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Gibberellic Acid Application and Plant Spacing Effects on Growth and Yield of Lettuce (*Lactuca sativa* L.)

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Authors' contributions

This work was carried out in collaboration among all authors. Authors MNI and MJR planned and designed the research. Author TA conducted the work on the field. Authors MRS, RS and CDP performed the statistical analysis. Authors FI and RS collected the data and managed literature searches. Author MMR wrote the manuscript. All the authors provided critical feedback, analysis. All authors read and approved the final manuscript.

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ABSTRACT

Aims: This study aimed to optimize the levels of gibberellic acid (GA_3) and plant spacing on growth and yield of lettuce.
Study Design: The experiment was laid out in Randomized Complete Block Design with three replications.
Place and Duration of Study: Horticulture farm of Sher-e-Bangla Agricultural University, Dhaka-1207, from November 2013 to January 2014.
Methodology: The experiment consisted of two factors. Factor A- two levels of gibberellic acid (GA_3,) application, viz. G_1= 25 ppm and G_2= 50 ppm in relation to a control G_0 and factor B- four plant spacing *viz*. S_1=15cm x 15cm, S_2=20 cm x 20 cm, S_3=25 cm x 25 cm and S_4=30 cm x 30 cm. GA_3 was applied twice as a foliar application by hand sprayer at 20 and 30 days after sowing. First, second and final harvesting was done at 25, 35 and 45 days after sowing respectively.

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Results: The growth and yield characters of lettuce showed significant variation for different levels of GA_3 and plant spacing. Among GA_3 levels, 25 ppm GA_3 produced the maximum number of leaves (15.6), leaf area (283.9 cm^2), fresh weight (91.6 g $plant^{-1}$), dry weight (11.8 g $plant^{-1}$), fresh yield (1794 g $plot^{-1}$) and gross yield (12 t ha^{-1}) at final harvesting compared to control where GA_3 was not used. Under plant spacing, highest plant height (17.5 cm), leaf area (281.1 cm^2), fresh weight (99.1 g $plant^{-1}$) and dry weight (12.1 g $plant^{-1}$) was revealed from wider spacing 30 cm x 30 cm followed by optimum spacing 25cm x 25cm. Meanwhile, closure spacing 15 cm x 15 cm showed maximum fresh yield (1710 g $plant^{-1}$) and gross yield (15.5 t ha^{-1}) due to higher plant density at final harvesting. Besides, lower chlorophyll content (0.43%) and the highest number of leaves (16.2) was found from 25 cm x 25 cm at final harvesting. So, optimum spacing 25 cm x 25 cm would be more suitable considering different points of view. Moreover, the treatment combinations 25 ppm GA_3 with 25 cm x 25 cm exhibited highest benefit-cost ratio (2.04) than other treatments.
Conclusions: It is concluded that the combinations 25 ppm GA_3 application with 25cm x 25cm spacing would be optimum for better growth and yield of lettuce.

Keywords: Lettuce; GA3; plant spacing; plant density; leafy vegetable; fresh weight; benefit-cost ratio.

1. INTRODUCTION

The demand for leafy vegetables has marked up rapidly due to achieving an immense economic interest around the world. The financial worth of vegetables has reached the global market extensively for its higher demand exceeding cereals [1]. Recently, people are more aware of their healthy diet and always prefer to take vegetables for its numerous nutritional values. Consequently, the consumption of vegetables is increasing continuously which influences the demand for higher yields [2]. Among the leafy vegetables, a huge quantity of lettuce is used in fast-food shops and various restaurants as fresh vegetables throughout the world. The need for green vegetables, especially lettuce is increasing to a great extent in Bangladesh. But the productivity of lettuce is not a satisfactory level to meet the growing demand. Lettuce (*Lactuca sativa* L.) belongs to the family Asteraceae is an important leafy vegetable. It is a cool-season crop that has deep taproot and leaves are arranged in a dense rosette on shortened stem [3]. It is usually used in salads, soups, sandwiches and wraps throughout the world. It is rich in calcium, magnesium, potassium, folic acid, vitamin K, vitamin C, beta-carotene, lycopene and other crucial components for human health [4]. It also contains minerals, antioxidants, phytochemicals and several bioactive compounds that promote human health and reduces many chronic diseases [5].

Gibberellic acid is one of the most important plant growth regulators used in agriculture. It enhances cell division, cell elongation and cell expansion which stimulate plant growth [6]. The exogenous application of GA_3 actively influenced many physiological activities of plants [7]. Among the plant growth regulators, GA_3 has been found that it increases plant height, number of leaves as well as fresh and dry weight in potato [8]. Singh [9] found the highest yield in tomato applying GA_3 at 80 ppm, where Baliah [10] observed the maximum growth characters of a green gram by foliar spraying of GA_3 at 50 ppm.

Plant spacing is an important criterion of proper vegetative growth of the plant for generating maximum yield. Optimizing plant density is crucial to gain good yield and quality products [11]. Optimum plant density ensures wise use of resources *viz*. water, light, nutrients and carbon dioxide which are decisive for crop production [12]. Khan [13] recorded optimum growth and maximum production of radish maintaining plant to plant distance 18 cm while Maraey [14] found the highest value of plant height, the number of leaves and dry weight with the spacing 20cm in capsicum. Besides, Vendruscolo [2] found positive profitability in lettuce cultivation maintaining 25cm x 25cm plant spacing.

Therefore, the commercial cultivation of lettuce is increasing to meet the rising demand in Bangladesh. Among the different plant growth regulators, GA_3 is strongly involved in the growth and developmental activities of plants. Ideal plant spacing can give on to optimum yields whereas too high or too low spacing results in comparatively lower yield and quality of plants. But information regarding the useful dose of GA_3 and optimum plant spacing for lettuce cultivation is insufficient. Considering the facts, the present study was aimed to find out the recommended levels of GA_3 and plant spacing on lettuce cultivation.

2. MATERIALS AND METHODS

2.1 Experimental Site

The experiment was conducted at Horticulture Farm of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, and Dhaka, Bangladesh during the period from November 2013 to January 2014.

2.2 Climate and Soil

The experimental site was subtropically characterized by high temperature, high humidity and heavy rainfall in Kharif season (April to September) and scanty of rainfall in Rabi season (October to March). The soil was non-calcareous dark grey having pH 5.6.

2.3 Experimental Treatment and Design

The experiment was laid out in Randomized Complete Block Design with three replications. The experiment consisted of two factors. Factor A- consisted of three levels of gibberellic acid *viz*. G_0= 0 ppm GA_3, G_1= 25 ppm GA_3 and G_2= 50 ppm GA_3 and Factor B- comprised four plant spacing *viz*. S_1= 15 cm x 15 cm, S_2= 20 cm x 20 cm, S_3= 25 cm x 25 cm and S_4= 30 cm x 30 cm. GA_3 was applied twice in the afternoon as a foliar application by hand sprayer at 20 and 30 days after sowing. An area of 16.8 x 6.5 m^2 was divided into three equal blocks. Each block was divided into 12 plots where 12 treatments were allotted at random. Thus there were 36 unit plots altogether in the experimental field. The size of each plot was 1.5 m × 1 m. The distance between two blocks and two plots were kept 0.5 m and 0.4 m respectively.

2.4 Crop Husbandry

Seeds of lettuce cultivar, “Grand Rapid” was collected from Kustia seed store, Dhaka and sown directly in the plot maintaining different spacing. The land was prepared and basal doses of manure and fertilizer were added during the final land preparation. Plots were prepared according to design and layout. The recommended doses of nitrogen, phosphorus and potassium were applied as Urea, Triple super phosphate (TSP) and Murate of potash (MP) at the dose of 450 kg ha^{-1}, 300 kg ha^{-1} and 250 kg ha^{-1} respectively [15]. The one-third urea, the entire amount of TSP and half of MP were applied during final land preparation. The rest of MP and urea was top-dressed in two equal splits at 15 days interval after seed sowing. Intercultural operations were done to ensure the normal growth of the crop. Plant protection measures were followed as and when necessary. First, second and final harvesting was done at 25, 35 and 45 days after sowing.

2.5 Data Collection

Five plants from each of the plots were selected randomly for recording data on the following parameters *viz*. plant height, number of leaves, leaf length, leaf breadth, fresh weight $plant^{-1}$, dry weight $plant^{-1}$, fresh yield $plot^{-1}$ and gross yield ha^{-1}. All the data were recorded at 25, 35 and 45 DAS, respectively. A meter scale measured plant height. The average number of leaves was counted from five randomly selected plants. The leaf area of matured leaves was measured by multiplying leaf length and breadth. A fresh and dry weight of leaves was recorded in gram. The previously sliced 100 g of leaf sample were taken into envelop and placed in the oven for drying at 60°C for 72 hours. The sample was then transferred into desiccators and allowed to cool down to the room temperature and then the final weight of the sample was taken to get dry weight. Chlorophyll percentage was measured as SPAD value with the Minolta SPAD-502 (Konica Minolta Sensing) with five leaf samples. Measurements were taken from the middle of the lamina of the second uppermost leaf. Fresh yield $plot^{-1}$ was recorded in gram while gross yield ha^{-1} was calculated in ton by converting the fresh yield $plot^{-1}$.

2.6 Statistical Analysis

The recorded data on various parameters were statistically analyzed by using MSTAT C statistical software. The average data for all the treatments was calculated and F-test performed the analysis of variance for all the characters. The difference between treatment means were determined by Duncan`s New Multiple Range Test (DMRT) at 5% level of probability [16].

3. RESULTS AND DISCUSSION

3.1 Plant Height

Plant height of lettuce showed significant variation due to two levels of GA_3 application, plant spacing and their interactions at different days after sowing (Fig. 1a, Fig. 2a and Table 1,

respectively). Among the GA_3, the tallest plant (18.2 cm) was found from 50 ppm GA_3 whereas the smallest plant (15.6 cm) was observed in control (0 ppm GA_3) at 45 days after sowing.

It might be due to the rapid cell division in the meristematic zone of the plant. Higher doses of GA_3 involve in cell division and cell elongation at the meristematic region rapidly that stimulate plant growth [9]. Kazemi [17] also observed that GA_3 is associated with the plant growth enhancement in tomato.

Under the different plant spacing, wider spacing of 30 cm x 30 cm revealed longer plant (17.6 cm) where the shorter plant (16.1 cm) was found from the closet spacing 15cm x 15cm at 45 days after sowing.

Due to wider spacing plants got proper space for natural resources *viz*. light, nutrients and water that favored plant development. This observation is in line with the findings of Li [18] who stated that proper management practices are essential to control weeds in avoiding competition for natural resources.

Besides, the highest plant height (18.98 cm) was recorded in a treatment combination of 50 ppm GA_3 with 30 cm x 30 cm spacing while lowest (13.97 cm) in 0 ppm GA_3 with 15 cm x 15 cm spacing at 45 days after sowing.

3.2 Number of Leaves

Different levels of GA_3, plant spacing and their interactions exposed a remarkable discrepancy on the number of leaves of lettuce at different days after sowing (Fig. 1b, Fig. 2b and Table 1, respectively). Under the different GA_3 levels, 25 ppm GA_3 produced maximum number of leaves (15.6) comparing to control at 45 days after sowing.

This could be the application of GA_3 which increased the vegetative growth of the plant through cell division and cell elongation. Exogenous application of GA_3 elevated division, elongation and proliferation of shoot cells that accelerated the vegetative growth of the plants [19].

Optimum plant spacing 25 cm x 25 cm exhibited the largest number of leaves (16.2) at 45 days after sowing comparing to other spacings.

With the increases in spacing, plants got proper space for vertical and horizontal expansion which accumulated more number of leaves in plants. Hasan [20] reported that vertical and horizontal expansion of the plant was correctly accomplished by the optimum spacing which produced the maximum number of leaves than closet spacing.

Table 1. The combined effect of GA_3 and plant spacing on plant height and number of leaves of lettuce

Treatment	Plant height (cm)			Number of leaves		
	25 DAS	35 DAS	45 DAS	25 DAS	35 DAS	45 DAS
G_0S_1	7.27 cde	11.18 ef	13.97 g	3.67 e	7.57 c	13.37 de
G_0S_2	6.06 e	10.79 f	16.14 def	3.80 e	7.53 c	13.40 de
G_0S_3	7.11 de	12.41 bcd	16.06 f	4.43 cde	9.10 bc	14.67 bcd
G_0S_4	6.97 de	13.11 abc	16.11 ef	6.33 ab	9.23 bc	14.53 bcd
G_1S_1	6.71 de	11.74 def	16.63 cde	4.33 de	8.63 c	13.80 cde
G_1S_2	9.70 ab	13.33 ab	16.14 def	4.47 cde	8.97 c	14.37 bcd
G_1S_3	7.62 cd	12.82 bc	17.68 bc	6.73 a	12.7 a	18.80 a
G_1S_4	7.42 cde	12.17 cde	17.40 bcd	5.57 abc	10.9 ab	15.30 bc
G_2S_1	9.51 ab	13.33 ab	17.63 bc	4.27 de	7.63 c	13.00 e
G_2S_2	8.54 bc	12.75 bcd	17.69 bc	4.33 de	8.37 c	13.40 de
G_2S_3	9.85 ab	13.98 ab	17.82 bc	6.00 ab	10.8 ab	15.07 bcd
G_2S_4	10.1 a	14.09 a	18.98 a	5.33 bcd	11.4 ab	15.53 ab
$LSD_{0.05}$	1.41	1.06	1.53	1.23	1.88	1.72
CV (%)	10.35	4.94	5.36	14.68	11.78	6.96

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability, G_0 = 0 ppm GA_3, G_1 = 25 ppm GA_3, G_2 = 50 ppm GA_3, S_1 = 15 cm x 15 cm, S_2 = 20 cm x20 cm, S_3 = 25 cm x 25 cm, S_4 = 30 cm x 30 cm

Therefore, a treatment combination of 25 ppm GA_3 with 25 cm x 25 cm spacing showed the largest number of leaves (18.8) than that of other treatment combinations.

3.3 Leaf Area

Various levels of GA_3, plant spacing and their combinations displayed indicatory impact on leaf area of lettuce at different days after sowing (Fig. 1c, Fig. 2c and Table 2, respectively). Among the different concentrations of GA_3, the widest leaf area was noticed from plants treated with 25 ppm GA_3 at 45 days after sowing which was 18.2% wider than the control treatment.

Application of GA_3 increased leaf length and leaf breadth profusely which helped to increase the leaf area of plants. The result agrees with the observations of Patel [21], who found that the application of GA_3 improved leaf length and breadth of onion.

For plant spacing, the topmost leaf area (281.1 cm^2) was noted from wider spacing 30 cm x 30 cm followed by optimum 25 cm x 25 cm spacing where the smallest leaf area (230.1 cm^2) was seen in closet spacing 15cm x 15cm at 45 days after sowing.

In the case of closer spacing, plants usually compete for light and with the time being leaf area decreases. Results showed that increasing plant spacing, leaf length and breadth of lettuce increased. Yordanova and Nikolov [22] found larger sized leaves with maintaining wider spacing in lettuce and he said that with increasing space, plants get a proper environment for leaf area proliferation.

Meanwhile, the maximum leaf area (313.3 cm^2) was pronounced by the treatment combination 25 ppm GA_3 with 30 cm x 30 cm spacing at final harvesting comparing to the rest of the treatment combinations.

3.4 Chlorophyll Percentage

The variation of chlorophyll percentage of lettuce under different levels of GA_3, plant spacing and their combinations was found significant at different days after sowing (Fig. 1d, Fig. 2d and Table 2, respectively). The lowest percentage of chlorophyll (0.24) was counted from 50 ppm GA_3 treated plant where the highest percentage of chlorophyll (0.79) was seen in control treatment at final harvesting.

It might be obtained because of the increased level of GA_3. This result is in agreement with Tsiakaras [23], who reported that chlorophyll content of lettuce decreased notably by GA_3 application due to the formation of paler and chlorotic new growth.

Table 2. The combined effect of GA_3 and plant spacing on leaf area and chlorophyll percentage of lettuce

Treatment	Leaf area (cm^2)			Chlorophyll (%)		
	25 DAS	35 DAS	45 DAS	25 DAS	35 DAS	45 DAS
G_0S_1	19.8 h	94.0 f	195.3 g	0.85 b	0.76 b	0.73 b
G_0S_2	23.4 gh	96.3 f	227.2 fg	0.73 b	0.68 b	0.64 b
G_0S_3	29.0 fg	124.7 e	236.2 ef	0.71 b	0.65 b	0.72 b
G_0S_4	33.1 f	124.6 e	241.6 def	1.01 a	1.09 a	1.08 a
G_1S_1	47.4 e	134.1 de	252.3 c-f	0.53 c	0.46 c	0.46 c
G_1S_2	60.7 cd	156.7 bc	274.7 a-e	0.41 cd	0.39 cd	0.39 cd
G_1S_3	67.7 b	169.5 ab	295.3 ab	0.36 de	0.33 cde	0.37 cd
G_1S_4	82.5 a	183.6 a	313.3 a	0.35 de	0.39 cd	0.36 cde
G_2S_1	35.8 f	127.2 de	242.6 def	0.26 ef	0.29 de	0.26 def
G_2S_2	55.8 d	144.0 d	256.8 b-f	0.27 def	0.25 e	0.31 def
G_2S_3	65.8 bc	155.6 bc	276.6 a-d	0.22 ef	0.22 e	0.19 f
G_2S_4	65.8 bc	160.2 bc	288.3 abc	0.20 f	0.22 e	0.21 ef
$LSD_{0.05}$	1.90	5.03	10.9	0.14	0.13	0.15
CV (%)	4.75	4.43	5.17	16.65	16.66	18.5

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability, G_0 = 0 ppm GA_3, G_1 = 25 ppm GA_3, G_2 = 50 ppm GA_3, S_1 = 15cm x 15cm, S_2 = 20cm x 20cm, S_3 = 25 cm x 25 cm, S_4 = 30 cm x 30 cm

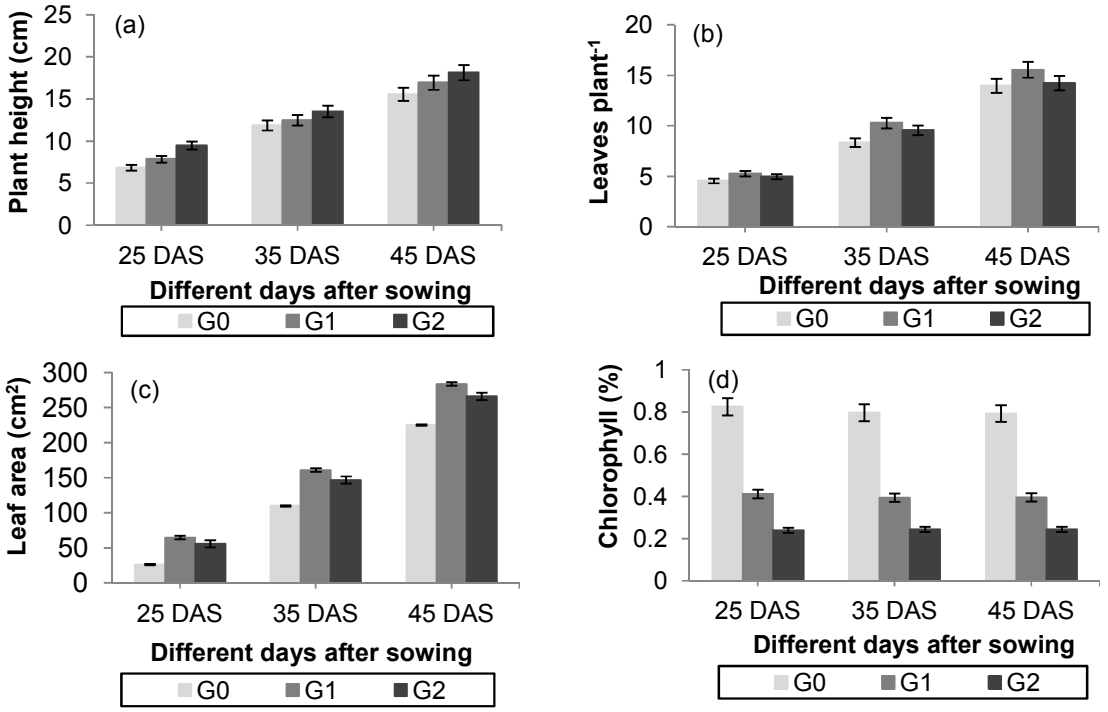

Fig. 1. Effect of different concentration of GA_3 on different growth parameters (a) plant height, (b) number of leaves plant^{-1}, (c) leaf area and (d) chlorophyll percentage

G_0=0 ppm, G_1=25 ppm and G_2=50 ppm

Among plant spacings, a minimal percentage of chlorophyll (0.43) was measured in optimum spacing 25 cm x 25 cm, while the maximal percentage of chlorophyll (0.55) was perceived in wider spacing 30 cm x 30 cm.

In wider spacing, plants accumulated more light intensity, thus chlorophyll content increased. Thakur [24] observed that wider spacing facilitates plants to accumulate more photosynthesis due to the availability of good sunshine and nutrients.

On the other hand, 50 ppm GA_3 with 25cm x 25cm treatment combination produced lower chlorophyll percentage (0.19) of lettuce contrasting to different treatment combinations at final harvesting.

3.5 Fresh Weight Plant^{-1}

Recorded data on fresh weight of lettuce asserted significant variation by the different levels of GA_3, plant spacing and their combinations at different days after sowing (Fig. 3a, Fig. 4a and Table 3, respectively). The maximum fresh weight of leaves was achieved from 25 ppm GA_3 at 45 days after sowing which was 27.7% superior to control treatment among the GA_3 levels.

Plant height, number of leaves and leaf area was found to be increased with the exogenous application of GA_3 which helped to enhance the fresh weight of leaves. GA_3 was involved in different activities viz. root length elongation, stem elongation, leaf area proliferation, conversion of starch to sugar etc. which elevated the fresh weight of lettuce [7]. Baliah [10] also found positive response of GA_3 on fresh weight of green gram.

Among the plant spacings, wider spacing 30 cm x 30 cm condemned highest fresh weight (99 g) followed by optimum 25 cm x 25 cm where lowest fresh weight (64.5 g) was remarked in closure spacing 15 cm x 15cm at final harvesting.

It might be due to the increased leaf length and leaf breadth which ultimately intensified the fresh weight of leaves. This result is supported with the observations of Yordanova and Nikolov [22] who found increased leaf length and breadth with maintaining wider spacing in lettuce. Due to

lower plant density (wider spacing), plants get enough nutrients, light and water for better vegetative growth [20].

In the case of treatment combinations, 25 ppm GA_3 with 30 cm x 30 cm spacing pretended supreme fresh weight of leaves (112 g) comparing to other treatment combinations at final harvesting.

3.6 Dry Weight Plant^{-1}

The results found from lettuce in terms of dry weight showed significant variation under different levels of GA_3, plant spacing and their interactions at different days after sowing (Fig. 3b, Fig. 4b and Table 3, respectively). Among the GA_3 levels, 25 ppm GA_3 treated plants exposed the highest dry weight of lettuce which was 29.61% more advance to control treatment at final harvesting.

GA_3 regulated developmental activities within the plant which helped for vigorous plant growth, thus fresh weight was increased. This result is following the observations of Altaey [25] who observed developmental activities *viz*. cell growth and cell elongation was pronounced by GA_3 application in pepper. Among the plant growth regulators, GA_3 has enhanced plant height, number of leaves as well as fresh and dry weight in potato [8].

For plant spacings, the maximum dry weight of lettuce (12.1 g) was perceived from wider spacing 30 cm x 30 cm followed by optimum 25 cm x 25 cm where the minimum dry weight of lettuce (8.8 g) was gained in closet spacing 15 cm x 15 cm at final harvesting.

It was revealed that increase of the spacing dry weight of plants showed an increasing trend because of less competition for nutrients among the plants during growth stages. Hasan [20] found that wider spacing (lower population) reduces the competition among plants for nutrients.

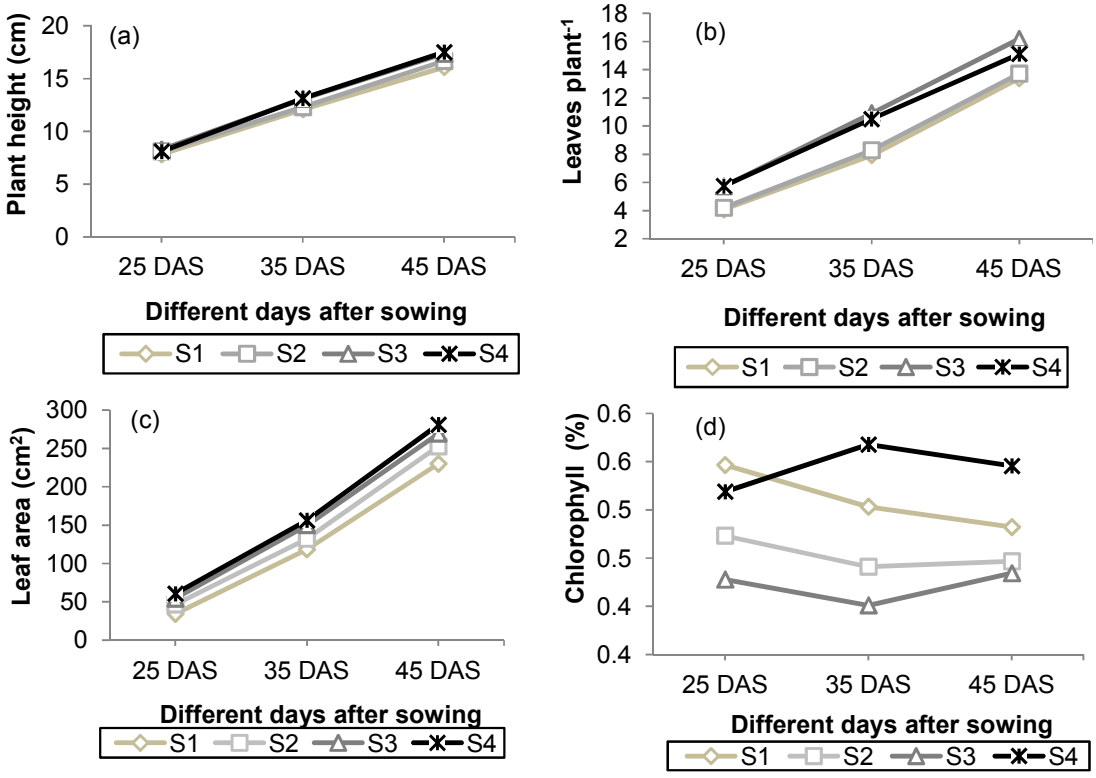

Fig. 2. Effect of different levels of plant spacing on different growth parameters (a) plant height, (b) number of leaves plant^{-1}, (c) leaf area and (d) chlorophyll percentage

S1=15 cm x 15 cm, S2=20 cm x 20 cm, S3=25 cm x 25 cm and S4=30 cm x 30 cm

Table 3. The combined effect of GA_3 and plant spacing on fresh weight and dry weight of lettuce

Treatment	Fresh weight (g)			Dry weight (g)		
	25 DAS	35 DAS	45 DAS	25 DAS	35 DAS	45 DAS
G_0S_1	4.43 f	17.87 cd	53.87 i	8.20 c	8.70 e	8.87 de
G_0S_2	5.80 de	19.13 cd	61.93 hi	8.70 c	8.53 e	8.53 e
G_0S_3	5.83 de	18.30 cd	84.03 def	8.03 c	9.13 e	9.43 de
G_0S_4	6.90 bcd	20.07 bc	86.97 cde	8.70 c	10.0 cde	9.63 de
G_1S_1	5.33 ef	18.67 cd	70.13 gh	9.30 bc	9.30 de	8.87 de
G_1S_2	6.20 cde	19.63 bcd	73.60 fgh	8.33 c	11.6 bcd	10.9 bcd
G_1S_3	8.90 ab	22.33 ab	110.0 ab	11.83 a	12.3 abc	13.2 ab
G_1S_4	8.97 a	25.43 a	112.0 a	9.37 bc	12.5 ab	14.4 a
G_2S_1	6.73 cd	16.30 d	69.63 gh	8.37 c	9.37 de	8.80 de
G_2S_2	6.87 bcd	17.93 cd	77.03 efg	9.20 bc	9.43 de	10.7 bcd
G_2S_3	7.47 bc	19.07 cd	92.53 cd	10.47 ab	10.7 cde	12.2 abc
G_2S_4	8.13 ab	20.27 bc	97.43 bc	9.63 bc	13.7 a	12.4 abc
$LSD_{0.05}$	1.32	3.47	3.28	1.65	2.44	2.35
CV (%)	11.49	10.45	9.51	10.61	13.82	12.94

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability, G_0 = 0 ppm GA_3, G_1 = 25 ppm GA_3, G2 = 50 ppm GA_3, S_1 = 15 cm x 15 cm, S_2 = 20 cm x 20 cm, S_3 = 25 cm x 25 cm, S_4 = 30 cm x 30 cm

Hence, it was noted that treatment combinations 25 ppm GA_3 with 30 cm x 30 cm spacing produced largest dry weight of lettuce (14.7 g) than the rest of other treatment combinations at final harvesting.

3.7 Fresh Yield Plot^{-1}

Variation in respect of fresh yield of lettuce affected significantly due to various concentrations of GA_3, plant spacing and their interactions at different days after sowing (Fig. 3c, Fig. 4c and Table 4, respectively). Plant treated with 25 ppm GA_3 interposed topmost fresh yield of lettuce at final harvesting which was 6.1% higher than control among the different GA_3 doses.

The medium level of GA_3 was associated with increasing of the total number of leaves and fresh weight of lettuce that ultimately gave the highest yield plot^{-1}. Tsiakaras [23] examined the effect of GA_3 on lettuce and confirmed that the optimum rate of GA_3 resulted in the largest number of leaves and maximum fresh weight. Similar results were also found by Miceli [7] related to yield of lettuce.

Besides, closet spacing 15cm x 15cm exhibited the highest fresh yield of lettuce (2324 g) while the lowest fresh yield (989.7 g) was acquired from wider spacing 30 cm x 30 cm at final harvesting.

Wider plant spacing stimulated individual fresh weight of the plant, but due to higher plant density, total yield plot^{-1} was increased by closet spacing. Hasan [20] observed the highest yield of lettuce maintaining closet plant spacing. Moniruzzaman [26] found a significant increase in fresh yield of lettuce at closet spacing over wider spacing due to the higher plant density in a unit area.

Therefore, 25 ppm GA_3 with 15cm x 15cm spacing as a treatment combination was found to be more supreme for the fresh yield of lettuce (2525 g) than other treatment combinations at final harvesting.

3.8 Gross Yield Ha^{-1}

Various levels of GA_3, plant spacing and their interactions exhibited significant variation on gross yield ha^{-1} of lettuce at different days after sowing (Fig. 3d, Fig. 4d and Table 4 respectively). Amid the GA_3 levels, 25 ppm GA_3 displayed the highest gross yield of lettuce at final harvesting that was 30% greater than the control treatment.

The result showed that the optimum dose of GA_3 produced the highest number of leaves, fresh weight and fresh yield which revealed maximum gross yield ha^{-1}. Aliyu [27] suggested that the application of GA_3 was found to be more pronounced in increasing vegetable production.

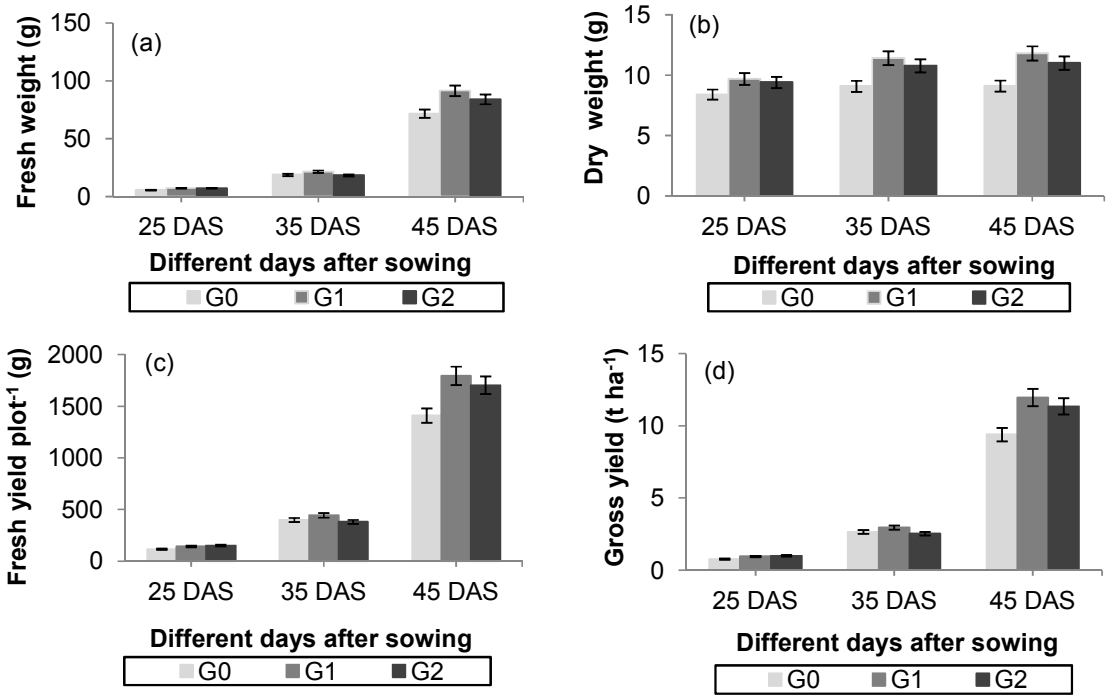

Fig. 3. Effect of different concentration of GA_3 on different yield parameters (a) fresh weight, (b) dry weight, (c) fresh yield plot^{-1} and (d) gross yield ha^{-1}

G0=0 ppm, G1=25 ppm and G2=50 ppm

Table 4. The combined effect of GA_3 and plant spacing on fresh yield and gross yield of lettuce

Treatment	Fresh yield plot^{-1} (g)			Gross yield ha^{-1} (t)		
	25 DAS	35 DAS	45 DAS	25 DAS	35 DAS	45 DAS
G_0S_1	166.8 bc	643.2 ab	1939.0 b	1.11 bc	4.29 ab	12.92 b
G_0S_2	139.2 cd	459.2 c	1486.0 cd	0.93 cd	3.06 c	9.91 cd
G_0S_3	93.3 ef	292.8 de	1345.0 de	0.62 ef	1.95 de	8.96 de
G_0S_4	69.0 f	200.7 f	869.7 f	0.46 f	1.34 f	5.80 f
G_1S_1	192.0 b	586.8 b	1825.0 b	1.28 b	3.48 b	16.13 b
G_1S_2	148.8 c	471.2 c	1766.0 bc	0.99 c	3.14 c	11.78 bc
G_1S_3	143.5 cd	406.9 c	1759.0 bc	0.95 cd	2.71 c	11.73 bc
G_1S_4	89.0 f	227.0 ef	1125.0 ef	0.59 f	1.51 ef	7.50 ef
G_2S_1	242.4 a	672.0 a	2507.0 a	1.61 a	4.48 a	16.83 a
G_2S_2	164.8 bc	430.4 c	1849.0 b	1.10 bc	2.87 c	12.33 b
G_2S_3	119.5 de	305.1 d	1481.0 cd	0.80 de	2.03 d	9.87 cd
G_2S_4	81.3 f	202.7 f	974.3 f	0.54 f	1.35 f	6.50 f
$LSD_{0.05}$	28.83	71.49	288.6	0.19	0.48	1.92
CV (%)	12.39	10.34	10.42	12.37	10.37	10.41

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability, G_0 = 0 ppm GA_3, G_1 = 25 ppm GA_3, G_2 = 50 ppm GA_3, S_1 = 15 cm x 15 cm, S_2 = 20 cm x 20 cm, S_3 = 25 cm x 25 cm, S_4 = 30 cm x 30 cm

Among the plant spacings, the maximum gross yield of lettuce (15.5 t) was remarked from closet spacing 15 cm x 15 cm, whereas minimum gross yield (6.2 t) was measured in wider spacing 30 cm x 30 cm at final harvesting.

It was observed that in the case of higher population density the gross yield of lettuce was increased by less spacing. This observation is following the findings of Plooy [28], who found an increase in plant population resulted in a

significant increase in yield. Similar findings were associated with Moniruzzaman [26].

Among the different treatment combinations, 25 ppm GA_3 with 15 cm x 15 cm spacing was found to be more superior in terms of gross yield of lettuce (16.8 t) than that of other treatment combinations.

3.9 Economic Analysis

Input costs for land preparation, fertilizer, irrigation, equipments and manpower required for all the operations from seed sowing to harvesting, interest on fixed capital of land (Leased land by loan basis) and miscellaneous cost were calculated for unit plot and converted into cost per hectare (Table 5). The price of lettuce leaves were considered as per market value. The economic analysis with the following headings is described below:

3.9.1 Gross return

The interactions of different levels of GA_3 and plant spacing exhibited various values about the gross return of lettuce (Table 5). The uppermost gross return (Tk. 268800) was found from the treatment combinations 25 ppm GA_3 with 25 cm x 25 cm spacing where lowermost gross return (Tk. 168000) in the combinations of 50 ppm GA_3 with 30 cm x 30 cm spacing.

3.9.2 Net return

The net return of lettuce showed different values under the interactions of different levels of GA_3 and plant spacing (Table 5). The highest net return (Tk. 137050) was obtained from the treatment combinations 25 ppm GA_3 with 25 cm x 25 cm spacing whereas lowest net return (Tk. 23890) in the combinations of 0 ppm GA_3 with 15 cm x 15 cm spacing.

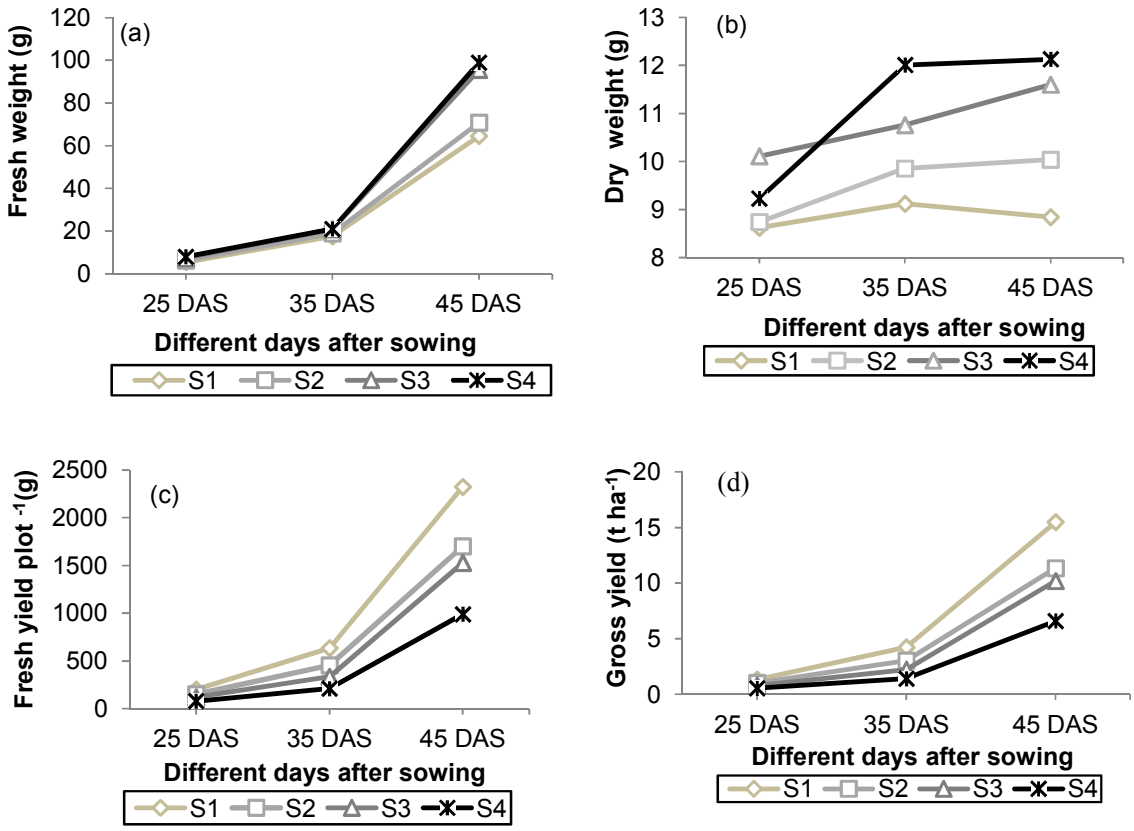

Fig. 4. Effect of different levels of plant spacing on different yield parameters (a) fresh weight, (b) dry weight, (c) fresh yield (g plot^{-1}) and (d) gross yield (t ha^{-1})

S1=15cm x 15cm, S2=20 cm x 20 cm, S3=25 cm x 25 cm and S4=30 cm x 30 cm

Table 5. Cost and return of lettuce cultivation as influenced by different levels of GA_3 and plant spacing

Treatments	Cost of production (Tk./ha)	Gross return (Tk./ha)	Net return (Tk./ha)	Benefit cost ratio (BCR)
G_0S_1	125870	149760	23890	1.19
G_0S_2	125870	172800	46930	1.37
G_0S_3	125870	153600	27730	1.22
G_0S_4	131750	192000	60250	1.46
G_1S_1	131750	207350	75600	1.57
G_1S_2	131750	184320	52570	1.4
G_1S_3	131750	268800	137050	2.04
G_1S_4	131750	216000	84250	1.64
G_2S_1	131750	207360	75610	1.57
G_2S_2	131750	185840	54090	1.41
G_2S_3	131750	182000	50250	1.38
G_2S_4	131750	168000	36250	1.28

Note: G_0 = 0 ppm GA_3, G_1 = 25 ppm GA_3, G_2 = 50 ppm GA_3, S_1 = 15cm x 15cm, S_2 = 20cm x 20cm, S_3 = 25cm x 25cm, S_4 = 30cm x 30cm. GA_3= 6000 tk/lit, Lettuce = 10 tk/kg, Cowdung = 10 tk/kg, Urea =16 tk/kg, TSP = 40 tk/kg and MP= 70 tk/kg

3.9.3 Benefit-cost ratio

The combinations of various levels of GA_3 and plant spacing revealed different values with the benefit-cost ratio of lettuce (Table 5). The interactions of 25 ppm GA_3 with 25 cm x 25 cm spacing recorded topmost benefit-cost ratio (2.04) while the lowest benefit-cost ratio (1.19) was obtained from the combinations of 0 ppm GA_3 with 15 cm x 15 cm spacing. From the economic point of view, it can be said that the treatment combinations 25 ppm GA_3 with 25 cm x 25 cm spacing was more supreme than that of other treatment combinations.

4. CONCLUSION

This study concludes that the different levels of GA_3 application and plant spacing significantly affected the growth and yield of lettuce. Among different levels of GA_3applications, 25 ppm GA_3 produced maximum growth and yield of lettuce. Moreover, the highest growth and yield with healthy leaves were obtained from the wider plant spacing i.e. 30 cm x 30 cm, however, the maximum fresh gross yield was recorded from closure spacing 15 cm x 15 cm due to the higher population density. The highest benefit-cost ratio was found in treatment combinations 25 ppm GA_3 with 25 cm x 25 cm spacing. From the different points of view including economic consideration, we recommend 25 ppm GA_3 with optimum spacing 25 cm x 25 cm would be more suitable for lettuce cultivation. However, further experimentation is required for overall conclusion for a practical purpose.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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