be superior treatments among the bioregulators that can be recommended for improving the yield and quality parameters of litchi cv. Bombai. However, for further studies, combinations of these nutrients and bioregulators should be studied to obtain the best result.

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References

1. Menzel, C.M. *Plant Resources of South East Asia. No. 2*; Edible Fruit and Nuts; Verheij, E.W.M., Coronel, R.E., Eds.; Pudoe: Wageningen, The Netherlands, 1991; 191p.
2. Raghavan, M.; Hazarika, B.N.; Susmita, D.; Ramjan, M.; Langstieh, L.B. Integrated nutrient management in litchi (*Litchi chinensis* Sonn.) cv. Muzaffarpur for yield and fruit quality at foothills of Arunachal Pradesh. *Int. J. Chem. Stud.* **2018**, *6*, 2809–2812.
3. Mozumder, S.N.; Faisal, S.M.; Sultana, D.; Firoz, Z.A. Effect of Growth Regulator and Irrigation on Fruit Cracking and Yield of Litchi in the Hilly Area. *Int. J. Adv. Innov. Res.* **2016**, *5*, 104–108.
4. Deng, X.P.; Han, Z.H.; Li, S.H. *Fruit Tree Biology*; Higher Education Press: Beijing, China, 1999.
5. Kumar, D.; Mishra, D.S.; Chakraborty, B.; Kumar, P. Pericarp browning and quality management of litchi fruit by antioxidants and salicylic acid during ambient storage. *J. Food Sci. Technol.* **2011**, *50*, 797–802. [CrossRef] [PubMed]
6. Saxena, S.; Hajare, S.N.; More, V.; Kumar, S.; Wadhawan, S.; Parte, M.N.P. Antioxidant and radio protective properties of commercially grown litchi (*Litchi chinensis*) from India. *Food Chem.* **2011**, *126*, 39–45. [CrossRef]

7. Kumari, P.; Kumar, P.; Karuna, K.; Aftab, A.; Kumar, A.; Ahmad, F. Effect of Pre-harvest Salicylic Acid Spray on Shelf Life and Biochemical Changes of Litchi during Storage. *Curr. J. Appl. Sci. Technol.* **2023**, *42*, 59–65. [CrossRef]
8. Marschner, H. *Mineral Nutrition of Higher Plants*; Academic Press Limited Harcourt Brace and Company: London, UK, 2012; pp. 347–364.
9. Singh, O.P.; Phogat, K.P.S. Effect of plant growth regulators on fruit drop, size and quality of litchi cv. Calcuttia. *Punjab Hortic. J.* **1984**, *24*, 83–88.
10. Menzel, C.M.; Simpson, D.R. Lychee nutrition: A review. *Sci. Hortic.* **1987**, *31*, 195–224. [CrossRef]
11. Shukla, P.S.; Shotton, K.; Norman, E.; Neily, W.; Critchley, A.T.; Prithiviraj, B. Seaweed extract improve drought tolerance of soybean by regulating stress-response genes. *AoB Plants* **2018**, *10*, plx051. [CrossRef] [PubMed]
12. Okolie, C.L.; Mason, B.; Critchley, A.T. Seaweeds as a source of proteins for use in pharmaceuticals and high-value applications. In *Novel Proteins for Food, Pharmaceuticals, and Agriculture: Sources, Applications, and Advances*; Hayes, M., Ed.; Wiley: Hoboken, NJ, USA, 2018; 217p.
13. Davarpanaha, S.; Tehranifara, A.; Abadíab, J.; Valb, J.; Davarynejada, G.; Aranc, M.; Khorassanid, R. Foliar calcium fertilization reduces fruit cracking in pomegranate (*Punica granatum* cv. Ardestani). *Sci. Hortic.* **2018**, *230*, 86–91. [CrossRef]
14. Ram, R.A.; Bose, T.K. Effect of foliar application of of magnesium and micronutrients on growth, yield and fruit quality mandarin orange (*Citrus reticulata* Blanco.). *Indian J. Hortic.* **2000**, *57*, 215–220.
15. Priyadarshi, V.; Hota, D.; Karna, A.K. Effect of Growth Regulators and Micronutrients Spray on Chemical Parameters of Litchi (*Litchi chinensis* Sonn.) cv. Calcuttia. *Int. J. Econ. Plants* **2018**, *5*, 99–103. [CrossRef]
16. Nardi, S.; Schiavon, M.; Francioso, O. Chemical structure and biological activity of humic substances define their role as plant growth promoters. *Molecules* **2021**, *26*, 2256. [CrossRef]
17. Yang, F.; Tang, C.; Antonietti, M. Natural and artificial humic substances to manage minerals, ions, water, and soil microorganisms. *Chem. Soc. Rev.* **2021**, *50*, 6221–6239. [CrossRef] [PubMed]
18. Begum, M.; Bordoloi, B.C.; Singha, D.D.; Ojha, N.J. Role of seaweed extract on growth, yield and quality of some agricultural crops: A review. *Agric. Rev.* **2018**, *39*, 321–326. [CrossRef]
19. Khan, A.S.; Ahmad, B.; Jaskani, M.J.; Ahmad, R.; Malik, A.U. Foliar application of mixture of amino acids and seaweed (*Ascophylum nodosum*) extract improve growth and physico-chemical properties of grapes. *Int. J. Agric. Biol.* **2012**, *14*, 383–388.
20. Mosa, W.F.; Sas-Paszt, L.; Górnik, K.; Ali, H.M.; Salem, M.Z. Vegetative growth, yield, and fruit quality of guava (*Psidium guajava* L.) cv. maamoura as affected by some biostimulants. *Bioresources* **2021**, *16*, 7379–7399. [CrossRef]
21. Ashour, M.; El-Shafei, A.A.; Khairy, H.M.; Abd-Elkader, D.Y.; Mattar, M.M.; Alataway, A.; Hassan, S.M. Effect of *Pterocladia capillacea* seaweed extracts on growth parameters and biochemical constituents of Jew's Mallow. *Agronomy* **2020**, *10*, 420. [CrossRef]
22. Sarkar, G.K.; Sinha, M.M.; Misra, R.S. Effect of NAA on fruit set, fruit drop, cracking, fruit size and quality in litchi cv. Rose Scented. *Progress. Hortic.* **1984**, *16*, 301–304.
23. Bhat, S.K.; Raina, B.L.; Chogtu, S.K.; Muthoo, A.K. Effect of exogenous auxin application on fruit drop and cracking of litchi (*Litchi chinensis* Sonn.) cv. Dehradun. *Adv. Plant Sci.* **1997**, *10*, 83–86.
24. Brahmachari, V.S.; Rani, R. Effect of growth substances on fruit drop, yield and physico-chemical composition of litchi fruits. *Progress. Hortic.* **2001**, *32*, 50–55.
25. Awasthi, R.P.; Tripathi, B.R.; Singh, A. Effect of foliar sprays of zinc on the fruit drop and quality of the litchi. *Punjab Hortic. J.* **1975**, *15*, 14–16.
26. Menzel, C.M.; Simpson, D.R. Lychee cultivars: Description and performance of major litchi cultivars in sub-tropical Queensland. *Qld. Agric. J.* **1986**, *112*, 126–136.
27. Kanwar, J.S.; Njjar, G.S. Litchi cultivation in the Punjab problem and prospect. *Punjab Hortic. J.* **1975**, *15*, 9–13.
28. Ahmed, Y.M.; Shalaby, E.A. Effect of different seaweed extracts and compost on vegetative growth, yield and fruit quality of cucumber. *J. Hortic. Sci. Ornam. Plants* **2012**, *4*, 235–240.
29. Hamed, S.M.; Abd El-Rhman, A.A.; Abdel-Raouf, N.; Ibraheem, I.B.M. Role of marine macroalgae in plant protection & improvement for sustainable agriculture technology. *Beni Suef Univ. J. Basic Appl. Sci.* **2018**, *7*, 104–110.
30. AOAC International. A.O.A.C. Official methods of analysis. In *Association of Official Analytical Chemists*, 20th ed.; Benjamin Franklin Station: Washington, DC, USA, 2016.
31. Priyadarshi, V.; Mehta, K.; Hota, D.; Mishra, G.; Jogur, A. Effect of growth regulators and micronutrients spray on vegetative growth of litchi (*Litchi chinensis* Sonn.) cv.Calcuttia. *Agric. Update* **2018**, *12*, 707–712. [CrossRef]
32. Rangana, S. *Handbook of Analysis and Quality Control for Fruit and Vegetable Products*, II ed.; Tata McGraw-Hill Publ. Co.: New Delhi, India, 1986.
33. Panse, V.G.; Sukhatme, P.V. *Statistical Methods for Agricultural Workers*; Indian Council of Agricultural Research: New Delhi, India, 1989; pp. 152–165.
34. Massay, W.F. Principal components regression in exploratory statistical research. *J. Am. Stat. Assoc.* **1965**, *60*, 234–246. [CrossRef]
35. Jolliffie, I.T. *Principal Component Analysis*; Springer: New York, NY, USA, 1986.
36. Brijpal, B.; Tiwari, J.P.; Mishra, K.K.; Lal, S. Effect of Zinc Sulphate on Vegetative Growth, Yield and Leaf Nutrient Status of Guava (*Psidium guajava* L.). *Int. J. Curr. Microbiol. App. Sci.* **2020**, *9*, 1265–1273.

37. Sharma, R.K.; Thakur, S.; Kumar, R. A note on the effect of foliar feeding of zinc and GA on fruiting of guava trees (*Psidium guajava* L.). *Haryana J. Hort. Sci.* **1993**, *22*, 207–208.
38. Nurbhanje, K.H.; Varu, D.K. Effect of biostimulant and biofertilizers on flowering and fruiting of pomegranate (*Punica granatum* L.) cv.Bhagwa. *Int. J. Chem. Stud.* **2019**, *7*, 378–382.
39. Bybordi, A.; Ebrahimian, E. Growth, yield and quality components of canola fertilized with urea and zeolite. *Commun. Soil Sci. Plant Anal.* **2013**, *44*, 2896–2915. [CrossRef]
40. Rana, V.S.; Sharma, V.; Sharma, S.; Rana, N.; Kumar, V.; Sharma, U.; Almutairi, K.R.; Avila-Quezada, G.D.; Abd_Allah, E.F.; Gudeta, K. Seaweed Extract as a biostimulant agent to enhance the fruit Growth, yield, and quality of Kiwifruit. *Horticulturae* **2023**, *9*, 432. [CrossRef]
41. Margal, P.B.; Thakare, R.S.; Kamble, B.M.; Patil, V.S.; Patil, K.B.; Titirmare, N.S. Effect of Seaweed Extracts on Crop Growth and Soil: A Review. *J. Exp. Agric. Int.* **2023**, *45*, 9–19. [CrossRef]
42. El-Khawaga, A.S. Partial replacement of mineral N fertilizers by Using humic acid and Spirulina platensis algae biofertilizer in Florida Prince peach orchards. *Middle East J. Appl. Sci.* **2011**, *1*, 5–10.
43. Fathi, M.A.; Eissa, F.M.; Yehia, M.M. Improving growth, yield and fruit quality of Desert Red peach and Anna apple by using some biostimulants. *Minia J. Agric. Res. Develop.* **2002**, *22*, 519–534.
44. Kabeel, H.; Abd El-Atif, F.M.; Baza, M.S.M. Growth, fruiting and nutritional status of "Le-Conte"pear trees in response to mineral and humate fertilizers. *Ann. Agric. Sci. Moshtohor.* **2008**, *46*, 139–156.
45. Parr, A.J.; Loughman, B.C. Boron and membrane functions in plants. In *Metals and Micronutrients Uptake and Utilization by Plants*; Annual Proceedings of the Phytochemical Society of Europe No. 21; Roff, D.A., Pirepoint, W.S., Eds.; Academic Press: London, UK, 1983; pp. 87–107.
46. Rajput, C.B.S.; Chand, S. Significance of boron and zinc in guava (*Psidium guajava* L.). *Bangladesh Hort.* **1975**, *3*, 22–27.
47. Singh, S.; Singh, J.P. Effect of foliar sprays of NAA and boron on flowering, fruiting, fruit retention and yield of litchi (*Litchi chinensis* Sonn.). *Int. J. Chem. Stud.* **2019**, *7*, 1995–1999.
48. Russel, D.A. Boron and Soil fertility. In *The Year Book of Agriculture*; U.S.D.A.: Washington, DC, USA, 1957.
49. Banyal, A.K.; Rangra, A.K. Response of yield and quality attributes of litchi cv. Dehradun to soil and foliar application of boron. *J. Hill Agric.* **2011**, *2*, 33–37.
50. Dugger, W.M. Boron in plant metabolism. In *Encyclopedia of Plant Physiology*; Lalichli, A., Bieleski, R.L., Eds.; Springer: Berlin/Heidelberg, Germany, 1968; Volume 5B, pp. 628–650.
51. Sharma, N.; Belsare, C. Effect of Plant Bio-Regulators and Nutrients on Fruit Cracking and Quality in Pomegranate (*Punica granatum* L.) 'G-137′ in Himachal Pradesh. *Acta Hortic.* **2011**, *890*, 347–352. [CrossRef]
52. Brahmachari, V.S.; Kumar, R. Effect of foliar sprays of mineral nutrients on fruit set retention and cracking in litchi (*Litchi chinensis* Sonn.) fruits. *Haryana J. Hortic. Sci.* **1997**, *26*, 177–180.
53. Babu, N.; Singh, A.R.; Babu, N. Effect of micronutrients spray on fruit cracking and fruit maturity in litchi (*Litchi chinensis* Sonn.) fruits. *Indian Agric.* **2002**, *46*, 203–204.
54. Khattab, M.M.; Shaban, A.E.; El-Shrief, A.; Mohamed, A. Effect of humic acid and amino acids on pomegranate trees under deficit irrigation. I: Growth, flowering and fruiting. *J. Hortic. Sci. Ornam. Plants* **2012**, *4*, 253–259.
55. Omar, A.H.; Abdelall, A.H. Influence of sulphuric acid, humic acid, sulphur and irrigation water on growth and productivity of Superior seedless vines grown under saline condition. *J. Agric. Sci.* **2005**, *30*, 6951–6961. [CrossRef]
56. Ismail, M.; Wanden, M.T.; EI-Sheikh, M. Response of 'Thompson seedless' and 'Roomy Red' grape cultivars to foliar sprays with yeast extract and GA. *J. Agric. Sci.* **2003**, *28*, 6321–6334.
57. Sanchez-Sanchez, A.; Sanchez-Andreu, J.; Jorda, J.; Bermudez, D. Humic substances and amino acids improve effectiveness of chelate Fe EDDHA in lemon trees. *J. Plant Nutr.* **2002**, *25*, 2433–2442. [CrossRef]
58. Kumar, M.; Kumar, R.; Singh, R.P. Effect of micronutrients and plant growth regulators on fruiting of litchi. *Int. J. Agric. Sci.* **2009**, *5*, 521–524.
59. Xu, W.P.; Wang, L.; Yang, Q.; Wei, Y.H.; Zhang, C.X.; Wang, S.P. Effect of Calcium and Boron on the Quality of Kiwifruit. *Acta Hortic.* **2015**, *1096*, 317–320. [CrossRef]
60. Gaur, B.; Beer, K.; Hada, T.S.; Kanth, N.; Syamal, M.M. Studies on the effect of foliar application of nutrients and GA3 on fruit yield and quality of winter Season Guava. *Ecoscan* **2014**, *6*, 479–483.
61. Singh, N.; Kaur, A.; Gill, B.S. Effect of foliar application of zinc and boron on yield and fruit quality of litchi cv. Dehradun. *Int. J. Dev. Res.* **2016**, *6*, 8686–8688.
62. Haq, I.; Rab, A.; Sajid, M. Foliar application of calcium chloride and borax enhance the fruit quality of litchi cultivars. *Anim. Plant Sci.* **2013**, *23*, 1385–1390.
63. Li, J.G.; Huang, H.B.; Gao, F.F.; Huang, X.M.; Wang, H.C. An overview of litchi fruit cracking. *Acta Hortic.* **2008**, *558*, 205–208. [CrossRef]
64. Kazuhiro, I.; Masashi, M.; Hiroyuki, F. The effect of spraying of calcium to the fruit quality the quality keeping period and the tree vigour of Kousui in green house. *Bull. Saga Prefect. Fruit Tree Exp. Stn.* **2004**, *15*, 8–14.
65. Singh, R.; Godara, N.R.; Singh, R.; Dahiya, S.S. Responses of foliar application of growth regulators and nutrients on ber cv. Umran. *Haryana J. Hort. Sci.* **2001**, *30*, 161–164.

66. Brahmachari, V.S.; Yadav, G.S.; Kumar, N. Effect of foliar feeding of calcium, zinc and boron on field and quality attributes of litchi (*Litchi chinensis* Sonn.). *Orissa J. Hortic.* **1997**, *25*, 49–52.
67. Alila, P.; Achumi, I. Pre-harvest chemical treatments affect post-harvest quality of litchi fruit. *Acta Hortic.* **2012**, *934*, 755–762. [CrossRef]
68. Misra, A.R.; Khan, I. Trichloro phenoxy acetic acid and micronutrient on fruit size, cracking, maturity quality of litchi cv. Rose Scented. *Progress. Hortic.* **1981**, *13*, 87–90.
69. Soppelsa, S.; Kelserer, M.; Casera, C.; Bassi, M.; Robatscher, P.; Andreotti, C. Use of biostimulants for organic apple production. Effects on tree growth, yield and fruit quality at harvest and during storage. *Front. Plant Sci.* **2018**, *9*, 1342. [CrossRef] [PubMed]
70. Nath, S.; Kumar, M.; Ojha, O.K.; Jha, K.K. Yield and physico-chemical properties of litchi fruits as affected by different rates of pruning and chemical spray. *Progress. Hortic.* **2012**, *44*, 166–169.