RESEARCH ARTICLE

Influence of Plant Spacing on Growth, Phenology, and Calyx Yield of Roselle (*Hibiscus sabdariffa* L.) under Subtropical Conditions

Zahid Hossain Hridoy, Md. Moshiur Rahman, Md. Parvez Anwar, Md. Ismail Hossain and Swapan Kumar Paul*

Department of Agronomy, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh

Received: 19 Nov 2025

Revised: 14 Jan 2026

Accepted: 20 Feb 2026

ABSTRACT

The experiment investigated the effect of spacing on roselle growth and calyx yield. The experiment consists of seven spacings, viz., 30 cm × 30 cm (S_1), 60 cm × 30 cm (S_2), 60 cm × 45 cm (S_3), 60 cm × 60 cm (S_4), 90 cm × 30 cm (S_5), 90 cm × 45 cm (S_6), and 90 cm × 60 cm (S_7). The experiment was conducted in a randomized complete block design with three replications. According to the study, the shortest duration from sowing to 50% budding (101 days) was recorded at S_1, whereas S_7 required the least time to reach 50% flowering (115 days), and to 90% maturity (148 days). The widest spacing (S_7) produced the tallest plants (196.87 cm), number of branches (14.33), number of leaves (134.22), the longest petiole (5.91 cm), petiole weight (24.41 g plant^{-1}), and stem weight (131.39 g plant^{-1}). The highest leaf area index (6.82) was found in S_1. Spacing of S_7 also produced the maximum number of fruits per plant (mature-70.41, immature-15.83), largest fruit size (6.46 cm), total fruit weight (93.73 g plant^{-1}), and calyces weight (44 g plant^{-1}). The highest fruit yield (fresh-36.77 t ha^{-1}, dry-2.25 t ha^{-1}), calyx yield (fresh -17.15 t ha^{-1}, dry-0.69 t ha^{-1}), and seed yield (fresh-19.62 t ha^{-1}, dry -1.57 t ha^{-1}) were obtained at S_4. Based on the findings, roselle cultivation at a spacing of 60 cm × 60 cm (S_4) is optional to achieve maximum calyx yield under Bangladesh conditions.

Keywords: *Roselle, Spacing, Growth, Calyx, Yield*

INTRODUCTION

Roselle (*Hibiscus sabdariffa*) is a tropical tetraploid (2n=72) annual crop of the Malvaceae family, originating in West Africa and now widely grown across tropical and subtropical regions (Jamini *et al.,* 2019; Omenna *et al.,* 2023). More than 300 species of roselle have been grown throughout the southern United States, Mexico, Central America, and the West Indies (Jadhav *et al.,* 2025). Major producing countries include Nigeria, Sudan, Thailand, and India, with yields ranging from 1.5–3 t/ha (El-Naim *et al.,* 2012). Roselle is popularly known as 'mesta' or 'chukur' in the Indian subcontinent, including Bangladesh. It grows in warm climates and produces yellow flowers with crimson calyces rich in "anthocyanins" (Basazinew Degu & Bizuayehu Tesfaye, 2016). Calyx is used in various foods and herbal beverages due to its high antioxidant content, nutrients, low in calories, and offers several health benefits, including anti-hypertensive and anti-cancer properties (Thimmaiah *et al.,* 2024). The crop is rich in protein (1.5%), fibre, calcium, iron, carotenes, vitamin C, phenolics, and sugars (6–8%), contributing to antimicrobial activity, diabetes control, reduced blood pressure (7–10 mmHg), lower cholesterol (10–15%), and anaemia prevention through folate-rich

*Corresponding author mail: skpaul@bau.edu.bd

leaves (El-Sagher *et al.,* 2024; Gebremedin, 2015; Hopkins *et al.,* 2013).

Despite its economic potential, roselle agronomic practices are largely optimized for fibre rather than calyx yield. Plant spacing plays a critical role in regulating growth, light interception, nutrient uptake, LAI development, and photosynthetic efficiency, ultimately influencing biomass and yield (Gebremedin, 2015; Paul *et al.,* 2018; Nazifi *et al.,* 2024). Many growers continue to use narrow spacing suitable for fibre production, even though wider spacing is often more favourable for calyx yield. Density affects growth traits such as plant height, leaf number, branching, and flower production, and interacts strongly with nutrient management (Inuwa *et al.,* 2022; Mendoza-Pérez *et al.,* 2024). Although closer spacing increases calyces per plant, intermediate spacing consistently produces the highest calyx yield per hectare by balancing individual plant performance and population productivity (Bako, 2025; El-Naim *et al.,* 2012).

Although roselle has been widely studied, spacing recommendations still vary due to differences in genotype, environment, and management practices. Since plant density plays a key role in shaping growth, flowering, and yield, this study examined how different spacing levels affect roselle phenology, growth, and calyx yield in Bangladesh, where local information remains limited.

MATERIALS AND METHODS

Description of the Experimental Site

The experiment was carried out at the Agronomy Field Laboratory of Bangladesh Agricultural University in Mymensingh from July 2023 to February 2024. The site (24 ° 75' N, 90 ° 50' E; 18 m elevation) lies in the Old Brahmaputra Floodplain (AEZ-9) with Sonatala series dark grey floodplain soil. The area is situated in a sub-tropical climate with heavy precipitation from April to October, and minimal rainfall from October to March (Figure 1).

Experimental Treatments, Design and Layout

The experiment comprised seven spacing treatments *viz*., viz., 30 cm × 30 cm (S_1), 60 cm × 30 cm (S_2), 60 cm × 45 cm (S_3), 60 cm × 60 cm (S_4), 90 cm × 30 cm (S_5), 90 cm × 45 cm (S_6), and 90 cm × 60 cm (S_7). The experiment followed a Randomized Complete Block Design with three replications. Each 6.0 m × 4.5 m plot (27.0 m²) contained seven treatments, randomly assigned, for a total of 21 plots. A spacing of 0.75 m between replications and 0.50 m between plots was maintained.

Planting material

The roselle variety, namely, BJRI VM-1 (Mesta-2), was used in the experiment. The seeds of these varieties were collected from the Bangladesh Jute Research Institute. BJRI VM-1 (Mesta-2) is a widely adaptable, disease-resistant, high-yielding, early maturing variety with a robust growth habit.

Cultural operations

The field was prepared with two ploughings and laddering, subsequently levelled and cleared of all weeds and residues. The land was prepared, and the layout of the plots was finalised on 26 July 2023, in accordance with the experimental design. Fertilisers were applied at 70 kg ha⁻¹ N, 20 kg ha⁻¹ P,

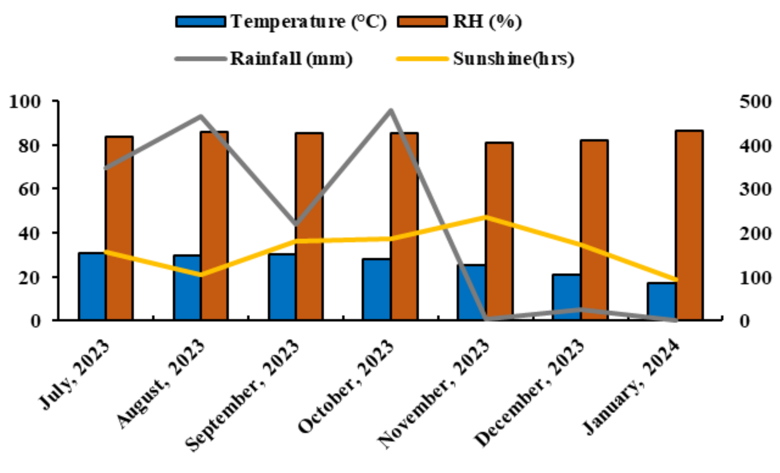

Figure 1: Monthly average temperature, rainfall, relative humidity, and sunshine (hr) during the experimental period

40 kg ha⁻¹ K, and 3.5 kg ha⁻¹ Zn, utilising urea, TSP, MoP, and zinc sulphate. One-third of the nitrogen and all other fertilisers were incorporated during the final land preparation, while the remaining nitrogen was applied at 30 and 60 DAS. Seeds were sown on 27 July 2023 according to the treatment, with three seeds planted in hill^{-1}.

Intercultural operations

Two hand weedings were done at 30 and 50 DAS. Thinning was done to keep one healthy seedling per hill at 30 days following seeding, and any spaces were replaced. The monsoon rains eliminated the need for additional irrigation, although drainage was installed to prevent waterlogging. Sevin 85SP was applied at 1.7 kg per acre to control mealybug infestations.

Sampling, Harvesting, and Processing

Data on 50% flowering were recorded on 30 November 2023. Four randomly selected plants (excluding border plants) were uprooted from each unit plot for plant characterisation and 90% physiological maturity. Red or crimson, firm calyces, fading flowers, enlarged calyces and drying seed pods identified maturity. Harvesting was carried out on 30 January 2024 from a 180 cm × 180 cm area at the centre of each plot. The harvested samples were tagged and transported to the Agronomy Field Laboratory threshing floor. Calyces were separated using a sharp knife, and seed pods were removed with a coring tool.

Data Collection

For data collection, five plants were randomly selected from each plot, and observations were recorded on vegetative growth, yield, and quality-related traits. The collected data included phenological parameters such as days to 50% flower bud appearance, 50% flowering, and 90% physiological maturity. At 50% flowering, plant height, number of main branches, number of leaves, leaf area index, leaf weight, petiole length, petiole weight, and stem weight were measured. At 90% physiological maturity, the number of fruits per plant, fruit length, fruit weight, and calyx weight were recorded. At harvest, biological yield, fruit yield, calyx yield, and seed yield were obtained.

Procedure for Leaf Area Index (LAI) data collection

The ground area occupied by each plant, based on the spacing in the plot, was determined, and the leaf area index was calculated using the following formula:

$$LAI = \frac{\text{Total leaf area of plant}}{\text{Ground area occupied by plant}}$$

Statistical Analysis

The data were examined using the Analysis of Variance (ANOVA) method, employing the statistical software packages Statistix-10 and R. Subsequently, mean differences were assessed using the Least Significant Difference (LSD) test.

RESULTS AND DISCUSSION

Phenological Characteristics

Number of days from sowing to 50% budding

The number of days from sowing to 50% budding varied widely among different spacings. The highest number of days from sowing to 50% budding was observed in S_4 (103), and the lowest number of days (101) in S_1 (Table 1). Closer spacing led to a faster transition to 50% budding in roselle plants compared to wider spacings, likely due to increased competition for light and resources, which accelerated early development, whereas wider spacings allowed slower but more robust vegetative growth (Kaur *et al.,* 2024).

Number of days from sowing to 50% flowering

Spacing clearly affected flowering time. The highest number of days (116.67) was observed with S_1, and the lowest number of days (115) was observed with S_7 (Table 1). Wider spacing enhanced light penetration and air circulation within the canopy, promoting healthier plant growth and contributing to faster flowering (Talpur *et al.,* 2023).

Number of days from sowing to 90% maturity

Spacing clearly influenced how quickly the plants matured. Plants in S_1 took the longest to reach 90% maturity (154 days), while the widest spacing (S_7) matured earliest (148 days), similar to S_4 (Table 1). Wider spacing allowed plants to reach maturity faster than the closest spacing, due to reduced competition for light, water, and nutrients (Pokhrel *et al.,* 2023).

Growth parameters

Plant height

Different spacings significantly influenced plant height. The highest plant height (196.87 cm) was found with S_7. The lowest plant height (155.59 cm) was found with S_1 (Table 2). Due to less competition and better access to light,

Table 1. Effect of spacing on phenological characteristics of roselle

Spacing	Sowing to 50% budding (days)	Sowing to 50% flowering (days)	Sowing to 90% maturity (days)
S_1	101.00 c	116.67 a	154.00 a
S_2	102.00 b	116.00 ab	151.33 b
S_3	102.00 b	115.33 bc	151.00 b
S_4	103.00 a	115.33 bc	148.33 c
S_5	102.00 b	116.00 ab	151.33 b
S_6	102.33 b	115.33 bc	150.67 b
S_7	103.00 a	115.00 c	148.00 c
Sig. Level	***	*	***
SE (±±)	1.782	0.378	0.767
CV (%)	0.21	0.40	0.62

In a column, the figures with the same letter(s) or without letter do not differ significantly, whereas figures with dissimilar letter(s) differ significantly. *= Significant at 5% level of probability, *** = Significant at 0.1% level of probability.

water, and nutrients, roselle plants spaced 50 × 50 cm grew higher than those spaced 30 × 30 cm (Bako, 2025)

Number of main branches plant^{-1}

Spacing affected the number of main branches per plant, with the highest (14.33) at S_7 and the lowest (6.00) at S_1 (Table 2). Roselle plants spaced 60 cm apart had more main branches than those at 30 cm, due to reduced competition, allowing bushier growth (Mendoza-Pérez *et al.,* 2024).

Number of leaves plant^{-1}

The number of leaves per plant varied with spacing: S_7 had the most (134.22), comparable to S_4 and S_6, and S_1 had the fewest (105.00), followed by S_2 (Table 2). Reducing plant density or increasing spacing allows each roselle plant to grow more vigorously, leading to enhanced leaf production (Ado *et al.,* 2015).

Leaf area index

Different spacings have a considerable impact on the leaf area index. The highest leaf area index (6.82) was found with S_1. The lowest leaf area index (1.52) was found with S_7 (Table 2). Roselle plants spaced at 30 cm exhibited a higher leaf area index than those at 50 cm, indicating that closer spacing increases leaf density and canopy coverage. However, excessively close spacing may lead to greater competition for light, water, and nutrients, potentially limiting overall plant growth and yield. Optimal spacing, therefore, is essential to balance leaf development with resource availability for healthier, more productive plants (Khan & Islam, 2023; Zuo *et al.,* 2024).

Weight of leaves plant^{-1}

Different spacings significantly influenced the weight of leaves plant^{-1}. The highest weight of leaves (134.99 g) was found with S_7 and the lowest weight of leaves (107.87 g) was found with S_1 (Table 2). Wider spacing reduces competition, allowing roselle plants to grow larger and produce heavier leaves. Closer spacing, on the other hand, increases competition and reduces leaf weight per plant despite higher total biomass (Muhie & Yimer, 2023).

Petiole length

Different spacings have a substantial impact on petiole length. The highest petiole length (5.91 cm) was found with S_7 and the lowest petiole length (4.67 cm) was found with S_1 (Table 2). Plants grown with wider spacing had longer petioles, as reduced competition allows more resources to be directed toward vegetative growth, including petiole elongation (Khattak *et al.,* 2016).

Weight of petioles plant^{-1}

Different spacings significantly influenced the weight of petioles plant^{-1}. The heaviest petioles (24.41 g) were found with S_7. The lowest petiole weight (19.54 g) was observed with S_1 (Table 2). Wider spacing lets roselle plants grow bigger petioles, increasing their weight, and shows how

Table 2. Effect of spacing on growth parameters of roselle

Spacing	Plant height (cm)	Branches plant^{-1} (no.)	Leaves plant^{-1} (no.)	Leaf area index	Weight of leaves (g)	Petiole length (cm)	Weight of petioles (g)	Stem weight (g)
S_1	155.59 e	6.00 e	105.00 d	6.82 a	107.87 e	4.67 d	19.54 c	84.60 d
S_2	158.23 de	7.67 d	112.11 cd	3.82 b	111.78 de	4.87 cd	21.47 b	102.90 c
S_3	165.53 c	11.45 bc	120.89 b	2.67 c	120.00 bc	5.42 b	21.71 b	104.29 c
S_4	191.22 a	13.55 a	131.22 a	2.11 d	124.67 b	5.47 b	23.93 a	113.82 b
S_5	164.40 cd	10.45 c	116.89 bc	2.61 c	114.78 cd	5.15 bc	21.71 b	103.39 c
S_6	181.73 b	12.22 b	128.89 a	1.85 e	122.43 b	5.42 b	23.54 a	106.62 bc
S_7	196.87 a	14.33 a	134.22 a	1.52 f	134.99 a	5.91 a	24.41 a	131.39 a
Sig. Level	***	***	***	***	***	***	***	***
SE(±±)	3.344	0.473	3.641	0.273	2.465	0.184	0.589	3.706
CV (%)	2.36	5.36	3.68	10.86	2.53	4.28	3.23	4.25

In a column, the figures with the same letter(s) or without letter do not differ significantly, whereas figures with dissimilar letter(s) differ significantly. *= Significant at 5% level of probability, *** = Significant at 0.1% level of probability

giving plants room can boost yield in vegetative crops (Khattak *et al.,* 2016).

Stem weight plant^{-1}

Stem weight plant^{-1} was significantly affected by spacing. The highest stem weight (131.39 g) was found with S_7, and the lowest stem weight (84.60 g) was found with S_1 (Table 2). Optimal spacing enhances stem biomass in roselle, making wider spacing a preferred approach for maximizing stem yield (Li *et al*., 2025).

Yield attributes

Length of fruits

Fruit length was significantly influenced by different spacings. The highest length of fruits (6.46 cm) was found with S_7, and the lowest length of fruits (4.77 cm) was found with S_1 (Table 3). Wider plant spacing, such as 60 cm, increased the length of *Hibiscus sabdariffa* fruits compared to denser spacing of 30 cm because of reduced inter-plant competition and improved resource availability (Ogam *et al*., 2024).

Weight of fruits plant^{-1}

Different spacings had a substantial impact on fruit weight per plant. S_7 produced the heaviest fruits (93.73 g). S_1 had the fruits with the lowest weight (58.27 g) (Table 3). Due to increased photosynthetic efficiency and better resource availability, roselle plants grown at wider spacing yielded noticeably larger fruit weights (Talpur *et al.,* 2023).

Weight of calyces plant^{-1}

Calyx weight per plant was significantly affected by spacing, with the highest value (44.00 g) recorded in S_7 and the lowest (22.22 g) in S_1 (Table 3). Because of better light access and reduced interplant competition, wider spacing increased nutrient uptake and plant growth, leading to a noticeable increase in calyx weight (ALobaidy *et al.,* 2023).

Biological yield

Plant spacing significantly affected biological yield. S_4 had the highest value (13.87 t ha^{-1}), while S_7 had the lowest yield (8.45 t ha^{-1}) (Table 3). In roselle cultivation, a 50 × 50 cm spacing maximised plant size and population density, leading to a higher biological yield per unit area than either closer or wider spacings (Samari *et al.,* 2023).

Number of fruits plant^{-1}

Different spacing treatments significantly influenced the number of fruits per plant. The highest number of mature fruits per plant (70.41) was recorded under S_7, whereas the lowest number (32.50) was observed under S_1. The maximum number of immature fruits per plant (15.83) was obtained from S_7, while the minimum number (9.58) was recorded under S_1 (Figure 2-A). Closer spacing tends to limit branch development and fruit production per plant in *Hibiscus* species due to increased inter-

Table 3. Effect of spacing on yield attributes and yield of roselle

Spacing	Fruits length (cm)	Fruits weight (g plant^{-1})	Calyces weight (g plant^{-1})	Biological yield (t ha^{-1})
S_1	4.77 d	58.27 e	22.22 e	10.90 c
S_2	5.80 c	67.20 de	27.16 d	12.20 b
S_3	6.16 ab	78.91 bc	36.03 c	12.34 b
S_4	6.30 ab	86.11 ab	39.73 b	13.87 a
S_5	6.02 bc	73.56 cd	28.61 d	10.03 d
S_6	6.21 ab	81.75 bc	38.69 bc	9.27 e
S_7	6.46 a	93.73 a	44.00 a	8.45 f
Sig. Level	***	***	***	***
SE(±±)	0.144	4..830	1.606	0.305
CV (%)	2.95	7.67	5.82	3.39

In a column, the figures with the same letter(s) or without letter do not differ significantly, whereas figures with dissimilar letter(s) differ significantly. *= Significant at 5% level of probability, *** = Significant at 0.1% level of probability.

plant competition. Roselle plants spaced 60 × 60 cm can produce more fruits than those at 30 × 30 cm, showing that giving plants enough space helps them grow stronger and produce more (Abrham & Shumbulo, 2024; Khan & Islam, 2023).

Fruit yield

Fruit yield varied significantly among spacing treatments, with the highest yield (36.77 t ha^{-1}) recorded in S_4 and the lowest (20.17 t ha^{-1}) in S_7. The highest dry fruit yield (2.25 t ha^{-1}) was found with S_4. The lowest dry fruit yield (1.24 t ha^{-1}) was found with S_7 (Figure 2-B). Wider plant spacing improved fruit yield and quality in roselle. The highest fresh fruit yield was achieved at 50 cm × 50 cm spacing due to reduced plant competition and more efficient use of light, water, and nutrients, which enhanced photosynthesis and fruit development (Samari *et al.,* 2023).

Calyx yield

Calyx yields were significantly influenced by plant spacing. The highest fresh calyx yield (17.15 t ha^{-1}) and dry calyx yield (0.69 t ha^{-1}) were recorded in S_4, while the lowest fresh (9.41 t ha^{-1}) and dry (0.38 t ha^{-1}) yields were observed in S_7 (Figure 2-C). Wider plant spacing produced better yield performance depending on soil and environmental conditions. An optimal spacing of 60–75 cm maximized fresh calyx yield by balancing individual plant growth with overall field productivity, reducing competition for light, water, and nutrients, and promoting better canopy development and photosynthetic efficiency (Gebremedin, 2015; Mendoza-Pérez *et al.,* 2024).

Seed yield

Fresh seed yield was significantly affected by spacing, with the highest yield (19.62 t ha^{-1}) in S_4 and the lowest (10.77 t ha^{-1}) in S_7. The highest dry seed yield (1.57 t ha^{-1}) was found with S_4. The lowest fresh seed yield (0.86 t ha^{-1}) was found with S_7 (Figure 2-D). Wider spacing optimized both individual plant performance and total seed yield per hectare, emphasizing the need to adjust spacing according to specific environmental and cultivation conditions. Roselle plants spaced at 60 × 40 cm produced higher seed yield than closer spacings, due to reduced inter-plant competition and enhanced vegetative growth (El-Sagher *et al.,* 2024).

Heatmap analysis

A heatmap was used to illustrate the relationships between growth traits and calyx yield of roselle (*Hibiscus sabdariffa*) under different plant spacing treatments (Figure 3). Growth and yield variables are shown on the x-axis, while spacing treatments appear on the y-axis. The heat map revealed clear differences in trait responses across spacing levels. Fresh calyx yield, fresh fruit yield, fresh seed yield, dry seed yield, days to flowering, days to maturity, and leaf area index showed higher contributions under optimum spacing, indicating favorable growth and yield performance. In contrast, plant height, calyx weight, leaf number, petiole length, leaf length, and leaf weight showed lower contributions at closer or non-optimal spacing, suggesting greater vegetative growth at the expense

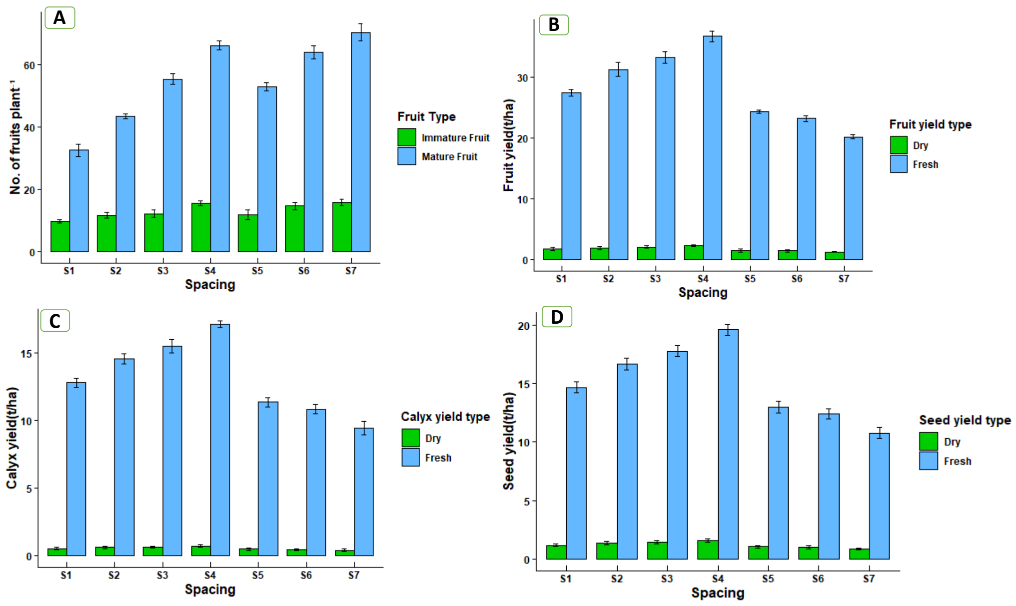

Figure 2. Effect of spacing on yield attribute characters of roselle (S$_1$ = 30 cm × 30 cm, S$_2$ = 60 cm × 30 cm, S$_3$ = 60 cm × 45 cm, S$_4$ = 60 cm × 60 cm, S$_5$ = 90 cm × 30 cm, S$_6$ = 90 cm × 45 cm, S$_7$ = 90 cm × 60 cm; Bar represents standard error)

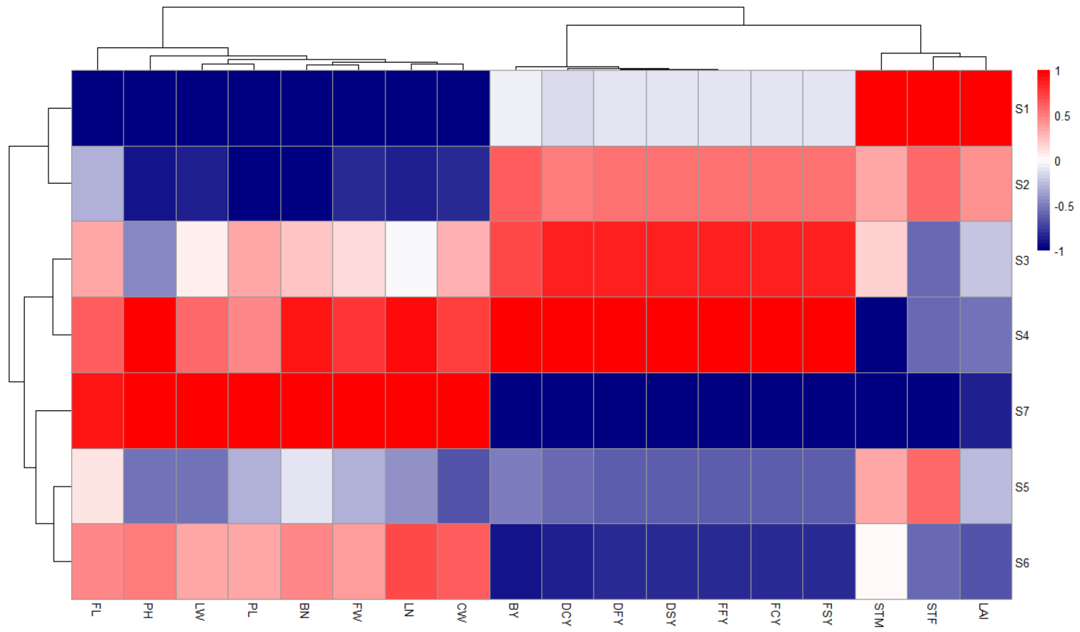

Figure 3: Heatmap analysis of growth and yield traits of roselle (Hibiscus sabdariffa) under different plant spacing

***, **, * and ns (not significant) represent probability of ≤0.001, ≤0.01, ≤0.05 and >0.05, respectively. Where, STB= No of days from sowing to 50% budding, STF= No of days from sowing to 50% flowering, STM= No of days from sowing to 90% maturity, PH= Plant height (cm), BN= Branches (plant^{-1}), LN= Leaf number, LAI= Leaf area index (cm^2), LW= Leaves weight (g), PL= Petiole length (cm), PW= Petioles weight (g), SW= Stem weight(g), MF= Mature fruits, IMF= Immature fruits, FL= Fruit Length (cm), FW= Fruit weight (g), CW= Calyx weight (g), BY= Biological yield, FFY= Fresh fruit yield (t ha^{-1}), DFY= Dry fruit yield (t ha^{-1}), FCY= Fresh calyx yield (t ha^{-1}), DCY= Dry calyx yield (t ha^{-1}), FSY= Fresh seed yield (t ha^{-1}), DSY= Dry seed yield(t ha^{-1})

of yield efficiency. Overall, the heat map shows that optimal spacing improves calyx yield primarily by enabling efficient biomass accumulation and balanced structural growth, rather than excessive vegetative expansion.

CONCLUSION

The study demonstrates that plant spacing significantly affects the vegetative growth, phenological development and yield attributes of roselle. Wider spacing enhances individual plant performance, such as branching, leaf number, fruit, and calyx weight plant^{-1}. In contrast, intermediate spacing (60 cm × 60 cm) produces the highest fruit, calyx, and seed yields per hectare. Therefore, cultivation of roselle at a spacing of 60 cm × 60 cm is suggested to maximize calyx yield and achieve sustainable productivity under Bangladesh's agro-climatic conditions.

Funding and Acknowledgment:

The author(s) received no specific funding for this work.

Ethics Statement:

Ethical approval was not applicable for this research experiment as only plant materials were used.

Originality and Plagiarism:

Authors confirm that this manuscript is an original work. No parts of the manuscript have been previously published, and proper citations have been provided. There is no known plagiarism in any form in this article.

Consent for Publication:

All authors agree to the content of the article and its publication in this journal.

Competing Interests:

Authors have no potential conflicts of interest, financial or otherwise, that could affect the research or its interpretation.

Data Availability:

The data supporting the findings of this study are included in the manuscript as tables and figures.

Author Contributions:

Zahid Hossain Hridoy conducted the experiment, analyzed the data, and prepared the first draft of the manuscript. Md. Moshiur Rahman assisted with experimental design and supervised the research. Md. Parvez Anwar contributed to data analysis and interpretation, and supervised the study. Md. Ismail Hossain assisted in field data collection and manuscript preparation. Swapan Kumar Paul critically revised the manuscript and approved the final version for publication.

REFERENCES

Abrham, Y. and Shumbulo, A. 2024. Growth, yield and quality response of Eggplant (*Solanum melongena* L.) to blended NPSB fertilizer rates and intra-row spacing in Boloso Bombe district, Wolaita zone, South Ethiopia. *Heliyon,* **10(15)**: e35671 https://doi.org/10.1016/j.heliyon.2024.e35671

Ado, G., Indabawa, I. and Sani, K.D. 2015. Effect of planting date and seed density on the growth and yield of roselle (*Hibiscus sabdariffa* L). *International Conference on Chemical, Environmental and Biological Sciences (CEBS-2015) Dubai, UAE*. https://dx.doi.org/10.15242/IICBE.C0315133

ALobaidy B. S. J., Hamed M. A., Ramadan A. S. A.-a., Malik M., & Ali F. A. 2023. Effect of plant distance and cultivation methods on the growth and yield of three sesame cultivars. *Bionatura*., 8: 1-11. https://dx.doi.org/10.21931/RB/ 2023.08.01.4

Bako, M.P. 2025. Assessing the Influence of Spacing on the Growth of Sorrel in Bali, Taraba State. *Journal of Agricultural and Environmental Science Research*., *7*(1): 272-289. https://doi.org/10.70382/hujaesr.v7i1.023

Basazinew Degu, B. D., & Bizuayehu Tesfaye, B. T. 2016. Effects of inter and intra row spacing on growth, yield and yield components of roselle (*Hibiscus sabdariffa* L.). *International Journal of Advanced Biological and Biomedical Research,* **4(3)**: 261-275. https://doi.org/10.18869/IJABBR.2016.260

Li, R., Xu, C., Wu, Z., Xu, Y., Sun, S., Song, W., & Wu, C. 2025. Optimizing canopy-spacing configuration increases soybean yield under high planting density. *The Crop Journal*, *13*(1): 233-245. https://doi.org/10.1016/j.cj.2024.12.005

El-Naim, A. M., Khaliefa, E. H, Ibrahim, K. A., Ismaeil, F. M., & Zaied, M. M. B. 2012. Growth and yield of roselle (*Hibiscus sabdariffa* l.) as influenced by plant population in arid tropic of Sudan under rain-fed. *International Journal of Agriculture and Forestry*, Vol. **2(3)**: 88-91. https://doi.org/10.5923/j.ijaf.20120203.02

El-Sagher, M., Mostafa, G. G., El-Ghadban, E.-M. A., Soliman, W. S., & Gahory, A.-A. 2024. Sowing date as a determining factor for roselle (*Hibiscus* *sabdariffa*) production: I. Effect on vegetative and yield components. *Aswan University Journal of Sciences and Technology*, *4*(1): 28-37. https://doi.org/10.21608/aujst.2023.252248.1072

Gebremedin, B. D. 2015. Influence of variety and plant spacing on yield and yield attributes of roselle (*Hibiscus sabdariffa* L). *Science, Technology and Arts Research Journal*, *4*(4): 25-30. https://dx.doi.org/10.4314/star.v4i4.4

Hopkins, A. L., Lamm, M. G., Funk, J. L., & Ritenbaugh, C. 2013. *Hibiscus sabdariffa* L. in the treatment of hypertension and hyperlipidemia: a comprehensive review of animal and human studies. *Fitoterapia*, *85*: 84-94. https://doi.org/10.1016/j.fitote.2013.01.003

Inuwa, N. M., Fagge, A. A., Mohamed, A. M. L., Lado, A., & Aliyu, A. M. 2022. Effect of stand densities and npk fertilizer on growth and calyx yield of roselle (*Hibiscus sabdariffa* L.) in Sudan Savanna zone of Nigeria: An Approach towards Growth Characters. *Journal of Experimental Agriculture International*, *44*(10): 238-247. https://doi.org/10.9734/JEAI/2022/v44i1030900

Jadhav, T. K., Awari, V. R., Dalvi, U. S., Narale, S. B., Gund, S., & Gore, V. B. 2025. Morpho-physio characters study, biochemical and calyx growth yield variation of roselle (*Hibiscus sabdarriffa* l.). *Plant Archives*, *25*(1): 2388-2398. https://doi.org/10.51470/PLANTARCHIVES.2025.v25.supplement-1.327

Paul, S. K., Paul, U., Sarkar, M. A. R., & Hossain, M. S. 2018. Yield and quality of tropical sugarbeet as influenced by variety, spacing and fertilizer application. *Sugar Tech*, 20(2), 175-181. https://doi.org/10.1007/s12355-017-0545-3

Jamini, TS., Islam, A. AKM., Mohi-ud-Din, M., & Saikat, H. MM. 2019. Phytochemical composition of calyx extract of roselle (*Hibiscus sabdariffa* L.) genotypes. *Journal of Agriculture and Food Sciences*, 16(1): 13–19. https://doi.org/10.4314/jafs.v16i1.2

Kaur, R., Kondal, P., Singh, N., Maurya, V., Sharma, A., & Kumar, R. 2024. Effect of spacing and sowing dates on growth, yield and quality of pea (*Pisum sativum* L.). International Journal of Research in Agronomy, *7*(2): 238-251. https://doi.org/10.33545/2618060X.2024.v7.i2d.312

Khan, M. A. H., & Islam, M. 2023. Performance of row spacing on the yield of sesame varieties. *Bangladesh Agronomy Journal*, *26*(1): 28-31. https://doi.org/10.3329/baj.v26i1.47645

Khattak, A. M., Sajid, M., Sarwar, H. Z., Rab, A., Ahmad, M., & Khan, M. A. 2016. Effect of sowing time and plant density on the growth and production of roselle (Hibiscus sabdariffa). *Int. J. Agric. Biol*, 18: 1219-1224. https://doi.org 10.17957/IJAB/15.0215

Mendoza-Pérez, C., Rubiños-Panta, J. E., Exebio-García, A. A., Delgadillo-Piñón, M. E., & Cazares-González, B. 2024. Evaluation of commercial biostimulants at three planting densities in roselle (*Hibiscus sabdariffa* L.) crop, guerrero variety. *Agro Productividad*, 17(11): 165-174. https://doi.org/10.32854/agrop.v17i11.2893

Muhie, S. H., & Yimer, H. S. 2023. Growth and yield performance of carrot (*Daucus carota* L.) as influenced by plant population density under irrigation condition. *Advances in Horticultural Science*, 37(3): 307-315. https://doi.org/10.36253/ahsc-14158

Nazifi, M., Madina, P., & Imrana, B. 2024. Production of roselle (*Hibiscus sabdarjffa* L.) as influenced by density and fertilizer rate in Kano state, Nigeria. *International Journal of Agriculture and Earth Science (IJAES) E-ISSN*, 2489-0081, Vol **10**: 37-53. https://doi.org/10.56201/ijaes.v10.no3.2024.pg37

Ogam, SS., Parulekar, YR., & Haldavanekar, PC. 2024. Effect of spacing and ratooning on growth and yield of okra (*Abelmoschus esculentus* L.) Var. Lal Bhendi No. 533. *J Adv Biol Biotechnol*, 27: 434-444. https://doi.org/10.9734/jabb/2024/v27i111628

Omenna, E., Olanipekun, O. T., Ejigbo, E.A., Farinde, E.O., Adelakun, O.J., Fasoyiro, S.B., & Ashaye, O.A. 2023. Knowledge-based assessment and training of agricultural development programme (adp)-staff on roselle as a functional and economic valuable crop for food security and income generation. *Sustainability, Agri, Food and Environmental Research-discontinued*, *11*. https://doi.org/10.7770/safer-V13N1-art657

Pokhrel, A., Manandhar, S., & Dangi, S. R. 2023. Effect of sowing date and variety on pigeonpea production in Nepal. *Asian Journal of Research in Crop Science*, *8*(3): 173-178. https://doi.org/10.9734/AJRCS/2023/v8i3177

Samari, L.K., Fagam, A.S., Shuaibu, Y.M, & Bala, R.A. (2023). Effects of nitrogen and spacing on growth and yield of kenaf (*Hibiscus Cannabinus* L.) in Bauchi state, Nigeria. *Nigerian Journal of Agriculture and Agricultural Technology*, 3(2): 159-167. https://doi.org/10.59331/njaat.v3i2.549

Talpur, M. M. A., Shaghaleh, H., Ali Adam Hamad, A., Chang, T., Zia-ur-Rehman, M., Usman, M., & Alhaj Hamoud, Y. 2023. Effect of planting geometry on growth, water productivity, and fruit quality of tomatoes under different soil moisture regimes. *Sustainability*, *15*(12): 9526. https://doi.org/10.3390/su15129526

Thimmaiah, M. R., Kumar, A. A., Mitra, J., & Kar, G. 2024. Agro-morphological and nutritional profiling of different roselle (*H. sabdariffa* var. sabdariffa) morphotypes. *Vegetos*, 37(1): 397-403. https://doi.org/10.1007/s42535-023-00608-2

Zuo, W., Wu, B., Wang, Y., Xu, S., Chen, M., Liang, F., Tian, J., & Zhang, W. 2024. Optimal row spacing configuration to improve cotton yield or quality is regulated by plant density and irrigation rate. *Field Crops Research*, *305*: 109187. https://doi.org/10.1016/j.fcr.2023.109187