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Effect of plant growth regulators and nutrient- based seed treatments on germination and seedling vigour of Acid Lime (*Citrus aurantifolia* swingle) cv. Kagzi Lime under shade-net house

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Abstract
An investigation was conducted during 2024–2025 at Pt. Kishori Lal Shukla College of Horticulture and Research Station, Rajnandgaon, Chhattisgarh, to evaluate the effect of different plant growth regulators and nutrients on seed germination and seedling growth of Acid lime (*Citrus aurantifolia* Swingle) cv. Kagzi lime under shade-net conditions. The experiment was laid out in a Completely Randomized Design with 13 treatments comprising various concentrations of GA_3, NAA, KNO_3 and thiourea, replicated thrice. Significant variations were observed among treatments for all germination indices and seedling vigour parameters. GA_3 @200 ppm consistently outperformed other treatments, recording the minimum days to germination (20.93 days) and 50% germination (23.60 days), along with the highest germination percentage (90%). It also produced the maximum seedling vigour index-I (3892.56) and seedling vigour index-II (1090.31). The untreated control exhibited delayed germination (30.73 and 37.73 days respectively) and the lowest germination percentage (60%). The results demonstrate that GA_3 @ 200 ppm is highly effective for improving germination behaviour and enhancing early seedling growth of Acid lime under protected nursery conditions.

Keywords: Acid lime, Seedling vigour index, Germination, GA_3, NAA, KNO_3, Thiourea etc.

Introduction

Citrus is the third largest fruit industry in India, which ranks sixth globally in citrus production. The group includes mandarins, oranges, lemons, limes, grapefruits and hybrids, and the North Eastern Region is a major centre of origin and diversity (Ghosh, 2007). Citrus fruits are valued for flavour, colour and high vitamin-C content, and serve both as commercial crops and rootstocks. Acid lime (*Citrus aurantifolia* Swingle) is the third most important citrus crop after mandarin and sweet orange, widely grown in tropical and subtropical regions (Chadha, 2003). It occupies 1.3 million ha worldwide, with India contributing 23.5% (Anonymous, 2022). Major producing states are Andhra Pradesh, Maharashtra, Karnataka, Tamil Nadu and Gujarat; in Chhattisgarh it covers 12.10 thousand ha with 102.21 thousand MT output (Anonymous 2023–24). The fruits are small, thin-rinded, greenish-yellow and polyembryonic (Abhilash *et al.*, 2018). Flowering occurs year-round, mainly during Ambe (Feb–Mar), Mrig (Jul–Aug) and Hasta (Sep–Oct) bahar, of which Hasta is most remunerative (Bagale *et al.*, 2024). Acid lime has wide culinary, medicinal and industrial use and is rich in vitamin-C and antioxidants with digestive and metabolic benefits (Mohanapriya *et al.*, 2013) [12].

Seed propagation is widely adopted due to polyembryony, ensuring true-to-type and vigorous seedlings (Khatana *et al.*, 2015) [9]. However, germination is slow and irregular (27–58%) with high early mortality due to seed-coat barriers and inhibitors (Jaiswal *et al.*, 2018) [8]. Pre-sowing treatments can overcome these limitations: GA_3 enhances enzymatic mobilisation of reserves (Panda *et al.*, 2018), NAA stimulates cell division and root development (Shivare *et al.*, 2023) [15], KNO_3 releases dormancy and improves seedling growth, and thiourea also breaks dormancy. Such treatments significantly improve germination, seedling vigour and stress tolerance in citrus

(Krishnaveni *et al.*, 2010) [10].

Materials and Methods

The investigation was carried out during the year 2024–2025 at Pt. Kishori Lal Shukla College of Horticulture and Research Station, Rajnandgaon, Chhattisgarh. The experiment was conducted on Acid lime under a shade-net house. The experiment was laid out in a Completely Randomized Design (CRD) comprising 13 treatments, each replicated three times, with 60 seeds per treatment. The treatments consisted of: T_0 – Control (water-soaked), T_1 – GA_3 @ 100 ppm, T_2 – GA_3 @ 200 ppm, T_3 – GA_3 @ 300 ppm, T_4 – NAA @ 50 ppm, T_5 – NAA @ 100 ppm, T_6 – NAA @ 150 ppm, T_7 – KNO_3 @ 1%, T_8 – KNO_3 @ 2%, T_9 – KNO_3 @ 3%, T_{10} – Thiourea @ 1%, T_{11} – Thiourea @ 2%, and T_{12} – Thiourea @ 3%. Mature, healthy and true-to-type Kagzi lime fruits were collected, and the extracted seeds were washed and shade-dried for 12 hours. A potting mixture of soil, sand and FYM (1:1:1) was filled uniformly into perforated 6" × 12" polythene bags. Working solutions of GA_3, NAA, thiourea and KNO_3 were prepared as per standard procedures, and uniform seeds were soaked for 12 hours in their respective solutions, while control seeds were soaked in distilled water. Treated seeds were sown and the bags were arranged according to the layout. Uniform cultural practices—including irrigation, weeding, insecticidal sprays for caterpillar and leaf miner were followed throughout. Observations were recorded at regular intervals on germination parameters, viz. days required for germination, days required for 50% germination and germination percentage. Seedling vigour indices (SVI-I and SVI-II) were computed as per standard procedures and the data were statistically analysed to determine significant differences among treatments.

Results and Discussion

Days required for seed germination

A significant variation in days required for germination was observed among the treatments. The earliest germination occurred in T_2 –GA_3 @ 200 ppm (20.93 days), which was significantly superior over all other treatments. This was followed by T_3 –GA_3 @ 300 ppm (22.53 days), T_6 –NAA @ 150 ppm (22.86 days) and T_1 – GA_3 @ 100 ppm (23.26 days), which were statistically at par. Several treatments, including T_1 & T_5, T_5 & T_9, T_9 & T_4, T_4 & T_8, T_8 & T_{12}, T_{12} & T_7, T_7 & T_{11} and T_{11} & T_{10}, showed non-significant differences, indicating similar germination responses. The maximum number of days for germination was recorded in T_0 (control, 30.73 days). The superiority of GA_3 @ 200 ppm in promoting early germination might be due to its role in enhancing hydrolytic enzyme activity, facilitating rapid mobilization of food reserves and promoting early radicle emergence. GA_3 also supports cell elongation and division, thereby creating favourable conditions for faster germination. These findings align with earlier reports by Jadhav *et al.*, (2019) [7] in rangpur lime, Yadav *et al.*, (2020) [17] in rangpur lime.

Days required for 50% seed germination

A significant variation was observed among the treatments for days required for 50% germination. The earliest 50% germination was recorded in T_2 (GA_3 @ 200 ppm) with 23.60 days, which was statistically at par with T_3 (24.40 days) and T_1 (26.06 days) and significantly superior over all remaining treatments. Several treatments exhibited non-significant differences among themselves, indicating comparable germination behaviour. The maximum number of days for 50% germination (37.73 days) was observed in the control (T_0 – Water-soaked seeds), clearly indicating delayed germination in untreated seeds. The enhanced response of GA_3, particularly at 200 ppm, might be associated with its role in stimulating hydrolytic enzyme activity, ensuring faster mobilization of stored reserves and promoting early radicle emergence. Similar results were reported by Yadav *et al.* (2020) [17] in rangpur lime, and Aishwarya *et al.* (2024) [2] in acid lime, supporting the superiority of GA_3 treatments for early germination.

Germination percentage

A significant influence of treatments on germination percentage was recorded under the different treatments. The highest germination (90%) occurred in T_2 (GA_3 @ 200 ppm), which was statistically at par with T_3 (GA_3 @ 300 ppm) registering 88.33% germination. Several treatments exhibited non-significant differences among themselves, indicating comparable germination behaviour, while T_7 (KNO_3 @ 1%) showed a significantly lower response than all other treatments. The minimum germination percentage (60%) was observed in the control (T_0 –Water-soaked seeds). The superior germination in GA_3-treated seeds may be due to enhanced hydrolytic enzyme activity, especially α-amylase, which ensures rapid mobilization of stored carbohydrates and supports early embryo growth. GA_3 is also known to counteract ABA-mediated inhibition, activate metabolic pathways and promote cell elongation and division, resulting in faster and more uniform germination. Similar promotive effects of GA_3 on germination percentage have been reported by Patel *et al.* (2024) [14] in wood apple and Kumar *et al.* (2025) [11] in papaya.

Seedling vigour index-I

Seedling vigour index-I varied significantly among the treatments. The maximum value (3892.56 cm) was obtained in T_2 –GA_3 @ 200 ppm, which remained statistically at par with T_3 – GA_3 @ 300 ppm (3677.53 cm). A sequence of non-significant differences was also observed among the treatments T_3 & T_6, T_6 & T_1, T_1, T_5, T_4 & T_9, T_9 & T_{12}, T_{12} & T_8, T8, T_{11} & T_{10}, and T_{10} & T_7, indicating similarity in their responses at the 5% level of significance. The lowest seedling vigour index-I (1666.40 cm) was recorded in the control (T_0 – water soaked). The marked improvement under GA_3 treatments, indicates its positive role in enhancing physiological vigour through accelerated enzymatic activity, efficient mobilization of stored reserves and rapid elongation of root and shoot during germination. Similar results were also reported by Solanki *et al.* (2018) [16] in papaya.

Table 1: Effect of Plant Growth Regulators and Nutrient-Based Seed Treatments on days required for seed germination, days required for 50% germination and germination percentage of Acid Lime (*Citrus aurantifolia* Swingle) cv. Kagzi Lime under Shade-Net House.

Treatments	Days required for seed germination	Days required for 50% seed germination	Germination percentage
T_0-Control (Water soaked)	30.73^{j}	37.73^{h}	60.00^{k}
T_1- GA_3 @ 100ppm	23.26^{bc}	26.06^{ab}	86.67^{bc}
T_2-GA_3 @200 ppm	20.93^{a}	23.60^{a}	90.00^{a}
T_3 -GA_3 @300ppm	22.53^{b}	24.40^{a}	88.3^{ab}
T_4 -NAA @ 50 ppm	25.40^{e}	28.66^{bcd}	81.67^{ef}
T_5-NAA @ 100 ppm	24.13^{cd}	28.00^{bc}	83.33^{de}
T_6-NAA @ 150 ppm	22.86^{b}	27.13^{b}	85.00^{cd}
T_7-KNO3 @1%	27.93^{gh}	32.80^{efg}	63.33^{j}
T_8-KNO3 @2%	26.73^{f}	31.20^{def}	75.00^{h}
T_9-KNO3 @3%	25.00^{de}	30.26^{cde}	80.00^{fg}
T_{10}- Thiourea @ 1%	29.80^{i}	34.53^{g}	71.67^{i}
T_{11} -Thiourea @ 2%	28.73^{h}	33.33^{fg}	73.33^{hi}
T_{12} -Thiourea @ 3%	27.80^{g}	32.20^{efg}	78.33^{g}
SE(m) ±	0.30	0.84	3.58
SE(d)	0.42	1.19	7.40
C.D.@ 5%	0.87	2.61	2.53
C.V	2.01	4.28	5.61

*The superscript letter indicates that the treatment means with same letters are at par at 5% level of significance, while the means with different letters are significantly different at 5% level of significance. These letters have been affixed based on CD-value comparison of treatment means.

Seedling vigour index- II

Seedling vigour index-II was significantly influenced by the different plant growth regulators and nutrient treatments. The highest value (1090.31 g) was obtained in T_2 –GA_3 @ 200 ppm, which remained statistically at par with T_3–GA_3 @ 300 ppm (1016.61 g). A sequence of non-significant differences was observed among the treatment pairs T_3 & T_6, T_6, T_1 & T_5, T_5, T_4, T_9 & T_{12}, and T_8, T_{11} & T_{10}, with their respective vigour index-II values falling within closely comparable ranges. Treatment T_7 (532.23 g) differed significantly from all other treatments, whereas the minimum value (387.20 g) was recorded in the control (T_0 – water soaked), which remained significantly inferior to all other treatments. Overall, seeds treated with GA_3 exhibited markedly higher seedling vigour index-II, reflecting enhanced physiological strength and improved seedling establishment. The promotive effect of GA_3 may be attributed to its ability to activate hydrolytic enzymes, improve reserve mobilization and facilitate cell elongation and division during early seedling development. These results corroborate earlier findings by Shivare *et al.* (2023) [15] in acid lime, who also reported significant improvement in vigour with GA_3 application.

Table 2: Effect of plant growth regulators and nutrient-based seed treatments seedling vigour index -I and seedling vigour index -II of Acid lime cv. Kagzi lime under shade net house

Treatments	Seed vigour index-I	Seed vigour index-II
T_0-Control (Water soaked)	1666.40^{i}	387.20^{g}
T_1- GA_3 @ 100ppm	3368.90^{cd}	918.50^{c}
T_2-GA_3 @200 ppm	3892.56^{a}	1,090.31^{a}
T_3 -GA_3 @300ppm	3677.53^{ab}	1,016.61^{ab}
T_4 -NAA @ 50 ppm	3186.33^{d}	837.55^{d}
T_5-NAA @ 100 ppm	3347.30$_{cd}$	878.53^{cd}
T_6-NAA @ 150 ppm	3527.76^{bc}	946.28^{bc}
T_7-KNO3 @1%	2212.40^{h}	532.23^{f}
T_8-KNO3 @2%	2709.50^{fg}	716.08^{e}
T_9-KNO3 @3%	3083.83^{de}	825.25^{d}
T_{10}- Thiourea @ 1%	2423.86^{gh}	672.96^{e}
T_{11} -Thiourea @ 2%	2552.66^{g}	705.4^{e}
T_{12} -Thiourea @ 3%	2883.06^{ef}	822.58^{d}
SE(m) ±	100.66	26.37
SE(d)	142.36	37.29
C.D.@ 5%	294.25	77.08
C.V	5.88	5.73

*The superscript letter indicates that the treatment means with same letters are at par at 5% level of significance, while the means with different letters are significantly different at 5% level of significance. These letters have been affixed based on CD-value comparison of treatment means.

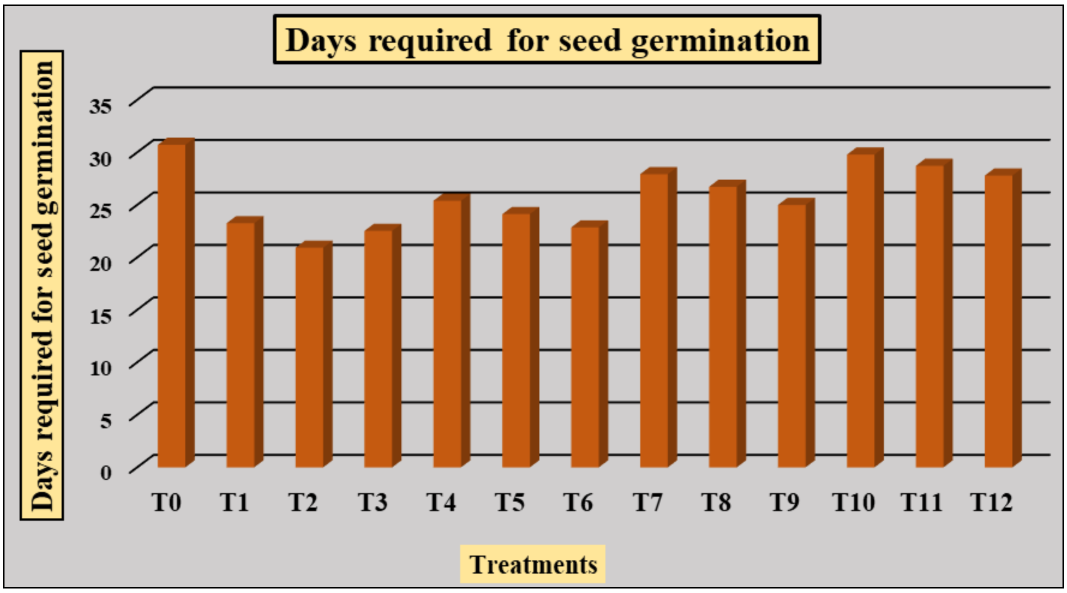

Fig 1: Effect of Plant Growth Regulators and Nutrient-Based Seed Treatments on days required for seed germination of Acid Lime (*Citrus aurantifolia* Swingle) cv. Kagzi Lime under Shade-Net House.

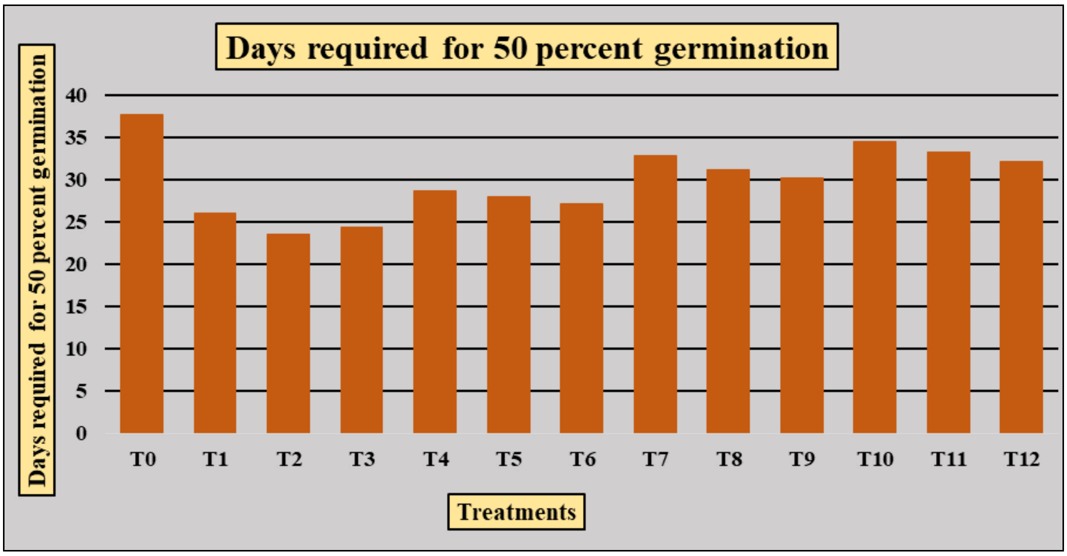

Fig 2: Effect of Plant Growth Regulators and Nutrient-Based Seed Treatments on days required for seed germination of Acid Lime (*Citrus aurantifolia* Swingle) cv. Kagzi Lime under Shade-Net House.

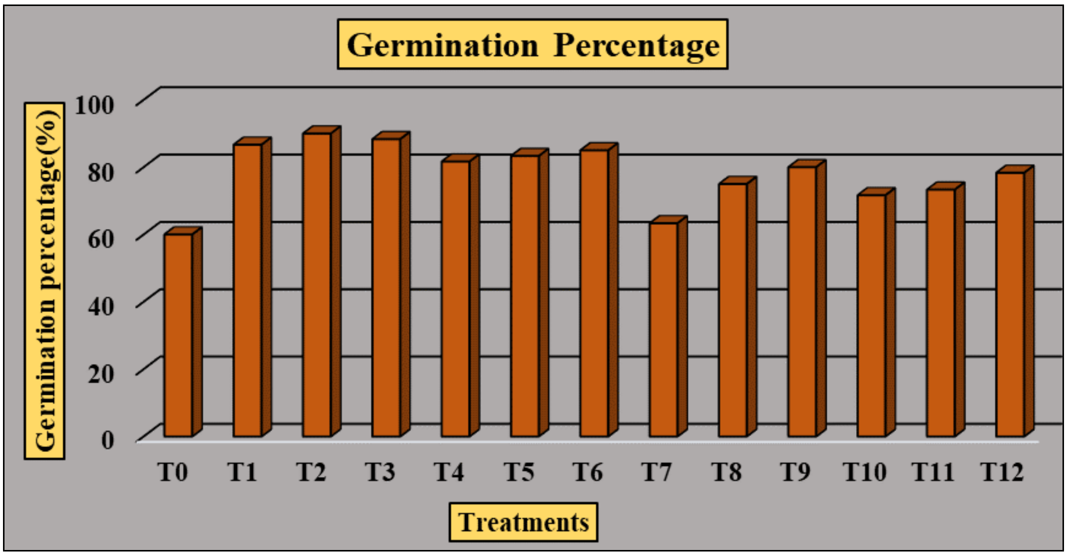

Fig 3: Effect of Plant Growth Regulators and Nutrient-Based Seed Treatments on germination percentage of Acid Lime (*Citrus aurantifolia* Swingle) cv. Kagzi Lime under Shade-Net House.

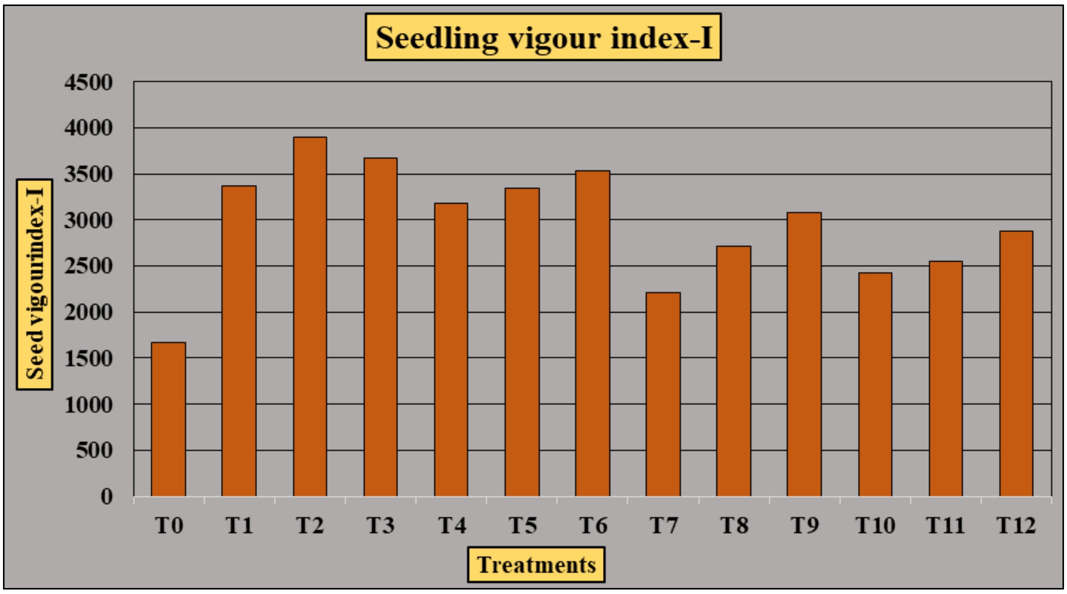

Fig 4: Effect of Plant Growth Regulators and Nutrient-Based Seed Treatments on seedling vigour index-I of Acid Lime (*Citrus aurantifolia* Swingle) cv. Kagzi Lime under Shade-Net House

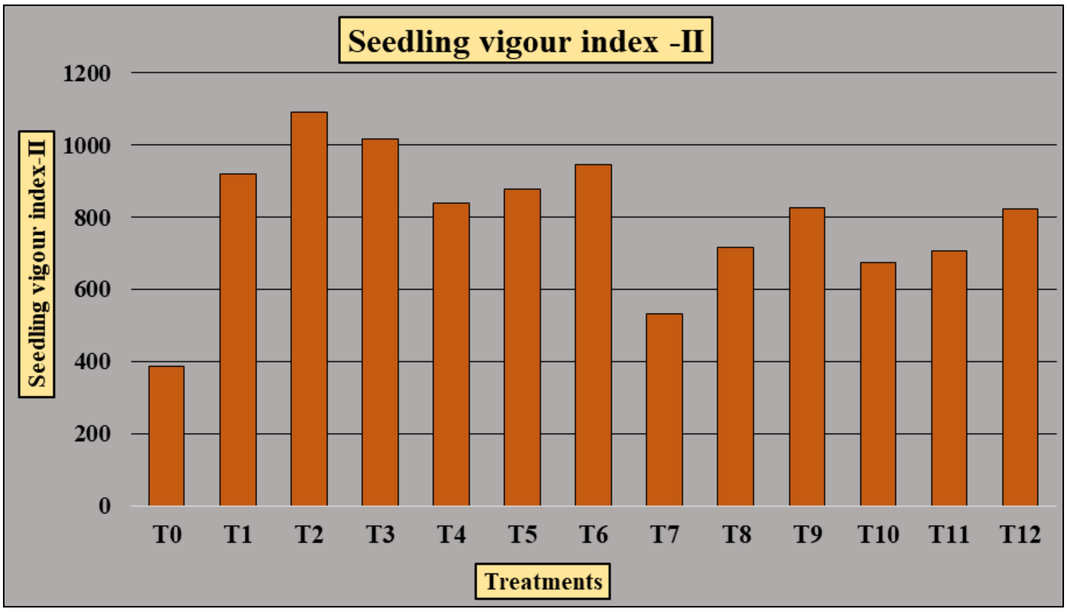

Fig 5: Effect of Plant Growth Regulators and Nutrient-Based Seed Treatments on seedling vigour index-II of Acid Lime (*Citrus aurantifolia* Swingle) cv. Kagzi Lime under Shade-Net House

Conclusion

It can be inferred from the present investigation that different plant growth regulators and nutrient treatments exert a clear influence on the germination behaviour and vigour of acid lime seeds. Among all treatments, GA_3 @ 200 ppm proved most effective, consistently promoting earlier germination, higher germination percentage and superior seedling vigour. The enhanced physiological activity induced by GA_3 significantly improved the overall performance of seedlings, indicating its suitability for achieving vigorous and uniform seedling establishment in acid lime.

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