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Optimizing yield and quality attributes of bottle gourd (*Lagenaria siceraria*) through growing methods and bio-regulators in semi-arid environment

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ABSTRACT

A field experiment was conducted during 2022 and 2023 at Rajasthan Agricultural Research Institute, Durgapura, Jaipur, Rajasthan to evaluate the effects of different growing methods and bio-regulators on the yield and quality of bottle gourd (*Lagenaria siceraria*). The experiment involved 10 treatment combinations, featuring two growing methods namely; G_1, Trailing system and G_2, Traditional system and five bio-regulators of different levels, viz. B_1, Control; B_2, NAA @200 ppm; B_3, GA_3 @50 ppm; B_4, Ethrel @200 ppm and B_5, Salicylic acid @150 ppm. The trial was laid out in a factorial randomized block design (F-RBD) with three replications. The findings revealed that the vertical trailing system resulted in significantly improved fruit length (17.7 cm), number of fruits/vine (4.1), average fruit weight (0.78 kg), fruit yield/vine (3.19 kg), total soluble solids (3.96%), total sugar content (3.07 g/100 g), crude protein content (0.51%) and ascorbic acid content (11.7 mg/100 g). Similarly, foliar application of GA_3 at 50 ppm registered greater fruit length (17.9 cm), number of fruits/vine (4.13), average fruit weight (0.77 kg), yield of fruits/vine (3.16 kg), total soluble solids (3.91%), total sugar (3.08 g/100 g), crude protein (0.52%) and ascorbic acid (11.4 mg/100g) as compared to rest of the treatments. The trailing method combined with GA_3 @50 ppm application offers notable enhanced yield and quality of bottle-gourd, while the use of ethrel @200 ppm may serve as a viable alternative for growers seeking similar results.

Keywords: Bottle gourd, Bio-regulators, Growing methods, Quality parameters, Yield

Bottle gourd (*Lagenaria siceraria*), commonly known as *lauki* or *doodhi*, is a popular vegetable in India and belongs to the Cucurbitaceae family. It is not only an essential vegetable crop but also holds significant medicinal and nutritional value. The fruit is used in a variety of culinary preparations, including sweets such as *halwa*, *kheer*, *petha*, *barfi*, and pickles. In India, bottle gourd is cultivated transversely 2 lakh ha, yielding an annual average production of 3.27 million metric tonnes. In Rajasthan alone, it is grown on 5,200 ha, with a production of 26,982 metric tonnes (Anonymous 2023).

The outdated method of planting bottle gourd involves creating small hills that give the vines plenty of room to grow, which is critical for a crop that possesses heavy foliage, which tends to restrict light penetration to lower leaves and thus reduce the photosynthetic efficiency of the crop. The dense vine canopy also hampers proper air circulation and enhances high humidity, which can promote the occurrence and spread of diseases. As vining plants, bottle-gourds grow best with support, which keeps them off the ground and encourages straight fruit growth. Since trailing allows vertical growth instead of sprawling all over the plot, it not only keeps the produce off the ground, but also allows for the growth of more plants in a smaller area.

The yield of cucurbit crops is heavily influenced by sex expression and the flower sex ratio. Male flowers typically appear earlier and in larger numbers on the lower nodes, while hermaphroditic and pistillate flowers are usually produced on higher nodes. This uneven distribution often results in delayed harvesting and reduced yield. These issues can be mitigated by the external application of plant growth regulators and bio-regulators. Plant growth regulators serve a crucial role in controlling various physiological processes that drive crop development, including flowering, fruiting, seed germination, growth inhibition, and the ripening of assimilates after harvest. They also have a significant impact on shoot and root growth patterns. Bio-regulators, in particular, are instrumental in altering the male-to-female flower ratio, improving fruit set, minimizing fruit drop, and

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enhancing overall yield. The use of bio-regulators like NAA, Ethrel and GA_3 in bottle gourd cultivation offers a viable strategy for increasing productivity. This study aimed to investigate the combined effects of a vertical trellis system and bio-regulators on the yield and quality of bottle gourd.

MATERIALS AND METHODS

A field experiment was conducted during 2022 and 2023 at Rajasthan Agricultural Research Institute, Durgapura (latitude 26.50°N and longitude 75.47°E), Jaipur, Rajasthan. The average annual rainfall of the region varies from 500–700 mm, received mainly during the months of July to September. The experimental site's soil was loamy sand in texture, exhibiting an alkaline reaction with a *p*H ranging from 8.1–8.3. It had a low organic carbon content (0.25%) and available nitrogen level (136.5 kg/ha). The soil was moderately rich in available phosphorus (15.0 kg/ha) and potassium (195 kg/ha). Ten treatment combinations including two growing methods namely, G_1, Trailing system and G_2, Traditional system and five bio-regulators of different levels, viz. B_1, Control; B_2, NAA @200 ppm; B_3, GA_3 @50 ppm; B_4, Ethrel @200 ppm and B_5, Salicylic acid @150 ppm was taken during the study. The experiment was laid-out in a factorial randomized block design (FRBD) replicated thrice. The bio-regulators were administered as a foliar spray at the two-true leaf stage. Raised beds of size 10 m × 0.50 m were made by the raised bed maker. A total of 10 raised beds were created in each of the three replicate groups. The seeds of bottle gourd variety 'Pusa Santushti' were hand-dibbled at a rate of three seeds/hill with spacing of 0.5 m between plants. Bamboo poles were inserted 2 ft deep into the raised beds where the vines were trailed. In the traditional method, the variety 'Pusa Santushti' of bottle gourd was grown using a spacing of 2.5 m × 0.5 m. The vines were allowed to grow naturally along the ground, following the hill-channel technique. The necessary agronomic and cultural practices, along with plant protection measures, were employed to ensure the healthy growth of the crop. During the study, five plants were randomly chosen from each treatment group to record growth and yield parameters. These observations were made to analyze various factors influencing growth and yield.

The total soluble solids (TSS) content of fruits selected at random was measured at harvest using a digital refractometer, and the average TSS content was calculated. The total sugar content in bottle gourd fruits was estimated using the anthrone reagent method. For this, 1 ml of a 100-fold diluted sample was combined with 4 ml of anthrone reagent and heated in a water bath for 10–15 min. The mixture was allowed to cool to room temperature, and its absorbance was measured at 630 nm using a Systronics UV-VIS spectrophotometer (Model 108). A calibration plot constructed from glucose standards served as the basis for determining the sample's sugar concentration. For nitrogen analysis, a colorimetric approach was employed utilizing Nessler's reagent for color development. The protein concentration was derived by applying a conversion factor of 6.25 to the measured nitrogen percentage. To quantify ascorbic acid levels, a sample of juice was first combined with 3% meta-phosphoric acid solution. This mixture was then titrated using 2, 6-dichlorophenol-indophenol until reaching a light pink endpoint. The 2, 6-dichlorophenol-indophenol solution used in the titration was first standardized against a reference ascorbic acid solution. This reference was created by dissolving 100 mg of analytical grade ascorbic acid in 3% meta-phosphoric acid and bringing the volume to 100 ml. The standardization process utilized a 10 ml portion of this prepared reference solution. The determination of moisture content was conducted gravimetrically. An aliquot of homogenized sample (5.0 ± 0.1 g) was transferred to a pre-dried analytical vessel (internal dimensions: 75 mm diameter × 25 mm depth) of known mass. The sample was subjected to thermal dehydration in a convection oven maintained at 105 ± 2°C for a minimum duration of 2 h. Following the drying interval, the vessel was transferred to a desiccator containing anhydrous desiccant for temperature equilibration to ambient conditions prior to gravimetric analysis. The drying-cooling-weighing cycle was repeated until consecutive mass measurements achieved a differential of <1.0 mg, indicating the attainment of constant mass.

$$\text{Moisture by weight (\%)} = [(M_1 - M_2) / (M_1 - M)] \times 100$$

Where M_1, Weight (g) of the dish with material before drying; M_2, Weight (g) of the dish with dried material; M, Weight (g) of the empty dish.

RESULTS AND DISCUSSION

Yield and yield attributes: The yield and yield-attributing characteristics of bottle gourd were significantly influenced by the growing methods (Table 1). Among the different methods, the trailing technique resulted in notably superior outcomes across various growth parameters. Specifically, it led to a significantly greater fruit length (17.7 cm), a higher number of fruits/vine (4.08), an increased average fruit weight (0.78 kg), greater fruit yield/vine (3.19 kg) and an enhanced marketable fruit yield (255 q/ha) when compared to the traditional growing method. The substantial increase in fruit length observed with the trailing method can be attributed to the positive effects of gravity, which likely promotes an optimal orientation for the plant's growth. Furthermore, the improvement in fruit weight is likely due to more efficient translocation of dry matter from the plant's source tissues to the key growth components, facilitating better overall development and fruit quality. This demonstrates how the trailing method not only boosts the quantitative aspects of bottle gourd production but also potentially improves the quality of the produce. These findings align with the results reported by various researchers. In bottle gourd, the results align with those of Sharma *et al.* (2016). In ridge gourd, similar outcomes were observed by Ahmed *et al.* (2021). Rajalingam *et al.* (2017) reported similar results in pointed gourd and in bitter gourd, the trends match those of Khan *et al.* (2021).

Bio-regulators had a significant impact on the yield and

Table 1 Yield and yield attributing characters of bottle gourd as affected by growing methods and bio-regulator

Treatments	Fruit length (cm)			No. of fruits/vine			Fruit weight (kg)			Fruit yield/vine (kg)			Fruit yield (q/ha)		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
Growing methods															
Trailing method	17.62	17.78	17.70	4.06	4.11	4.08	0.77	0.79	0.78	3.12	3.26	3.19	249	261	255
Traditional method	16.93	17.06	17.00	3.98	4.03	4.01	0.68	0.69	0.68	2.69	2.76	2.73	215	221	218
SEM±	0.19	0.20	0.14	0.02	0.02	0.02	0.01	0.01	0.01	0.04	0.05	0.03	3.25	3.42	2.38
LSD (p=0.05)	0.57	0.58	0.39	0.06	0.07	0.04	0.02	0.03	0.02	0.11	0.16	0.09	9.67	10.17	6.83
Bio-regulators															
Control (water spray)	16.25	16.42	16.34	3.88	3.93	3.91	0.68	0.69	0.68	2.62	2.69	2.65	209	215	212
NAA @200 ppm	17.45	17.64	17.55	4.05	4.10	4.08	0.73	0.75	0.74	2.94	3.06	3.00	235	245	240
GA_3 @50 ppm	17.88	17.96	17.92	4.10	4.15	4.13	0.76	0.78	0.77	3.10	3.22	3.16	248	258	253
Ethrel @200 ppm	17.65	17.72	17.69	4.08	4.13	4.11	0.73	0.76	0.74	2.96	3.12	3.04	237	250	243
Salicylic acid @150 ppm	17.16	17.35	17.26	3.99	4.04	4.02	0.73	0.74	0.73	2.89	2.97	2.93	231	238	235
SEM±	0.301	0.312	0.220	0.030	0.040	0.021	0.011	0.022	0.014	0.061	0.083	0.051	5.15	5.41	3.76
LSD (p=0.05)	0.90	0.92	0.62	0.10	0.11	0.07	0.04	0.05	0.03	0.17	0.25	0.15	15.3	16.1	10.8

yield-attributing characteristics of bottle gourd (Table 1). Among the various treatments, the foliar application of GA_3 at 50 ppm emerged as particularly effective in enhancing both the yield and related traits. The greater values for fruit length (17.9 cm), number of fruits/vine (4.13), average fruit weight (0.77 kg), fruit yield/vine (3.16 kg) and overall fruit yield (253 q/ha) were observed with the application of GA_3 at 50 ppm, surpassing the results of other treatments. The marked improvement in fruit development can be attributed to the increased metabolic activity stimulated by the bio-regulator, which facilitated more efficient physiological processes during the reproductive phase of growth. Specifically, the enhanced fruit weight is likely the result of greater translocation of dry matter from the source tissues to the developing fruits, which allowed for more substantial growth. Moreover, the increased marketable fruit yield can likely be attributed to an acceleration in carbohydrate metabolism, promoting a more efficient accumulation of carbohydrates within the plant. Additionally, the auxin-mediated mobilization of metabolites from source to sink further contributed to the improved development of the fruit. Together, these processes underlined the pivotal role of GA_3 in boosting both the quality and quantity of the bottle gourd yield, particularly by optimizing key physiological functions, crucial for fruit growth and maturation. The trends of the results were also obtained by different researchers in various crops. In bottle gourd, the findings were observed by Rapha and Deepanshu (2022). In bitter gourd, comparable results were stated by Ahmad *et al.* (2019). In cucumber, the trends were noted by Kadi *et al.* (2018), Sapkota *et al.* (2020), Pandey *et al.* (2021), and Chowdhury *et al.* (2023). Finally, Jaysawal and Suresh Kumar (2022) observed the trends in ridge gourd.

The interaction between cultivation methods and bio-regulators significantly influenced the fruit yield of bottle gourd, as highlighted in Table 2. The combination of the trailing method with the foliar application of GA_3 at 50 ppm (designated as G_1B_3) yielded the paramount results, producing 3.60 kg of fruit per vine and an impressive 288 q/ha in terms of total fruit yield. This particular treatment combination outperformed all other treatments, showing a marked increase in yield. Interestingly, the only treatment that produced statistically comparable results to this combination was the use of ethrel at 200 ppm in conjunction with the trailing method, which also yielded significant fruit production. However, in the pooled analysis, the GA_3 + trailing method combination (G_1B_3) still led to the highest fruit yield, underscoring the superior efficacy of this specific interaction. This finding suggests that both the chosen cultivation method (trailing) and the bio-regulator application (GA_3 @50 ppm) work synergistically to enhance the yield, offering a promising approach for optimizing bottle gourd production. The comparable results achieved with ethrel also indicate that different bio-regulators, when used with the trailing method, can lead to similar increases in yield, though the GA_3 treatment remains the most effective in this instance.

Table 2 Interaction effect of growing methods and bio-regulators on fruit yield of bottle gourd

Treatment	Fruit yield (kg/vine)					Fruit yield (q/ha)				
Year	Control (water spray)	NAA @200 ppm	GA_3 @ 50 ppm	Ethrel @ 200 ppm	Salicylic acid @ 150 ppm	Control (water spray)	NAA @200 ppm	GA_3 @ 50 ppm	Ethrel @ 200 ppm	Salicylic acid @ 150 ppm
Trailing method										
2022	2.39	3.27	3.52	3.46	2.94	191.3	261.8	281.6	276.9	235.4
2023	2.50	3.47	3.68	3.62	3.02	199.8	277.9	294.7	290.0	241.3
Pooled	2.44	3.37	3.60	3.54	2.98	195.5	269.9	288.2	283.5	238.3
Traditional method										
2022	2.84	2.61	2.68	2.46	2.84	227.4	208.5	214.3	197.1	227.5
2023	2.88	2.64	2.76	2.62	2.92	230.6	211.3	220.5	209.6	233.9
Pooled	2.86	2.62	2.72	2.54	2.88	229.0	209.9	217.4	203.4	230.7

Interaction	Fruit yield (kg/vine)			Fruit yield (q/ha)		
Year	2022	2023	Pooled	2022	2023	Pooled
SEM±	0.08	0.12	0.07	7.28	7.66	5.32
LSD (*p*=0.05)	0.25	0.35	0.21	21.62	22.75	15.26

Table 3 Quality parameters of bottle gourd as affected by growing methods and bio-regulators

Treatments	TSS content (%)			Total sugar content (g/100 g)			Crude protein (%)			Ascorbic acid (mg/100 g)		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
Growing methods												
Trailing method	3.95	3.98	3.96	3.08	3.06	3.07	0.50	0.52	0.51	11.70	11.73	11.72
Traditional method	3.44	3.46	3.45	2.67	2.79	2.73	0.44	0.47	0.46	10.05	10.18	10.11
SEM+	0.05	0.04	0.03	0.02	0.03	0.02	0.00	0.01	0.00	0.12	0.12	0.09
LSD (*p*=0.05)	0.16	0.11	0.09	0.07	0.08	0.05	0.01	0.02	0.01	0.37	0.37	0.25
Bio-regulators												
Control (water spray)	3.32	3.34	3.33	2.57	2.61	2.59	0.43	0.46	0.45	9.82	9.88	9.85
NAA @200 ppm	3.84	3.81	3.83	2.95	3.01	2.98	0.48	0.50	0.49	11.26	11.36	11.31
GA_3 @50 ppm	3.88	3.94	3.91	3.05	3.10	3.08	0.51	0.52	0.52	11.41	11.46	11.44
Ethrel @200 ppm	3.86	3.88	3.87	2.99	3.05	3.02	0.49	0.51	0.51	11.35	11.42	11.39
Salicylic acid @150 ppm	3.58	3.61	3.60	2.82	2.85	2.84	0.45	0.48	0.47	10.54	10.65	10.60
SEM±	0.080	0.061	0.050	0.041	0.040	0.030	0.011	0.010	0.011	0.200	0.201	0.141
LSD (*p*=0.05)	0.25	0.17	0.15	0.12	0.13	0.08	0.02	0.03	0.02	0.59	0.58	0.40

Quality parameters: The quality parameters of bottle gourd were significantly influenced by the different growing methods, as shown in Table 3. Analyzing the combined data on quality traits, it was evident that the trailing method resulted in notable improvements across several key quality indicators. Specifically, the trailing method led to increases in total soluble solids (3.96%), total sugar content (3.07 g/100 g), crude protein levels (0.51%) and ascorbic acid content (11.7 mg/100 g), all of which were considerably higher compared to the traditional growing method. These enhancements in quality characteristics can be attributed to the more efficient accumulation of proteins, carbohydrates, and other vital photosynthates in the trailing method. The likely reason for this improvement is that the trailing method promotes better exposure of the plant to sunlight, optimizing photosynthesis and the subsequent translocation of essential nutrients and energy throughout the plant. This increased exposure to light enables the plant to harness more energy for growth, resulting in enhanced development of key quality components like sugars, proteins, and vitamins. The improved distribution of resources within the plant thus contributes to superior fruit quality, making the trailing method a more effective cultivation strategy for improving both the yield and the nutritional content of bottle gourd. These findings align with the results reported by Rajalingam *et al.* (2017) in cucumber.

The application of bio-regulators had a significant and positive effect on the quality parameters of bottle gourd (Table 3). The data clearly indicated that the foliar spray of GA_3 resulted in peak values for several critical quality traits, including TSS (3.91%), total sugars (3.08 g/100 g), crude protein (0.52%) and ascorbic acid content (11.4 mg/100 g) in the pooled analysis of fruit tissues. These values were higher than those observed in all other treatments and controls, underscoring the efficacy of GA_3 in enhancing fruit quality. The increase in ascorbic acid content can be attributed to the enhanced synthesis of key metabolites, which, in turn, stimulate the production of ascorbic acid precursors, a process likely facilitated by GA_3. This enhanced metabolic activity may also account for the increased TSS content observed in the GA_3 treated fruits. The role of auxins and gibberellins, including GA_3, in promoting the synthesis of metabolites and their rapid translocation to the developing fruits is critical in this regard. These hormones help in the efficient movement of nutrients and energy, ensuring that the fruits receive adequate resources for optimal development, leading to higher concentrations of soluble solids.

Furthermore, the elevated levels of soluble solids in GA_3 treated fruits may be the result of several intertwined physiological processes. The mobilization of metabolites from the source tissues to the developing fruits plays a vital role, along with the conversion of starch and organic acids into sugars, which are key components of soluble solids. This process is facilitated by the hormonal actions of GA_3, which promote metabolic changes that contribute to higher sugar levels in the fruit. Additionally, GA_3 application likely enhances phloem unloading, which improves the transport of sugars to the fruits during maturation. This increased sugar transport enhances sink activity, contributing to greater sugar accumulation, which is a key determinant of sink strength and, consequently, fruit quality.

The increase in crude protein content in GA_3 treated fruits may also be attributed to the mobilization of photo-assimilates and enhanced chloroplast activity, both of which are influenced by GA_3 application. By promoting the efficient utilization of assimilated carbon and nitrogen, GA_3 ensures that these nutrients are allocated to the developing fruit, boosting protein synthesis and accumulation. This enhanced protein content further contributes to the nutritional value and overall quality of the bottle gourd. Thus, the foliar spray of GA_3 not only boosts yield but also significantly improves the nutritional and biochemical composition of bottle gourd, making it a valuable tool for optimizing fruit quality. These findings align with the results of Shafeek *et al.* (2016) in summer squash, Kadi *et al.* (2018) in cucumber, Anayat *et al.* (2020) in bitter gourd and Pandey *et al.* (2021) in cucumber.

The present study concluded that the combination of the trailing growing method with the application of GA_3 at 50 ppm significantly enhances both the yield and quality of bottle gourd. This treatment resulted in notable improvements in various growth and quality parameters, making it an effective approach for boosting bottle gourd production. Additionally, the use of ethrel @200 ppm emerges as a viable alternative, providing growers with an option that delivers comparable results in terms of yield and quality. These findings underscore the importance of optimizing cultivation practices and selecting appropriate growth regulators to maximize bottle gourd productivity. By integrating such practices, farmers can experience substantial benefits, including higher yields and improved marketable quality, which can ultimately lead to greater profitability and better market competitiveness.

Furthermore, the study highlights the potential for refining farming practices to enhance the overall efficiency of bottle gourd production. Given the promising outcomes observed with both GA_3 and Ethrel treatments, it is clear that the use of growth regulators can be a key strategy for optimizing production. However, future research should focus on evaluating the long-term effects of these treatments on soil health and the overall sustainability of bottle gourd cultivation. Understanding how the repeated application of bio-regulators and specific growing methods may influence soil nutrient content, microbial activity and long-term soil fertility will be critical for ensuring that these practices remain environmentally sustainable over time. Additionally, research should explore the broader ecological impacts of such agricultural practices to develop integrated approaches that balance productivity with environmental preservation. Through these efforts, farmers can adopt strategies that not only boost short-term yields but also ensure the long-term viability of bottle gourd farming, fostering sustainable agricultural practices in the future.

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