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Impact of Different Plant Growth Regulators on Growth, Yield and Quality of Fennel (*Foeniculum vulgare* Mill.) in Alluvial Regions of West Bengal

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ABSTRACT

An experiment was conducted during the *rabi* seasons (November, 2018 –April, 2020) at the Horticultural Research Station, Mondouri, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal (741 252), India to assess the impact of different plant growth regulators on the growth, yield, and quality of fennel (*Foeniculum vulgare* Mill.). The experiment was designed in Randomized Block Design with a total of 9 treatment combinations that were replicated three times. Fennel seeds were sown during the first week of November in 2.5×1.5 m^2 plots with a spacing of 50×30 cm^2. Growth regulators were applied at 30, 45, and 60 days after sowing. The results revealed that the application of naphthalene acetic acid @ 100 ppm significantly optimized fennel yield and quality in the alluvial regions of West Bengal. This was evident through various yield and its attributing parameters, including number of umbel $plant^{-1}$, number of umbellate $umbel^{-1}$, number of seeds $umbellate^{-1}$, test weight (g), and seed yield (22.95 q ha^{-1}) as well as quality parameters including total soluble sugar content (2.91 mg 100 mg^{-1}) and volatile oil content (1.448%). Additionally, Kinetin @ 10 parts per million significantly enhanced the total chlorophyll content (0.344 mg g^{-1}), while gibberellic acid positively influenced growth parameters like plant height, number of primary and secondary branches, days to 50% flowering, flower stalk length, and umbel diameter.

KEYWORDS: Fennel, growth regulators, seed yield, volatile oil

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1. INTRODUCTION

India, renowned as the spice hub of the world, holds the prestigious title of being the largest global producer, consumer, and exporter of seed spices (Sable et al., 2022). Among these esteemed spices, fennel (*Foeniculum vulgare* Mill.) emerges as one of the earliest and most essential, valued for its seeds, leaves, and stems. This well-known medicinal and aromatic herb, belongs to the Apiaceae family (Pavela et al., 2016; Abd El-Kareem et al., 2024), is native to Europe and the Mediterranean region but has thrived in temperate and subtropical regions worldwide, growing naturally up to 2100 m above sea level (Sarma et al., 2014; Alipour et al., 2021; Ali et al., 2024). Fennel's adaptability has allowed it to spread across Asia, Europe, Africa, America and Oceania (Khammassi et al., 2018; Datiles and Popay, 2015). As a resilient herbaceous perennial herb with yellow blossoms, feathery leaves, and hollow stems, fennel is a pivotal cash crop in regions with diverse and challenging climates. India ranks prominently among the largest fennel producers, alongside Lebanon, Egypt, China, Russia, Romania, Hungary, and Germany. In India, fennel cultivation covers 64,922 ha, yielding 114,971 t of seeds with an averaging productivity of 1,770 kg ha^{-1}. Gujarat leads in both cultivation area (41,957 ha) and seed production (87,173 t), followed closely by Rajasthan (19,370 ha and 22,832 t, respectively) (Anonymous, 2023). Fennel plays a vital role in various systems of traditional medicine, such as Ayurveda, Unani, Siddha, and the Indian and Iranian traditional systems of alternative medicine (Rahimi and Ardekani, 2013). The stem, leaf, fruit, seed, and entire plant have been utilized in treating various diseases and in culinary traditions worldwide (Pushkar, 2022). It is also used as a spice to enhance the flavour of fish, liquors, bread, ice cream, cheese, and salad (Rather et al., 2016). Fennel's fruits and essential oil are significant in the pharmaceutical, nutritional, food, and cosmetic industries (Peymaei et al., 2024; Javed et al., 2020; Parmoon et al., 2022). Beyond their culinary and medicinal uses, fennel seeds are prized for their stimulating and carminative properties, which are deeply rooted in traditional medicine (Noreen et al., 2023). Fennel oil, primarily composed of *trans*-anethole, estragole, limonene, fenchone, and other components, finds applications across various industries (Diao et al., 2014). Fennel seeds are high in carbohydrates (42.3%), fibre (18.5%), lipids (10%), protein (9.5%), minerals, and vitamins (Badgujar et al., 2014; Rather et al., 2016). Even after oil extraction, fennel residues serve as valuable cattle feed due to their high protein (14–22%) and fat (12–18.5%) content (De and De, 2022).

Fennel cultivation in India involves strategic seasonal selection, from Rabi to Kharif crops, consistently showing higher production potential than direct seeding. The integration of plant growth regulators (PGRs), such as gibberellic acid (GA_3), naphthalic acetic acid (NAA), and Indole butyric acid (IBA) has gained traction to further optimize growth, yield, and quality attributes in spice crops (Singh et al., 2017; Kurmi et al., 2020). These regulators enhance photosynthetic efficiency and early flowering, ultimately affecting both yield and plant quality (Liu et al., 2019; Simkin et al., 2019). However, fennel faces challenges from climatic variability, soil conditions, insect pests, and diseases, necessitating the appropriate application of growth regulators, under optimal conditions (Haokip et al., 2016; Khan and Mazid, 2018). This study explores the impact of growth regulators, including GA_3, NAA, Kinetin, and IBA, on fennel cultivation in West Bengal, focusing on eco-friendly and cost-effective nutrient management practices. By shedding new light on the future of fennel cultivation, this research endeavour aims to enhance its journey from the farm to the spice rack, ensuring sustainable production and quality enhancement.

2. MATERIALS AND METHODS

The study was carried out over two consecutive *rabi* seasons (November, 2018–April, 2020) at the Horticultural Research Station, Mondouri, Bidhan Chandra Krishi Viswavidyalaya (BCKV), Nadia, West Bengal (741252), India. The experimental site is situated at 23.5° N (latitude) and 80°E (longitude), with an altitude of 9.75 m above mean sea level, within a subtropical humid climate. The experiment was laid out in a Randomized Block Design with three replications of each treatment. Total 9 treatments, comprising four different plant growth regulators, each applied at two concentrations, and a control group (Table 1). Fennel seeds (variety PF–39) were sown in 2.5×1.5 m^2 plots during the first week of November, with a spacing of 50×30 cm^2. Growth regulators were applied at 30, 45, and 60 days after sowing (DAS). Thinning was conducted 3 weeks after germination to maintain the plant to plant distance of 30 cm by removing weak and unhealthy seedlings. Recommended fertilizer doses were applied, and essential cultural practices, like irrigation, weeding, and staking, were carried out as required. Harvesting was done by carefully uprooting the plants from the soil when they turned brownish, followed by drying, threshing, and winnowing to extract and clean the seeds. Data on various growth, yield, and quality parameters were recorded from five randomly selected plants per treatment per replication. Observations included plant height (cm) at 80 DAS, 120 DAS, and harvest; primary branches at 80 DAS, 120 DAS, and harvest; secondary branches at 120 DAS and harvest; flower stalk length (cm) and umbel diameter (cm) at 120 DAS, and harvest; umbels $plant^{-1}$ at 80 DAS, 120 DAS, and

harvest; and umbellate umbel^{-1} at 120 DAS, and harvest. Additional parameters recorded post-harvest included number of seeds umbellate^{-1}, seed yield plant^{-1}, seed yield plot^{-1}, test weight, total chlorophyll content, total soluble sugar, and volatile oil content of seeds.

2.1. Determination of quality parameters

2.1.1. Total chlorophyll content (mg g^{-1})

To determine the total chlorophyll content, a fresh seed sample of 0.1 g was taken in a test tube. Added 5 ml of N, N-dimethyl formamide (solvent) to the test tube and kept it for 12 h. Then, centrifuge the mixture. Record the chlorophyll content by taking observations at 645 nm and 663 nm using a spectrophotometer. It was calculated using the formula advocated by Moran and Porath (1980).

Total chlorophyll (mg g^{-1}) = (20.2×A645-8.02×A663)/(1000×W)×V .....(1)

Where,

A=Absorbance at specific wavelengths

V=Final volume of chlorophyll extracted in solvent (N, N-dimethyl formamide)

W= Seed weight

2.1.2. Total soluble sugar (TSS)

The method described by Franscistt et al. (1971) was used to determine the amount of TSS. Begin by weighing 300 mg of the seed sample and extracting it with 80% ethanol. Measure the colour intensity (A_{600}) of the final product at 600 nm using a spectrophotometer calibrated against a glucose standard solution (100 µg ml^{-1}). The amount of TSS is calculated using a formula.

TSS=(C×A600,sample)/(A600, standard) .....(2)

Where,

C is the concentration of the glucose standard solution (100 µg ml^{-1}),

A_{600}, sample, is the absorbance reading of the sample at 600 nm,

A_{600}, standard, is the absorbance reading of the glucose standard solution at 600 nm.

2.1.3. Volatile oil content (%)

To determine volatile oil content as described by Tiwari et al. (1974) using the rapid and non-destructive determination of seed oil by Pulsed Nuclear Magnetic Resonance (NMR) Technique, begin by weighing a known amount of the seed sample, ensuring it is dry and free from any external moisture. Then, calibrate the NMR spectrometer with samples of known oil content to create a standard curve that relates NMR signal intensity to oil content. Place the seed sample in the NMR spectrometer and measure its NMR signal intensity. Using the standard curve obtained from calibration, determine the oil content of the sample based on its NMR signal intensity. Finally, convert the oil content to a percentage on a weight basis using the formula.

Volatile oil (%)=(Oil content (g)/Sample weight (g))×100…(3)

2.2. Statistical analysis

The collected data from two years of experimentation were subjected to statistical analysis using the methodology recommended by Gomez and Gomez, (1984). The significance of variation among different treatments was assessed using Fisher and Snedecor's 'F' test at a significance level of 0.05%. To determine the least significant difference at 5% level of significance, statistical tables formulated by Fisher and Yates, (1979) were consulted.

3. RESULTS AND DISCUSSION

3.1. Growth parameters

3.1.1. Plant height (cm)

The pooled data from two years, presented in Tables 1 and 2 showed significant differences in growth parameters influenced by different plant growth regulators. Regarding plant height, the application of GA_3 @ 100 ppm outperformed all other treatments at all observation points: 80 DAS (79.03 cm), 120 DAS (112.59 cm), and at harvest (158.09 cm). This was followed by GA_3 @ 50 ppm, which resulted in plant heights of 72.19 cm, 110.94 cm, and 155.02 cm, respectively. Conversely, NAA @ 200 ppm also positively affected plant height across various observation dates. However, Kinetin @ 15 ppm resulted in the lowest plant heights with measurements of 57.9 cm at 80 DAS, 98.77 cm at 120 DAS and 134.15 cm at harvest, which were even lower than the control (water spray). These findings align with previous studies by Prajapat et al. (2015) and Kusuma et al. (2019) in fennel, Pariari et al. (2012) in black cumin, Singha et al. (2022) in mint, Anolisa et al. (2020) in chili, Rafique et al. (2021) in chickpea, and Singh et al. (2012), Haokip et al. (2016), Yugandhar et al. (2017) and Kurmi et al. (2020) in coriander, all of which reported enhanced plant height with the application of GA_3. The rapid cell division in the apical meristem, promoted by GA_3 might explains the higher plant height achieved with higher concentrations of GA_3 (Gupta et al., 2013). However, studies by Shivran and Jat, (2013), Singh et al. (2017) and Khadka et al. (2024) had also highlighted the positive impact of NAA on plant height through foliar application, demonstrating its efficacy in different contexts.

3.1.2. Primary branch plant^{-1} and secondary branch plant^{-1}

The application of GA_3 @ 100 ppm resulted in the highest number of primary branches plant^{-1} with values recorded at 4.34 at 80 DAS, 5.99 at 120 DAS, and 10.60 at harvest.

Table 1: Effect of different plant growth regulators on fennel growth parameters

Treatments	Plant height (cm)			Primary branches plant^{-1}			Secondary branches plant^{-1}	
	80 DAS	120 DAS	Harvesting	80 DAS	120 DAS	Harvesting	80 DAS	120 DAS
NAA @ 100 ppm	62.81	105.85	145.83	3.86	5.34	8.13	8.29	11.33
NAA @ 200 ppm	63.54	109.80	148.07	3.82	5.42	7.57	8.16	11.24
IBA @ 100 ppm	69.88	101.85	141.22	3.73	5.54	7.24	8.01	10.76
IBA @ 200 ppm	66.13	98.81	139.11	3.79	5.75	7.92	7.97	11.05
GA_3 @ 50 ppm	72.19	110.94	155.02	4.06	5.76	8.75	8.45	11.03
GA_3 @ 100 ppm	79.03	112.59	158.09	4.34	5.99	10.60	8.57	11.38
Kinetin @ 10 ppm	62.09	101.79	139.10	3.62	5.26	7.29	7.89	10.79
Kinetin @ 15 ppm	57.90	98.77	134.15	3.67	5.18	7.12	7.88	10.85
Control (water spray)	58.85	89.95	136.49	3.61	5.09	7.06	7.69	10.15
SEm±	0.160	0.118	0.180	0.026	0.022	0.024	0.038	0.056
CD (p=0.05)	0.484	0.355	0.545	0.080	0.066	0.074	0.116	0.168

Table 2: Effect of different plant growth regulators on fennel growth parameters

Treatments	Days to 50% flowering	Flower stalk length (cm)		Umbel diameter (cm)	
		120 DAS	Harvesting	120 DAS	Harvesting
NAA @ 100 ppm	93.58	16.22	26.63	8.47	13.59
NAA @ 200 ppm	93.71	16.66	26.43	8.18	13.43
IBA @ 100 ppm	93.61	15.69	25.55	8.99	14.48
IBA @ 200 ppm	93.76	15.76	25.88	8.71	14.23
GA_3 @ 50 ppm	93.65	20.35	29.64	9.48	15.89
GA_3 @ 100 ppm	93.22	21.58	30.49	10.30	16.82
Kinetin @ 10 ppm	96.09	13.16	22.18	8.37	13.61
Kinetin @ 15 ppm	96.66	12.65	21.58	7.98	12.31
Control (water spray)	93.77	14.19	23.35	8.39	13.69
SEm±	0.094	0.115	0.088	0.142	0.151
CD (p=0.05)	0.283	0.348	0.267	0.430	0.458

This was followed by GA_3 @ 50 ppm and NAA @ 200 ppm, while Kinetin @ 15 ppm consistently resulted in the fewest primary branches across all observation points. For secondary branches plant^{-1}, significant variation was observed among the growth regulator treatments. GA_3 @ 100 ppm had the most pronounced effect, with 8.57 secondary branches at 120 DAS and 11.38 at harvest, outperforming all the other treatments. NAA @ 100 ppm showed a similar positive effect on secondary branch development, while Kinetin @ 15 ppm had the least impact, with only 7.88 secondary branches at 120 DAS. Interestingly, Kinetin @ 10 ppm resulted in lowest number of secondary branches at harvest, with a count of 10.79. The observed increase in number of branches plant^{-1} could be attributed to GA_3 ability to stimulate lateral bud development, suppress apical dominance, and promote vegetative growth through rapid cell division in the apical meristem (Gupta et al., 2013). These findings were consistent with previous studies by Prajapat et al. (2015), and Pariari et al. (2012), where GA_3 @ 100 ppm showed significant enhancements in number of branches plant^{-1} for fennel and black cumin, respectively. Recently, Singha et al. (2022) also reported that application of GA_3 @ 100 ppm produced higher number of primary and secondary branches plant^{-1} in mint. Similarly, research by Singh et al. (2012) and Haokip et al. (2016) reported an increased number of primary and secondary branches plant^{-1} in coriander with GA_3 @ 50 ppm. Additionally, studies by Shivran and Jat (2013) and Singh et al. (2017) had highlighted the positive effects of NAA foliar application on various aspects of plant growth, further emphasizing the role of growth regulators in influencing plant architecture and productivity.

3.1.3. Days to 50% flowering

The data on the number of days taken to reach 50% flowering showed variation among the different treatments. The treatment with GA_3 @ 100 ppm required the fewest days for flowering, averaging 93.22 days. This was closely followed by NAA @ 100 ppm which took an average of 93.58 days. However, Kinetin @ 15 ppm required the longest time, averaging 96.66 days. These findings align with previous research. Prajapat et al. (2015) in fennel and Reddy et al. (2021) in ajowan reported that the application of 100 ppm of GA_3 resulted in the fewest days to reach 50% flowering. Similar results were observed by Pariari et al. (2012) in black cumin, where growth parameters improved with the application of GA_3 @ 100 ppm. Additionally, Haokip et al. (2016) and Kurmi et al. (2020) found that applying GA_3 @ 50 ppm led to the fewest days to 50% flowering in black cumin and coriander, respectively. Furthermore, Yugandhar et al. (2014) and Yugandhar et al. (2017) also reported that applying GA_3 @ 75 ppm resulted in the least number of days to 50% flowering in coriander. These results suggested that GA_3 was highly effective in accelerating flowering process. Optimizing GA_3 application could significantly reduce time to flowering, offering valuable insights for enhancing flowering period and overall plant development through targeted growth regulator use.

3.1.4. Flower stalk length (cm) and umbel diameter (cm)

The effects of various treatments on flower stalk length and umbel diameter showed significant differences. Maximum flower stalk length was observed in GA_3 @ 100 ppm, measuring 21.58 cm at 120 DAS and extending to 30.49 cm by harvest. This treatment was statistically at par with GA_3 @ 50 ppm, which produced a flower stalk length of 20.35 cm at 120 DAS and 29.64 cm at harvest, while the shortest flower stalk length was recorded with the application of Kinetin @ 15 ppm, measuring 12.65 cm at 120 DAS and 21.58 cm at harvest. Regarding umbel diameter, GA_3 @ 100 ppm also showed the best results, yielding the largest umbel diameters of 10.30 cm at 120 DAS and 16.82 cm at harvest. This was closely followed by GA_3 @ 50 ppm and IBA @ 200 ppm, which produced umbel diameters of 9.48 cm at 120 DAS and 15.89 cm at harvest. However, treatment Kinetin @ 15 ppm recorded the smallest umbel diameter, with 7.98 cm at 120 DAS and 12.31 cm at harvest. Supporting these findings, Mohanta et al. (2015) also recorded significant increase in maximum flower stalk length (28.20 cm) and umbel diameter (14.77 cm) in carrot seed production with the application of GA_3 @ 200 ppm. This consistency across studies highlighted the efficacy of GA_3 in promoting both flower stalk elongation and umbel diameter growth.

3.2. Yield and its attributing parameters

3.2.1. Umbels plant^{-1} and umbellate umbel^{-1}

The pooled data shown in Table 3 revealed that the application of plant growth regulators significantly influenced the number of umbels plant^{-1} and umbellate umbel^{-1} at harvest. Specifically, the application of NAA @ 100 ppm resulted in the highest number of umbels plant^{-1}, with values of 10.43 at 80 DAS, 18.27 at 120 DAS, and 29.67 at harvest. This was followed by NAA @ 200 ppm and IBA @ 200 ppm. Conversely, the lowest number of umbels was recorded in plants treated with Kinetin @ 15 ppm. Regarding the number of umbellate umbel^{-1}, the application of NAA @ 100 ppm resulted in significantly higher numbers, with values of 17.13 at 120 DAS and 23.13 at harvest. This was followed by NAA @ 200 ppm (16.77 at 120 DAS and 22.71 at harvest) and IBA @ 100 ppm, while the lowest number of umbellate umbels^{-1} was recorded in plants treated with Kinetin @ 15 ppm. These results were supported by Shivran and Jat (2013) and Sarada et al. (2008), who reported that NAA significantly increased the number of umbels plant^{-1} and umbellate umbel^{-1} in cumin and coriander, respectively.

3.2.2. Seeds umbellate^{-1}, test weight (g), and seed yield (t ha^{-1})

The application of NAA @ 100 ppm recorded the highest number of seeds umbellate^{-1} (19.39), followed by IBA @ 100 ppm (18.68). The least influence was observed in plants treated with Kinetin @ 15 ppm (18.21), while the control yielded 17.10 seeds. The seed yield ha^{-1}, as presented in Table 3, indicated a significant effect of growth regulators on average yield. The highest yield (22.95 q ha^{-1}) was obtained with the application of NAA @ 100 ppm, followed by NAA @ 200 ppm (22.11 q ha^{-1}). The lowest yield was obtained from the application of Kinetin @ 15 ppm (18.22 q ha^{-1}). The treatment with NAA @ 100 ppm produced the maximum test weight of 5.80 g, closely followed by IBA @ 100 ppm (5.76 g). The lowest test weight was recorded in the control treatment (5.48 g). The increase in yield parameters may be attributed to the greater accumulation of total dry matter in the plant's sink system. Significant differences were observed in test weight (g) among different treatments. The positive effect of NAA on enhancing fennel seed yield might be attributed to improved translocation of carbohydrates towards grain development, as indicated by the increased seed yield umbel^{-1} and test weight. This finding aligned with the results of Pariari et al. (2012) in black cumin, where higher seed yield and yield attributes were recorded with the application of NAA @ 100 ppm. Consistent results were also found in studies by Raoofi et al. (2014); Meena et al. (2014); Raj et al. (2016), who reported higher yield and yield attributes influenced by the application of NAA in various crops.

Table 3: Effect of different plant growth regulators on yield and yield-attributing parameters of fennel

Treatments	Umbels plant^{-1}			Umbellate umbel^{-1}		Seeds umbellate^{-1}	Test weight (g)	Seed yield (q ha^{-1})
	80 DAS	120 DAS	Harvesting	120 DAS	Harvesting			
NAA @ 100 ppm	10.43	18.27	29.67	17.13	23.13	19.39	5.80	22.95
NAA @ 200 ppm	10.12	18.13	28.48	16.77	22.71	18.59	5.74	22.11
IBA @ 100 ppm	8.74	16.74	25.77	16.45	22.04	18.68	5.76	21.79
IBA @ 200 ppm	9.17	16.57	26.13	16.25	21.68	18.57	5.71	20.71
GA_3 @ 50 ppm	7.41	15.63	24.18	16.44	21.95	18.38	5.63	19.96
GA_3 @ 100 ppm	7.73	15.87	24.70	15.82	21.22	18.46	5.55	20.43
Kinetin @ 10 ppm	7.18	15.27	23.09	15.53	21.21	18.52	5.64	19.71
Kinetin @ 15 ppm	7.04	14.82	22.99	15.17	20.81	18.21	5.52	18.22
Control (water spray)	7.48	15.41	23.70	14.53	20.91	17.10	5.48	17.72
SEm±	0.034	0.037	0.059	0.049	0.081	0.068	0.021	0.194
CD (p=0.05)	0.102	0.111	0.177	0.149	0.246	0.207	0.063	0.064

3.3. Quality parameters

3.3.1. Total chlorophyll content (mg g^{-1})

The impact of different growth regulators on fennel seed quality parameters, including total chlorophyll content, total soluble sugar, and volatile oil content, is detailed in Table 4. Among the treatments, Kinetin @ 10 ppm exhibited the maximum chlorophyll content (0.344 mg g^{-1}), followed closely by Kinetin @ 15 ppm (0.343 mg g^{-1}) and NAA @ 100 ppm (0.341 mg g^{-1}), while the lowest chlorophyll content was observed in plants treated with GA3 @ 50 ppm (0.336 mg g^{-1}). These findings were consistent with those of El-Bably and Nahed, (2017), who reported a significant increase in total chlorophyll content with the application of kinetin in *Clivia miniata* L. The results suggested that kinetin had a positive influence on chlorophyll levels in plants by stimulating the production of photosynthetic proteins, accelerating cell division, and modifying apical dominance (Bielach et al., 2017). This effect was attributed to kinetin's promotion of certain genes at the cellular level, inducing mitosis, and fostering chloroplast development. Consequently, plant leaves treated with high levels of kinetin exhibited increased photosynthetic activity and metabolite accumulation (Yaronskay et al., 2007). These results aligned with similar findings reported by Youssef and Abd El-Aal, (2014).

3.3.2. Total soluble sugar (TSS)

For total soluble sugar content (TSS) in fennel seeds (mg 100 mg^{-1}), NAA @ 100 ppm produced the highest content (2.91 mg 100 mg^{-1}), while the lowest TSS content was observed with Kinetin @ 15 ppm (2.69 mg 100 mg^{-1}), which was statistically similar to the control (water spray). Notably, lower doses of NAA @ 100 ppm were slightly more effective in enhancing TSS content compared to higher doses of NAA @ 200 ppm, highlighted the positive impact of NAA on the TSS content of fennel seeds. Supporting these findings, Singh and Bons, (2020) and Kaur and Bons, (2019) in sapota; Kumar and Tripathi, (2009) in strawberries and Abbas et al. (2014) in guava also reported increased TSS content with the application of NAA, aligning with our results for fennel seeds. The potential mechanism behind this enhancement could be attributed to NAA's role in the photosynthesis, translocation, accumulation, and the conversion of carbohydrates into sugars, during the maturity of fruits and seeds, as shown by Aluko et al. (2021), Durán-

Table 4: Effect of different plant growth regulators on quality parameters of fennel seed

Treatments	Total chlorophyll content (mg g^{-1})	Total soluble sugar (mg 100 mg^{-1})	Volatile oil (%)
NAA @ 100 ppm	0.341	2.91	1.448
NAA @ 200 ppm	0.338	2.84	1.427
IBA @ 100 ppm	0.338	2.80	1.425
IBA @ 200 ppm	0.340	2.87	1.439
GA_3 @ 50 ppm	0.336	2.70	1.421
GA_3 @ 100 ppm	0.338	2.71	1.434
Kinetin @ 10 ppm	0.344	2.77	1.441
Kinetin @ 15 ppm	0.343	2.69	1.428
Control (water spray)	0.331	2.68	1.399
SEm±	0.001	0.003	0.001
CD (p=0.05)	0.002	2.910	0.004

Soria et al. (2020) and Hifny et al. (2017). Additionally, the conversion of organic acids into soluble sugars and the solubilization of insoluble starch and pectin presented in the cell wall and middle lamella might contribute to the increase in TSS. These results aligned with the findings of Kottapu et al. (2023) in broccoli.

3.3.3. Volatile oil (%)

The analysis of volatile oil content revealed that NAA @ 100 ppm resulted in the highest volatile oil content (1.448%). Conversely, the minimum volatile oil content was observed with kinetin @ 15 ppm (1.428%) among the various treatments. These results suggested that NAA and Kinetin @ 10 ppm were effective in enhancing volatile oil content in fennel plants. This finding aligned with previous studies by Pariari et al. (2012), who reported maximum volatile oil content with NAA @ 100 ppm in black cumin. Similarly, Begum et al. (2018), found that NAA application maximized oil content in mustard plants. Moreover, Singha et al. (2022) noted a significant enhancement in essential oil content in mint with the application of IAA @ 125 ppm.

4. CONCLUSION

Demonstrated significant variations in growth, yield, and quality parameters of fennel. GA_3 @ 100 ppm was best for growth traits, including plant height, number of branches, and flowering. NAA @ 100 ppm excelled in yield parameters such as umbels, seeds umbel^{-1}, seed yield, and overall productivity. Kinetin @ 10 ppm effectively enhanced the total chlorophyll content. Overall, NAA @ 100 ppm was the most promising for optimal fennel yield and quality in West Bengal's alluvial regions, providing valuable insights to improve cultivation practices.

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7. REFERENCES

Abbas, M.M., Ahmad, S., Javaid, M.A., 2014. Effect of naphthalene acetic acid on flower and fruit thinning of summer crop of guava. Journal of Agricultural Research 52, 111–116.

Abd El-Kareem, M.S.M., Rabbih, M.A., Rashad, A.M., El-Hefny, M., 2024. Essential oils from fennel plants as valuable chemical products: gas chromatography-mass spectrometry, FTIR, quantum mechanical investigation, and antifungal activity. Biomass Conversion Biorefinery. https://doi.org/10.1007/s13399-024-05675-2.

Alipour, A., Rahimi, M.M., Hosseini, S.M.A., Bahrani, A., 2021. Mycorrhizal fungi and growth-promoting bacteria improves fennel essential oil yield under water stress. Industrial Crops and Products 170(5), 113792.

Ali, M.A., Al-Farga, A., Seddik, M.A., 2024. The positive impact of honeybee activity on fennel crop production and sustainability. Scientific Reports 14, 14869. https://doi.org/10.1038/s41598-024-64283-2

Aluko, O.O., Li, C., Wang, Q., Liu, H., 2021. Sucrose utilization for improved crop yields: a review article. International Journal of Molecular Sciences 22(9), 4704. https://doi.org/10.3390%2Fijms22094704.

Anolisa., Hossen, M.A.-I.R., Islam, A.R., Das, S.K., 2020. Effect of plant growth regulators on growth and yield of chili (*Capsicum annuum* L.). Journal of Phytology 12, 117–120.

Anonymous, 2023. Spice Board, Ministry of Commerce & Industry, Govt. of India. Available from:https://www.indianspices.com/sites/default/files/Major%20spice%20wise%20area%20production2022-23.pdf.

Badgujar, S.B., Patel, V.V., Bandivdekar, A.H., 2014. *Foeniculum vulgare* Mill: a review of its botany, phytochemistry, pharmacology, contemporary application, and toxicology. BioMed Research International 2014(1), 842674. https://doi.org/10.1155/2014/842674.

Begum, F., Hossain, F., Islam, M.M., Mondal, M.R.I., 2018. Effect of naphthalene acetic acid (NAA) on oil content and quality of the mustard plant (*Brassica campestries* L.). Pertanika Journal of Tropical Agricultural Science 41(1), 191–208.

Bielach, A., Hrtyan, M., Tognetti, V.B., 2017. Plants under stress: involvement of auxin and cytokinin. International Journal of Molecular Sciences 18(7), 1427. https://doi.org/10.3390/ijms18071427.

Datiles, M., Popay, I., 2015. *Foeniculum vulgare* (fennel), invasive species compendium. Wallingford CABI in https://www.cabidigitallibrary.org/doi/10.1079/cabicompendium.24271. Last accessed on July 2024.

De, A.K., De, M., 2022. Functional and therapeutic applications of some general and rare spices. In: Functional foods and nutraceuticals in metabolic and non-communicable diseases, Academic Press, 411–420. https://doi.org/10.1016/B978-0-12-819815-5.00044-6.

Diao, W., Hu, Q., Zhang, H., Xu, J., 2014. Chemical composition, antibacterial activity and mechanism of action of essential oil from seeds of fennel (*Foeniculum vulgare* Mill.). Food Control 35(1), 109–116.

Durán-Soria, S., Pott, D.M., Osorio, S., Vallarino, J.G.,

2020. Sugar signaling during fruit ripening. Frontiers in Plant Science 11, 564917. https://doi.org/10.3389/fpls.2020.564917.

El-Bably, S.M., Nahed, M.R., 2017. Effect of kinetin and zinc foliar spray on growth Performance of *Clivia miniata* L. plant. Alexandria Journal of Agricultural Sciences 62(6), 356–381.

Fisher, R.A., Yates, F., 1979. Statistical table for biological, agricultural and medical research (6th Edn.). Longman Publication, London, 63.

Franscistt, W., David, F.B., Robert, M.D., 1971. The estimation of the total soluble carbohydrate in cauliflower tissue. In: Witham, F.H., Blaydes, D.F., Devlin, R.M. (Eds.), Experiment in plant phyisiology, Van Nostrand Reinhold, New York, 16. https://scholar.google.com/scholar_lookup?title=Experiment+in+plant+phyisiology,+Van,+Nostrand&author=W+Franscistt&author=FB+David&author=MD+Robert&publication_year=1971&.

Gomez, K.A., Gomez, A.A., 1984. Statistical procedures for agricultural research (2nd Edn.), John wiley & sons, 316–355.

Gupta, R., Chakrabarty, S.K., 2013. Gibberellic acid in plant: still a mystery unresolved. Plant Signaling and Behavior 8(9), e25504. https://doi.org/10.4161%2Fpsb.25504.

Haokip, C.M., Sharangi, A.B., Debbarma, K., Devi, A.K.R., Karthik, C.S., 2016. Role of plant growth regulators on the growth and yield of coriander (*Coriandrum sativum* L.). Journal of Crop and Weed 12(3), 33–35.

Kaur, N., Bons, H.K., 2019. Influence of different plant growth regulators on yield and quality of sapota (*Manilkara achras*) cv. Kalipatti. The Indian Journal of Agricultural Sciences 89(5), 842–845.

Khammassi, M., Loupassaki, S., Tazarki, H., Mezni, F., Slama, A., Tlili, N., Zaouali, Y., Mighri, H., Jamoussi, B., Khaldi, A., 2018. Variation in essential oil composition and biological activities of *Foeniculum vulgare* Mill. populations growing widely in Tunisia. Journal of Food Biochemistry 42(3), e12532. https://doi.org/10.1111/jfbc.12532.

Kottapu, S., Minz, A., Verma, A., 2023. Effect of foliar application of plant growth regulators on quality and economics of broccoli production under walk-in-tunnel. Environment and Ecology 41(4), 2315–2319. DOI: https://doi.org/10.60151/envec/QWYU4037.

Hifny, H.A., Khalifa, S.M., Hamdy, A.E., Abd El-Wahed, A.N., 2017. Effect of GA_3 and NAA on growth, yield and fruit quality of Washington Navel orange. Egyptian Journal of Horticulture 44(1), 33–43.

Javed, R., Hanif, M.A., Ayub, M.A., Rehman, R., 2020. Fennel. In: Hanif, M.A., Nawaz, H., Khan, M.M., Byrne, H.J. (Eds.), Medicinal plants of South Asia. Elsevier, 241–256. https://doi.org/10.1016/B978-0-08-102659-5.00019-7.

Khadka, P., Paudel, C., Jha, K.K., Chauhan, A., 2024. Assessment of performance of foliar application of GA_3 and NAA on growth and yield attributes of onion (*Allium cepa* L.) cv. Nashik Red (N-53). Asian Research Journal of Agriculture 17(2), 206–211.

Khan, K., Mazid, M., 2018. Chickpea responses to application of plant growth regulators, organics and nutrients. Advances in Plants and Agriculture Research 8(3), 259–273.

Kumar, R., Tripathi, V.K., 2009. Influence of NAA, GA_3 and boric acid on growth, yield and quality of strawberry cv. chandler. Progressive Horticulture 41(1), 113–115.

Kurmi, A.K., Naruka, I.S., Kushwah, S.S., Shaktawat, R.P.S., 2020. Effect of plant growth regulators on growth, yield and quality of coriander (*Coriandrum sativum* L.). Environment and Ecology 38(3B), 710–714.

Kusuma, M.V., Venkatesha, J., Ganghadarappa, P.M., Hiremath, J.S., Mastiholi, A.B., Manjunatha, G., 2019. Effect of growth regulators at different stages on growth and yield of fennel (*Foeniculum vulgare* Mill.). International Journal of Current Research 11(1), 392–397.

Liu, C., Feng, N., Zheng, D., Cui, H., Sun, F., Gong. X., 2019. Uniconazole and diethyl aminoethyl hexanoate increase soybean pod setting and yield by regulating sucrose and starch content. Journal of the Science of Food and Agriculture 99(2), 748–758.

Meena, S.S., Mehta, R.S., Bairwa, M., Meena, R.D., 2014. Productivity and profitability of fenugreek (*Trigonella foenum-graecum* L.) as influenced by bio-fertilizers and plant growth regulators. Legume Research 37(6), 646–650.

Mohanta, H.C., Hossain, M.M., Islam, M.S., Salam, M.A., Saha, S.R., 2015. Effect of plant growth regulators on seed yield of carrot. Annals of Bangladesh Agriculture 19, 23–31.

Moran, R., Porath, D., 1980. Chlorophyll determination in intact tissues using N, N-dimethylformamide. Plant Physiology 65(3), 478–479.

Noreen, S., Tufail, T., Badar Ul Ain, H., Awuchi, C.G., 2023. Pharmacological, nutraceutical, functional and therapeutic properties of fennel (*Foeniculum vulgare*). International Journal of Food Properties 26(1), 915–927.

Pariari, A., Chatterjee, R., Khan, S., 2012. Effect of GA_3 and NAA on growth and yield of black cumin (*Nigella sativa* L.). Journal of Crop and Weed 8(1), 165–166.

Parmoon, G., Ebadi, A., Hashemi, M., Hawrylak-Nowak,

B., Baskin, C., Jahanbakhsh, S., 2022. Plant growth regulators improve grain production and water use efficiency of *Foeniculum vulgare* Mill. under water stress. Plants 11(13), 1718. https://doi.org/10.3390/plants11131718.

Pavela, R., Zabka, M., Bednar, J., Triska, J., Vrchotova, N., 2016. New knowledge for yield, composition and insecticidal activity of essential oils obtained from the aerial parts or seeds of fennel (*Foeniculum vulgare* Mill.). Industrial Crops and Products 83, 275–282.

Peymaei, M., Sarabi, V., Hashempour, H., 2024. Improvement of the yield and essential oil of fennel (*Foeniculum vulgare* Mill.) using external proline, uniconazole and methyl jasmonate under drought stress conditions. Scientia Horticulturae 323, 112488. https://doi.org/10.1016/j.scienta.2023.112488.

Prajapat, S.K., Malik, T.P., Sanjay, K., 2015. Effect of gibberellic acid on growth and yield parameters of fennel (*Foeniculum vulgare* Mill.). International Journal of Tropical Agriculture 33(4), 3911–3916.

Pushkar, P., 2022. *Foeniculum vulgare*: A review of its botany, phytochemistry, pharmacology, traditional uses, environmental application, and toxicology, 1–19. https://www.researchgate.net/publication/359706961.

Rafique, M., Naveed, M., Mustafa, A., Akhtar, S., Munawar, M., Kaukab, S., Ali, H.M., Siddiqui, M.H., Salem, M.Z.M., 2021. The combined effects of gibberellic acid and rhizobium on growth, yield and nutritional status in chickpea (*Cicer arietinum* L.). Agronomy 11(1), 105. https://doi.org/10.3390/agronomy11010105.

Rahimi, R., Ardekani, M.R.S., 2013. Medicinal properties of *Foeniculum vulgare* Mill. in traditional Iranian medicine and modern phytotherapy. Chinese Journal of Integrative Medicine 19(1), 73–79.

Raj, A.C., Holebasappa, K., Hore, J.K., Das, S., 2016. Effect of plant growth regulators on growth and yield of chilli (*Capsicum annuum* L.). Research on Crops 17(2), 320–323. https://gauravpublications.s3.amazonaws.com/Articles/resOnCrop/vol_17-no_2/v17-s2-320-323.pdf.

Raoofi, M.M., Dehghan, S., Keighobadi, M., Poodineh, O., 2014. Effect of naphthalene acetic acid in agriculture and the role of increased yield. International Journal of Agriculture and Crop Sciences 7(14), 1378–1380. https://www.cabidigitallibrary.org/doi/full/10.5555/20143359394.

Rather, M.A., Dar, B.A., Sofi, S.N., Bhat, B.A., Qurishi, M.A., 2016. *Foeniculum vulgare*: A comprehensive review of its traditional use, phytochemistry, pharmacology, and safety. Arabian Journal of Chemistry 9(S2), S1574–S1583.

Reddy, Y.R., Ramanandam, G., Subbaramamma, P., Dorajeerao, A.V.D., 2021. Effect of foliar application of plant growth hormones on yield and quality parameters in ajowan (*Trachyspermum ammi* L. Sprague). International Journal of Plant and Soil Science 33(17), 116–123.

Sable, D.P.A., Amin, A.U., Mistry, J.J., 2022. Rabi fennel crop pays dividend to the farmers of North Gujarat region. Indian Horticulture 67(4), 15–17. https://epubs.icar.org.in/index.php/IndHort/article/view/115550.

Sarada, C., Kalidasu, G., Reddy, T.Y., 2008. Effect of bio-regulators and their time of application on growth and yield of coriander (*Coriandrum sativum*). Journal of Spices and Aromatic Crops 17(2), 183–186.

Sarma, Y.R., Babu, K.N., Aziz, S., 2014. Spices and aromatics. Encyclopaedia of Agriculture and Food Systems, Reference Module in Food Science, 211–234. https://sci-hub.wf/10.1016/b978-0-444-52512-3.00153-4.

Shivran, A.C., Jat, N.I., 2013. Effect of bioregulators and their time of application on growth and yield of cumin. Annals of Plant and Soil Research 15(1), 5–8.

Simkin, A.J., López-Calcagno, P.E., Raines, C.A., 2019. Feeding the world: improving photosynthetic efficiency for sustainable crop production. Journal of Experimental Botany 70(4), 1119–1140. https://doi.org/10.1093/jxb/ery445.

Singh, G., Bons, H.K., 2020. Influence of naphthalene acetic acid on fruit setting, fruit quality and yield of *Manilkara achras* L. cv. kalipatti under subtropical conditions. Indian Journal of Experimental Biology 58(9), 661–666.

Singh, D., Singh, P.P., Naruka, I.S., Rathore, S.S., Shaktawat, R.P.S., 2012. Effect of plant growth regulators on growth and yield of coriander. Indian Journal of Horticulture 69(1), 91–93.

Singh, P., Mor, V., Punia, R., Kumar, S., 2017. Impact of growth regulators on seed yield and quality of coriander (*Coriandrum sativum* L.). Current Journal of Applied Science and Technology 22(5), 01–10.

Singha, U., Chattopadhyay, N., Ghosh (LKN), D.K., Bandyopadhyay, A., 2022. Influence of plant growth regulators on yield and quality of mint (*Mentha arvensis* L.). Journal of Crop and Weed 18(2), 126–133.

Tiwari, P.N., Gambhir, P.N., Rajan, T.S., 1974. Rapid and non-destructive determination of seed oil by pulsed nuclear magnetic resonance technique. Journal of the American Oil Chemists Society 51(3), 104–109.

Yaronskaya, E.B., Gritskevich, E.R., Trukhanovets, N.L., Averina, N.G., 2007. Effect of kinetin on early stages of chlorophyll biosynthesis in streptomycin-

treated barley seedlings. Russian Journal of Plant Physiology 54, 388–395.

Youssef, A.S.M., El-Aal, A., 2014. Effect of kinetin and mineral fertilization on growth flowering, bulb productivity, chemical compositions and histological features of *Hippeastrum vittatum* plant. Journal of Plant Production 5(3), 357–381.

Yugandhar, V., Reddy, P.S.S., Sivaram, G.T., Ramesh, E., 2017. Impact of pre-soaking and foliar application of plant growth regulators on growth and seed yield of coriander (*Coriandrum sativum* L.). Journal of Crop and Weed 13(1), 100–102.

Yugandhar, V., Reddy, P.S.S., Sivaram, G.T., Reddy, D.S., 2014. Effect of growth regulators on growth, seed yield, and quality of coriander (*Coriandrum sativum* L.) cv. sudha. Plant Archives 14(2), 1083–1086.