Research Article

Journal of Sher-e-Bangla Agricultural University 15, 43-52
ISSN 1997-6038

EFFECT OF SPACING AND VARIETY ON BIOMASS PRODUCTION AND QUALITY OF *Moringa oleifera* L.

M. H. Hossain[1], N. Sultana[1], J. Nesa[1], H. Kausar[1] and N. Sultana[2*]

[1]*Department of Agroforestry and Environmental Science, Sher-e-Bangla Agricultural University, Dhaka-1207,*
[2]*Chief Scientific Officer, Bangladesh Livestock Research Institute, Savar, Dhaka*
***Corresponding author**: director.research@blri.gov.bd*

Cite as
Hossain, M. H., Sultana, N., Nesa, J., Kausar, H. and Sultana, N. 2024. Effect of spacing and variety on biomass production and quality of *Moringa oleifera* L.. J. Sher-e-Bangla Agric. Univ. 15 (1&2): 43-52.

ABSTRACT

Moringa (*Moringa oleifera* Lam), is a multipurpose tree that has gained considerable attention due to its exceptional nutritional and medicinal properties. This experiment was done at the Cattle Research Farm, Pachutia, Bangladesh Livestock Research Institute (BLRI), Savar, Bangladesh during the period from August 2019 to August 2020 at three cutting intervals. This study investigated how different planting distances and varieties affect the yield and quality of moringa biomass as well as quality. Sixteen treatments combining four varieties and four planting spacings were tested at three cutting intervals. The experiment was laid out by following Randomized Complete Block Design (RCBD) with four replications. The maximum germination rate at 83.98% was found in PKM1 variety, followed by Paraynal at 82.52%. The Paraynal variety, (1×1.5 feet), treatment T_7, produced the highest plant height (213.4 cm), maximum leaves (46), thickest stems (6.9 cm), maximum survival rate (96.9%), with the highest biomass (138.2 t/ha), and crude protein (19.8%). Among different cutting interval, maximum plant height, stem girth and biomass yield were found at 220 DAT cutting interval among all treatments. The Black variety with wider spacing showed the lowest germination rate (77.09%), stem girth (1.7cm), biomass yield (27 t/ha) and crude protein (14.6%) at different cutting interval. Thus, the Paraynal variety at 1×1.5 feet spacing perhaps consider as the best treatment for optimum moringa biomass production with better quality.

Key words: *Moringa oleifera* L., spacing, biomass yield, dry matter synthesis, crude protein

INTRODUCTION

Moringa oleifera Lam, a member of the *Moringaceae* family, is widely cultivated in tropical and subtropical regions due to its high nutritional value (Ponnuswami *et al.,* 2019). Native to the Indian subcontinent, this fast-growing and drought-resistant tree has spread globally, offering solutions to challenges like food security, malnutrition, and sustainable agriculture (Islam *et al*., 2021). *Moringa* leaves are rich in protein and essential amino acids, making it a valuable nutritional source (Moyo *et al.,* 2012; Valdez-Solana *et al.,* 2015). In addition to its nutritional benefits, *moringa* exhibits medicinal properties, including antioxidant, anti-inflammatory, and antimicrobial activities, which support its use in nutraceuticals and pharmaceuticals (Mahaveerchand and Salam, 2024).

Beyond nutrition and medicine, *moringa* plays an essential role in sustainable agriculture. Its rapid growth and high biomass production make it ideal for use as green manure, contributing to soil fertility improvement (Joshi and Pandit, 2020). Seed germination is a critical parameter for biomass production because it directly impacts the establishment, growth, and overall productivity of plants. *Moringa* also serves as a high-quality feed for livestock, potentially improving meat and milk production (Mendieta-Araica *et al.,* 2013). Crude protein is an essential quality parameter for moringa biomass because it directly impacts its nutritional value and potential applications, particularly in livestock feed, food products, and bioenergy. The higher the crude protein content, the more beneficial for biomass which promotes weight gain, milk production, and overall health in livestock. Additionally, the oil extracted from its seeds has shown potential as a biodiesel feedstock, supporting renewable energy initiatives (Takase *et al.,* 2022). Given its diverse applications, optimizing cultivation practices for *moringa* is essential to maximize its benefits.

Two critical factors influencing *moringa* cultivation are plant spacing and variety selection (Farahzety *et al*., 2024; and Rajamanickam and Arokiamary, 2022). The management of the moringa to produce biomass, as it is for the other vegetal species, must consider some aspects that foster productivity. Among these aspects, cultivation density is a crucial element. Proper spacing is crucial for resource access and can improve biomass production by enhancing light, water, and nutrient availability (Goss, 2012). It is also affected by microclimatic conditions, such as light penetration, air circulation, and humidity, which perhaps impact leaf quality and reduce disease incidence (Pandey *et al.,* 2012; Nouman *et al.,* 2013). Variety selection is equally important, as different *Moringa* varieties exhibit varying adaptability to environmental conditions, influencing yield stability and nutritional content (Mai *et al*., 2021). Different varieties may have varying yield potentials under similar growing conditions. Identifying high-yielding varieties can significantly impact the economic viability of Moringa cultivation. Research related to between spacing and variety interaction is necessary to develop optimal *Moringa* cultivation systems suitable to specific conditions and production goals. Therefore, this study was undertaken to investigate the effect of variety on seed germination of *moringa*, as well as to assess the effect of spacing and variety on biomass production and quality of moringa with different cutting interval.

MATERIALS AND METHODS

Study Area

This study was conducted from August 2019 to August 2020, at the Cattle Research Farm, Pachutia, Bangladesh Livestock Research Institute (BLRI), in Savar, Bangladesh. The location is situated between 23°89'0" N and 90°27'9" E. The altitude is seven meters above sea level. The average maximum temperature was 33.7°C, and the minimum was 10.2°C. The highest rainfall occurred in July, measuring 373.1 mm. The lowest rainfall was in January, at 7.7 mm (Source: Bangladesh Meteorological Department (climate division), Agargoan, Dhaka-1207). The soil was clayey and acidic, with a pH of 4.5-5.7. It contained very little organic matter, less than 1.5% (Source: Soil Resource and Development Institute (SRDI), Khamar Bari, Farmgate, Dhaka).

Seedling Establishment

First, a layer of gunny bag was placed and was soaked with tap water. Two layers of tissue paper were placed on top. The soaked seeds were placed on the tissue paper. They were covered with two more layers of tissue paper and one layer of gunny bag. This setup was kept for 3 days with regular watering (Basra *et al.,* 2002). After 3 days, the seeds sprouted and were ready for sowing. The seedlings were placed in plastic bags (15 × 15 cm) filled with soil. The soil was a mix of cow dung and soil in a 1:2 ratio. The seedlings were kept on platforms above ground in a controlled environment and watered manually every day.

Land Preparation

The land was prepared using a power tiller and left fallow for 30 days prior to seedling transplantation. Recommended dose of manure was applied during the final stage of land preparation. Pits of 15 × 15 × 15 cm were prepared for transplanting the seedlings into the main field.

Plant Establishment and Management

Following land preparation, 60-day-old uniform *M. oleifera* seedlings were transplanted into the main field. Each seedling was carefully placed in its respective pit, and the pits were filled with soil. The recommended dose of NPK fertilizer was applied during the experiment. Manual weeding was conducted to reduce competition from weeds. Furadan 3G, at a rate of 1 kg/ha, was applied during final land preparation, as well as at 90 and 180 days after transplanting (DAT). To control insects and pests, Actara® (Thiamethoxam) at 3 ml/L and Ripcord 400 EC at 1 ml/L were applied at 50, 65, 120, and 135 DAT. Irrigation was provided as needed to maintain optimal soil moisture throughout the growing season (Maria Goss, 2007).

Data Collection

Germination rate (%) − The germination rate of *M. oleifera* seedlings was calculated by the following formula.

Germination rate ×100

Plant height (cm) − Plant height was measured at 180 DAT, 220 DAT, and 260 DAT at the time of harvest. The height of the plant was determined by measuring the distance from the soil surface to the tip of the fully opened leaf on the main shoot by measuring tape and the mean plant height was expressed in cm.

Leaf number − Number of leaves from five randomly selected plants was recorded at various growth stages. The mean number of leaves per plant was calculated.

Stem girth (cm) −The diameter of the stem was measured at the top, middle, and bottom parts of the selected moringa plants. The average value of these measurements was then recorded in cm.

Survival rate (%) −The survival rate of the moringa plant was calculated by using the following formula.

Survival rate =

Fresh weight- After a post-transplantation growth period of 180 DAT, 220 DAT, and 260 DAT, branch tops with leaves were harvested at a height from the ground of 60 cm. The plants were allowed to grow after each cut and fertilized accordingly. The fresh weight of shoots harvested from five selected plants was determined using an electronic beam balance in the field.

Dry matter: Fresh sample was weighed and then dried (72 hours) in a vacuum drying oven at 70°C. The final weight was the dry matter (dm) of the sample (Chaimala *et al.,* 2020**).**

Crude protein (CP) − All the samples were kept in a forced draft oven at 65 ^{0}C for 48 h for crude protein (CP) analysis and dry matter determination. The dried samples were milled to pass through a 1 mm sieve for chemical analysis. The crude protein (CP) concentration was determined using the Kjeldahl method (AOAC, 1984).

Experimental Design and Treatment

The experiment was conducted by using a Randomized Complete Block Design (RCBD) with four replications. The treatments consisted of four *M. oleifera* varieties, namely V1 (PKM-1), V2 (PKM-2), V3 (Paraynal), and V4 (Black), along with four planting spacings: D1 (1.0 × 1.0 feet), D2 (1.0 × 1.5 feet), D3 (1.5 × 1.5 feet), and D4 (2.0 × 2.0 feet). The total experimental area was divided into four blocks, and each block was further subdivided into sixteen experimental plots. Thus, a total of plots were 64. The size of each sub-plot was 8 × 8 feet.

Table 1. The treatment combinations of *M. oleifera* used in the study

Treatment	Descriptions
T_1	PKM-1 (1×1 feet)
T_2	PKM-2 (1×1 feet)
T_3	Paraynal (1×1 feet)
T_4	Black (1×1 feet)
T_5	PKM-1 (1×1.5 feet)
T_6	PKM-2 (1×1.5 feet)
T_7	Paraynal (1×1.5 feet)
T_8	Black (1×1.5 feet)
T_9	PKM-1 (1.5×1.5 feet)
T_{10}	PKM-2 (1.5×1.5 feet)
T_{11}	Paraynal (1.5×1.5 feet)
T_{12}	Black (1.5×1.5 feet)
T_{13}	PKM-1 (2×2 feet)
T_{14}	PKM-2 (2×2 feet)
T_{15}	Paraynal (2×2 feet)
T_{16}	Black (2×2 feet)

Data Analysis

Collected data were statistically analyzed using Statistix 10 software. Mean for every treatments were calculated and analysis of variance and difference between treatments was assessed by Least Significant Difference (LSD) test at 5% level of significance (Gomez and Gomez, 1984).

RESULTS AND DISCUSSIONS

Germination percentage (%) of moringa seeds

Germination rates of various moringa varieties were assessed and compared (Figure 1). Among the four varieties, PKM1 exhibited the highest germination rate at 83.98%, followed by Paraynal with 82.52 % and PKM2 at 81.17%. The Black variety demonstrated the lowest germination rate at 77.09%, indicating a significantly lower efficiency in seed germination compared to the other varieties. Although three varieties (PKM1, Paraynal, and PKM2) showed relatively high germination rates exceeding 80%, PKM1 emerged as the most efficient variety, suggesting its potential as enhanced cultivation inputs. Despite PKM2's slightly lower germination rate, it remains competitive in terms of seed germination. Varietal effect on germination rate of moringa was not substantially documented (Chau *et al.*, 2021).

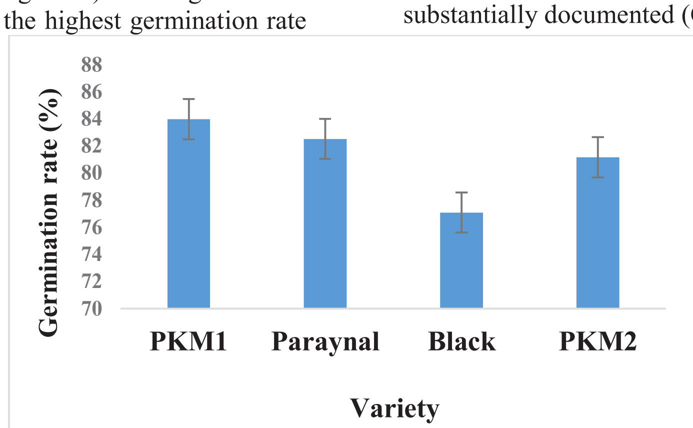

Figure 1. Effect of variety on the germination percentage of *Moringa oleifera* Lam

Plant height

The variation in *M. oleifera* plant heights across treatments was significantly affected by regrowth following harvesting at 60 cm above the soil surface (Table 2). At 180 days after transplanting (DAT), the tallest plants were recorded in treatment T3, reaching 225.75 cm. Treatments T6, T2, and T1 also exhibited strong growth, with plant heights exceeding 210 cm. In contrast, T8 showed the lowest plant height at 115.30 cm. By 220 DAT, after a second regrowth phase, significant differences in plant height were observed, with T1 producing the tallest plants at 291.2 cm. In contrast, T13 had the lowest plant height at 179.7 cm. At 260 DAT, T7 exhibited the greatest height at 213.4 cm, which is statistically identical with T15, followed by T16, and T1, all of which maintained strong growth between 206 and 211 cm. In some cases, treatments showed similar effect at different DAT such as T1, T2, T6 (180 DAT) and T3, T4, T8 (260 DAT).

Table 2. Effect of variety and spacing on plant height (cm) of *M. oleifera* at different measurement dates

	Plant height (cm)		
Treatments	**180 DAT**	**220 DAT**	**260 DAT**
T_1	210.2ab	291.1a	206.6ab
T_2	212.9ab	273.3bc	201.8bc
T_3	225.7a	264.4cd	179.5f
T_4	142.3h	225.6hi	179.2f
T_5	198.2bd	233.8fh	191.3de
T_6	214.9ab	251.3de	190.6de
T_7	181.3de	286.1ab	213.4a
T_8	115.3i	273.8bc	180.8f
T_9	160.9fg	247.5ef	184.6ef
T_{10}	192.0cd	241.7eg	195.1cd
T_{11}	173.7ef	207.5j	186.3ef
T_{12}	131.1hi	241.5eg	201.1bc
T_{13}	119.3i	179.7k	169.0g
T_{14}	146.6gh	231.7gh	191.5de
T_{15}	161.4fg	212.8ij	211.2a
T_{16}	120.9i	253.5de	206.8ab
Lsd	18.2	15.4	7.6

Note: Different alphabetical letters within the same column indicate significant differences among treatment combinations ($P < 0.01$).

T_1–PKM-1 (1×1 feet), T_2– PKM-2 (1×1 feet), T_3–Paraynal (1×1 feet), T_4–Black (1×1 feet), T_5– PKM-1 (1×1.5 feet), T_6– PKM-2 (1×1.5 feet), T_7– Paraynal (1×1.5 feet), T_8– Black (1×1.5 feet), T_9– PKM-1 (1.5×1.5 feet), T_{10}– PKM-2 (1.5×1.5 feet), T_{11}–Paraynal (1.5×1.5 feet), T_{12}– Black (1.5×1.5 feet), T_{13}– PKM-1 (2×12 feet), T_{14}– PKM-2 (2×2 feet), T_{15}– Paraynal (2×2 feet), T_{16}– Black (2×2 feet).

Treatments T1 (PKM-1; 1×1 feet), T3 (Paraynal; 1×1 feet), and T7 (Paraynal; 1×1.5 feet) consistently resulted in superior plant heights, suggesting that these combinations may be optimal for maximizing post-harvest plant growth. In contrast, T8 (Black; 1×1.5 feet) and T13 (PKM-1; 2×2 feet) exhibited consistently lower growth, indicating that these treatments may be less effective in promoting regrowth. These findings emphasize the importance of selecting appropriate treatments to enhance regrowth potential and optimize yield in *moringa* cultivation. Under optimal plant densities, plants utilize available water, light, and nutrients efficiently; however, at excessively high densities, competition between plants can reduce economic productivity (Sadeghi, 2009). Our investigation found that medium plant density (Paraynal; 1×1.5 feet), followed by low density (PKM-1; 1×1 feet), resulted in better plant height. In contrast, closer spacing generally produced shorter plants, while wider spacing yielded taller plants, as observed by Olawepo *et al.* (2020). Higher spacing tends to result in taller plants with more leaves per plant, though leaf yield per hectare may decrease. This may be due to the fact that plants in medium densities had sufficient access to growth resources, reducing root competition for nutrients and water.

Leaf number

The results indicate that the variety Paraynal consistently produced the highest number of leaves, particularly when planted at a spacing of 1×1.5 feet (T7), across all measurement dates (180, 220 and 260 DAT) (Table 3). This suggests that both variety and spacing significantly influence leaf development. The wider spacing (1×1.5 feet) for Paraynal resulted more leaves, likely due to reduced competition for resources such as nutrients, light, and space. Poor-performing varieties, such as Black, PKM-1produced fewer leaves in narrower spacing, indicating a sensitivity to higher planting density. Therefore, the combination of the Paraynal variety and 1×1.5 feet spacing (T7) appears to be optimal for maximizing leaf production in *M. oleifera*.

These findings are consistent with previous studies. For instance, Olawepo *et al.* (2020) observed that wider spacing produced the highest number of leaves per plant, while closer spacing resulted in fewer leaves. Similarly, Amaglo (2006) reported that high plant spacing promotes better nutrient absorption and translocation into the leaves, leading to increased leaf production. Chau *et al.* (2021) also demonstrated that wider spacing resulted in the highest leaf count per plant, followed by medium spacing, with close spacing yielding the least number of leaves. High planting density increases competition for nutrients, space, and light, which negatively affects leaf production and plant growth.

Table 3. Effect of variety and spacing on number of leaves of moringa at different measurement dates

Treatment	Number of Leaves		
	180 DAT	220DAT	260 DAT
T_1	18ac	38ab	12g
T_2	21ac	22c	13fg
T_3	21ab	41a	13fg
T_4	12df	27ac	26ce
T_5	17ad	23bc	31bd
T_6	21ac	22c	38b
T_7	22a	41a	46a
T_8	7f	22c	24de
T_9	20ac	23bc	21ef
T_{10}	18ad	19c	22e
T_{11}	16 ae	12c	25ce
T_{12}	8ef	20c	37b
T_{13}	16be	15c	12g
T_{14}	16be	15c	32bd
T_{15}	17ad	38ab	33bc
T_{16}	10ef	19 c	22e
Lsd	6.11	15.44	8.1

Note: Different alphabetical letters within the same column indicate significant differences among treatment combinations ($P < 0.01$).

T_1–PKM-1 (1×1 feet), T_2– PKM-2 (1×1 feet), T_3–Paraynal (1×1 feet), T_4–Black (1×1 feet), T_5– PKM-1 (1×1.5 feet), T_6– PKM-2 (1×1.5 feet), T_7– Paraynal (1×1.5 feet), T_8– Black (1×1.5 feet), T_9– PKM-1 (1.5×1.5 feet), T_{10}– PKM-2 (1.5×1.5 feet), T_{11}–Paraynal (1.5×1.5 feet), T_{12}– Black (1.5×1.5 feet), T_{13}– PKM-1 (2×12 feet), T_{14}– PKM-2 (2×2 feet), T_{15}– Paraynal (2×2 feet), T_{16}– Black (2×2 feet).

Table 4. Effect of variety and spacing on stem girth of moringa at different measurement dates

Treatment	Stem Girth (cm)		
	180 DAT	220 DAT	260 DAT
T_1	4.3ab	7.8a	6.5a
T_2	4.5ab	6.7bc	4.3c
T_3	4.9a	5.7de	3.6de
T_4	3.2de	5.4ef	4.1cd
T_5	4.4ab	4.1h	4.0ce
T_6	4.8a	6.6bc	3.5e
T_7	4.0bc	6.9b	6.9a
T_8	2.4f	5.5ef	1.7f
T_9	3.5cd	4.0h	1.8f
T_{10}	3.7cd	6.2cd	1.8f
T_{11}	3.4cd	4.8g	3.5e
T_{12}	2.5f	5.0fg	4.2c
T_{13}	2.6f	2.8i	3.6e
T_{14}	3.4ce	5.4eg	3.8cde
T_{15}	3.5cd	5.7de	6.5b
T_{16}	2.8ef	6.5bc	4.1cd
Lsd	0.62	0.61	0.52

Note: Different alphabetical letters within the same column indicate significant differences among treatment combinations ($P < 0.01$).

T_1–PKM-1 (1×1 feet), T_2– PKM-2 (1×1 feet), T_3–Paraynal (1×1 feet), T_4–Black (1×1 feet), T_5– PKM-1 (1×1.5 feet), T_6– PKM-2 (1×1.5 feet), T_7– Paraynal (1×1.5 feet), T_8– Black (1×1.5 feet), T_9– PKM-1 (1.5×1.5 feet), T_{10}– PKM-2 (1.5×1.5 feet), T_{11}–Paraynal (1.5×1.5 feet), T_{12}– Black (1.5×1.5 feet), T_{13}– PKM-1 (2×12 feet), T_{14}– PKM-2 (2×2 feet), T_{15}– Paraynal (2×2 feet), T_{16}– Black (2×2 feet).

Stem girth

Stem girth of moringa plants varied significantly depending on both variety and spacing (Table 4). Stem girth generally increased across most varieties between 180 and 220 days after transplanting (DAT), though the trend became more variable by 260 DAT. At 260 DAT, T7 treatment exhibited the highest stem girth with the value of 6.9 cm. In contrast, the Black variety, especially in narrower spacings like T8 (1×1 feet), consistently recorded the smallest girth values, with 1.7 cm at 260 DAT which is statistically similar with T9 and T10.

Wider spacings, such as 1×1.5 feet and 2×2 feet, were generally associated with increased stem girth by 260 DAT, for Paraynal (T7) and PKM-1 (T1) variety. Narrower spacings, such as 1×1 feet, resulted in mixed outcomes. Even at wider spacing (T16, Black, 2×2 feet), the Black variety did not perform as well as other varieties, suggesting its underperformance might be more intrinsic to the variety than influenced by spacing alone. These findings consistent with Adegun and Ayodele (2015), who noted that closer spacing could limit lateral growth and encourage vertical growth. Studies by Olawepo *et al.* (2020) and Amaglo (2006) also supported that wider spacing result in larger stem diameters, which is favorable for seed and firewood production due to faster individual plant growth. Moreover, a positive correlation between wider spacing and increased stem girth has been observed, as it reduces competition and enhances nutrient availability, leading to higher canopy density and lateral growth (Kumalasari *et al.,* 2017; Santos *et al.,* 2011).

Survival rate

Figure 2 shows the effect of variety and plant spacing on the survival rate of *moringa* across different measurement dates. Overall, the results suggest that both variety and spacing significantly influence survival rates. Tighter spacing (1×1 feet) showed lower survival rates across all varieties compared to wider spacings (1.5×1.5 feet and 2×2 feet), indicating crowding might negatively affects plant survival. Among varieties, T_{15} (Paraynal, 2×2 feet) generally exhibited a higher survival rate (96.9%) across most spacings at 180 DAT followed by T_{16} (Black) and T_{13} (PKM-1) with same plant spacing (Figure-2). The wider spacing treatments (2×2 feet) led to improved survival for all varieties at early vegetative growth stage. With increasing DAT, survival rate is decreasing. The lowest survival rate (56.0%) was recorded in T_{10} (PKM-2) at 260 DAT (Figure-2). These findings highlight the importance of appropriate spacing and variety selection for optimizing *moringa* survival.

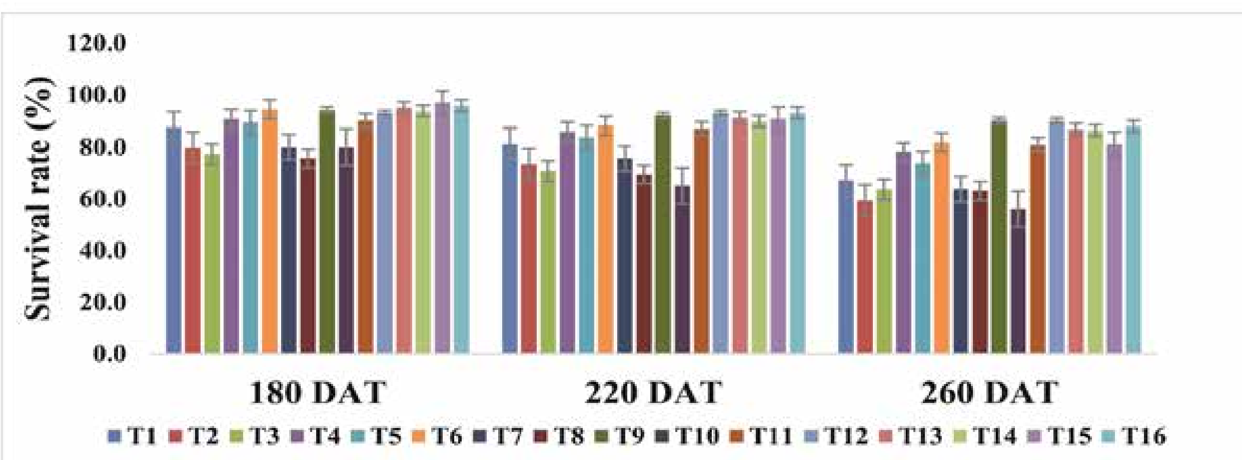

Figure 2. Effect of variety and spacing on the survival rate of moringa at different measurement dates

T_1–PKM-1 (1×1 feet), T_2– PKM-2 (1×1 feet), T_3–Paraynal (1×1 feet), T_4–Black (1×1 feet), T_5– PKM-1 (1×1.5 feet), T_6– PKM-2 (1×1.5 feet), T_7– Paraynal (1×1.5 feet), T_8– Black (1×1.5 feet), T_9– PKM-1 (1.5×1.5 feet), T_{10}– PKM-2 (1.5×1.5 feet), T_{11}–Paraynal (1.5×1.5 feet), T_{12}– Black (1.5×1.5 feet), T_{13}– PKM-1 (2×12 feet), T_{14}– PKM-2 (2×2 feet), T_{15}– Paraynal (2×2 feet), T_{16}– Black (2×2 feet).

Biomass Production

Moringa biomass production is crucial for sustainable agriculture and agroforestry systems due to its high nutritional content, rapid growth, and ability to improve soil fertility. Figure 3 shows the effect of variety and spacing on the biomass production of *moringa* at different measurement dates. The results indicate that 1×1.5 feet spacing showing the highest biomass yield across all varieties. Paraynal consistently produced the most biomass across different spacings, while the Black variety had lower biomass. At 180 DAT, T_7 (Paraynal, 1×1.5 feet) exhibited the highest biomass yield at 47.9 t/ha and the lowest (9 t/ha) was found in T_{16} (Black) (Figure 3).

At 220 DAT, the lowest biomass was recorded in T_{16} (Black, 2×2 feet) at 27 t/ha and the highest biomass was found in T_7 (Paraynal, 1×1.5 feet) at 138.2 t/ha (Figure 3). At 260 DAT, we again observed a decreasing trend in biomass productions in all varieties. This intends that both the variety and spacing combinations significantly stimulated moringa leaf yield as well as total biomass production. Olawepo *et al.* (2020) investigated that wider spacing produced the highest number of leaves per plant and leaf yield compared to close spacing. Moderate wider spacing produced the highest biomass yield compared to closer spacing with fewer leaves were previously described by Olawepo *et al.* (2020). Overall, our findings suggest that 1×1.5 feet spacing and the selection of specific varieties or genotypes particularly Paraynal, significantly enhance biomass production in *moringa.*

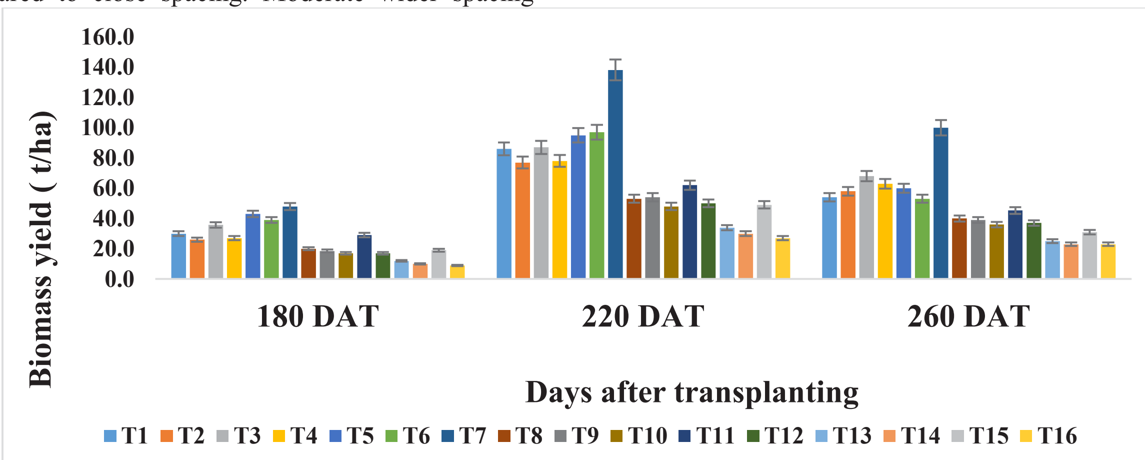

Figure 3. Effect of variety and spacing on Biomass production of Moringa different measurement dates

T_1= PKM-1 (1×1 feet); T_2= PKM-2 (1×1 feet); T_3= Paraynal (1×1 feet); T_4= Black (1×1 feet); T_5= PKM-1 (1×1.5 feet); T_6= PKM-2 (1×1.5 feet); T_7= Paraynal (1×1.5 feet); T_8= Black (1×1.5 feet); T_9= PKM-1 (1.5×1.5 feet); T_{10}= PKM-2 (1.5×1.5 feet); T_{11}= Paraynal (1.5×1.5 feet); T_{12}= Black (1.5×1.5 feet); T_{13}= PKM-1 (2×12 feet); T_{14}= PKM-2 (2×2 feet); T_{15}= Paraynal (2×2 feet); T_{16}= Black (2×2 feet).

Table 5. Effect of variety and spacing on dry mater of moringa at different measurement dates

Treatment	Dry mater (%)		
	180 DAT	220 DAT	260 DAT
T_1	22.1bc	23.3ab	24.2a
T_2	21.9ad	21.8be	22.8cg
T_3	23.1ab	21.4ce	22.4dg
T_4	22.3ac	23.7a	24.0ab
T_5	19.9eg	21.5ce	22.9bg
T_6	22.1ac	22.8ac	23.0af
T_7	20.6df	20.9df	21.9fh
T_8	21.7bd	22.4ad	22.8cg
T_9	19.2g	19.7f	21.0 h
T_{10}	19.5fg	19.6f	21.1h
T_{11}	19.5fg	21.5ce	21.8gh
T_{12}	21.1ce	21.0df	22.0 eh
T_{13}	22.4ac	22.2ad	23.1ae
T_{14}	23.1a	23.4a	23.9ac
T_{15}	22.7ab	20.7ef	21.1h
T_{16}	22.6ab	22.3ad	23.3ad
Lsd	1.4	1.5	1.2

Note: Different alphabetical letters within the same column indicate significant differences among treatment combinations ($P < 0.01$).

T_1–PKM-1 (1×1 feet), T_2– PKM-2 (1×1 feet), T_3–Paraynal (1×1 feet), T_4–Black (1×1 feet), T_5– PKM-1 (1×1.5 feet), T_6– PKM-2 (1×1.5 feet), T_7– Paraynal (1×1.5 feet), T_8– Black (1×1.5 feet), T_9– PKM-1 (1.5×1.5 feet), T_{10}– PKM-2 (1.5×1.5 feet), T_{11}–Paraynal (1.5×1.5 feet), T_{12}– Black (1.5×1.5 feet), T_{13}– PKM-1 (2×12 feet), T_{14}– PKM-2 (2×2 feet), T_{15}– Paraynal (2×2 feet), T_{16}– Black (2×2 feet).

Dry matter

Variety and spacing showed significant variations on dry mater accumulation of moringa at different days after transplanting (DAT) (Table 5). At 180 DAT, the highest dry matter content of 23.1% was observed in treatments T14, while T9 recorded the lowest value of 19.2%. At 220 DAT, dry matter content ranged from 19.6% (T10) to 23.7% (T4), with T4 recording the highest value, which is similar with T14 (23.4%) followed closely by T1 (23.3%). The lowest values were found in T9 (19.7%), which had similar value with T10 (19.6%). By 260 DAT, T1 and T4 showed the highest dry matter content of 24.2% and 24.0%, respectively, while T9, T10, and T15 had the lowest values. Across all measurement periods, denser spacing consistently resulted in higher dry matter content compared to wider spacings. The data suggest that denser planting promotes greater competition for resources such as light, water, and nutrients, which may enhance biomass accumulation, particularly in the early and mature stages of plant development. This trend aligns with previous findings (Santos *et al.,* 2021; Mabapa *et al.,* 2017), which support closer spacing for increased dry matter production per unit area despite reduced per-plant yield. Genetic factors also played a role, as PKM-2 and the Black variety (T4) consistently outperformed, while the PKM-1 variety (T9) underperformed particularly under wider spacings at early growth stage. But at 260 DAT, PKM-1 and Black variety performed better than other variety. Therefore, closer spacing appears to be more beneficial for maximizing the overall dry matter yield of moringa.

Crude Protein

Significant differences in crude protein content (%) of moringa were observed across treatments due to the effects of variety and spacing at different days after transplanting (DAT) (Table 6). At 180 DAT, the highest crude protein content was found in treatment T15 (19.5%), which was similar with T6 (19.4%), T4 (19.4%), T2 (19.3%) and T3 (19.3%). The lowest value was recorded in T8 (14.6%). At 220 DAT, crude protein content ranged from 15.6% (T14) to 19.5% (T11), with T11 showing the highest value, which had statistically similar value with T2 (19.3%) and closely followed by T12 (18.7%). At 260 DAT, T11 again had the highest crude protein content (19.8%), which is statistically identical with T12 (19.2%) and T2 (19.1%), while T14 showed the lowest value at 16.1%.

The Paraynal and PKM-2 (T2) consistently showed high crude protein content, making them good candidate for protein production. The Black variety (T16), however, performed variably, showing higher protein content in wider spacings but lower in denser plantings, such as in T8. These results align with previous studies, which found moringa leaves to be a rich protein source compared to other crops, with protein content reaching 8.4% in densely planted moringa in Ghana (Amaglo *et al.,* 2006). Additionally, protein levels in moringa leaves ranged between 193 to 264 g/kg dry weight in various studies (Aregheore, 2002; Al-Masri, 2003).

Table 6. Effect of variety and spacing on Crude Protein (CP) of moringa at different measurement dates

Treatment	**Crude Protein, CP (%)**		
	180 DAT	**220 DAT**	**260 DAT**
T_1	18.9 ac	16.7de	17.1df
T_2	19.3ab	**19.3a**	**19.1a**
T_3	19.3ab	17.1cd	17.3bf
T_4	19.4ab	16.7de	16.9f
T_5	18.4c	16.6de	16.8f
T_6	19.4ab	17.3cd	17.1ef
T_7	17.4d	17.1cd	17.2cf
T_8	14.6f	17.8bc	17.8bd
T_9	17.6d	16.1ef	16.7f
T_{10}	16.3e	17.7c	17.7be
T_{11}	17.5d	19.5a	**19.8a**
T_{12}	18.8bc	18.7ab	**19.2a**
T_{13}	17.2d	17.2cd	17.9b
T_{14}	16.5e	15.6f	16.1g
T_{15}	**19.5a**	17.1cd	17.8bc
T_{16}	19.4ab	17.5cd	17.9bc
Lsd	0.66	0.91	0.71

Note: Different alphabetical letters within the same column indicate significant differences among treatment combinations ($P < 0.01$).

T_1–PKM-1 (1×1 feet), T_2– PKM-2 (1×1 feet), T_3–Paraynal (1×1 feet), T_4–Black (1×1 feet), T_5– PKM-1 (1×1.5 feet), T_6– PKM-2 (1×1.5 feet), T_7– Paraynal (1×1.5 feet), T_8– Black (1×1.5 feet), T_9– PKM-1 (1.5×1.5 feet), T_{10}– PKM-2 (1.5×1.5 feet), T_{11}–Paraynal (1.5×1.5 feet), T_{12}– Black (1.5×1.5 feet), T_{13}– PKM-1 (2×12 feet), T_{14}– PKM-2 (2×2 feet), T_{15}– Paraynal (2×2 feet), T_{16}– Black (2×2 feet).

In conclusion, the spacing and type of moringa significantly affected its growth and quality. The PKM-1 variety had the highest germination rate (83.98%), while the Black variety had the lowest (77.09%). The Paraynal variety showed the highest plant height and leaves at all cutting intervals except at 260 days after transplanting (DAT). In the T7 treatment (1×1.5 feet spacing), the Paraynal variety produced the tallest plants (213.4 cm), the maximum leaf count (46), and thick stems (6.9 cm), matched only by the PKM-1 variety. The Paraynal variety also had the best survival rate (96.9%) and the highest biomass yield (138.2 t/ha) at 220 DAT. At various DAT, the highest crude protein levels were observed in the Paraynal and PKM-2 varieties. Thus, planting the Paraynal variety with this spacing may provide the optimum performance for moringa cultivation in terms of yield and quality.

Acknowledgement: We sincerely acknowledge the financial support from SAURES, Sher-e-Bangla Agricultural University, Dhaka, and the technical assistance from Bangladesh Livestock Research Institute, Savar, Dhaka, which were helpful in facilitating the smooth conduct of our research.

Conflict of interest: The authors declared there is no conflict of interest.

REFERENCES

Adegun, M. K. and Ayodele, O. J. 2015. Growth and yield of *Moringa oleifera* as influenced by spacing and organic manures in South-Western Nigeria. *Int. J. Agron. Res.* (IJAAR).

Amaglo, N. K., Timpo, G. M., Ellis, W.O., Bennett, R. N. and Foidl, N. 2006. Effect of spacing and harvest frequency on the growth and leaf yield of moringa (*Moringa oleifera* Lam), a leafy vegetable crop. In: Moringa and other highly nutritious plant resources: Strategies, standards, and markets for a better impact on nutrition in Africa. Accra, Ghana. p. 16-18.

Aregheore, E. M. 2002. Intake and digestibility of *Moringa oleifera*-batiki grass mixtures by growing goats. *Small Rumin. Res.,* 46: 23–28

AOAC 1990. Official Methods of Analysis. 15th ed. Association of Official Analytical Chemists, Arlington, VA, USA, pp: 1-1298.

Basra, S. M. A., Zia, M. N., Mehmood, T., Afzal, I. and Khaliq, A. 2002. Comparison of different invigoration techniques in wheat (*Triticum aestivum* L.) seeds. *Pakistan J. Arid. Agric.,* **5**: 11-16.

Basra, S. M. A., Nouman, W., Rehman, H., Usman, M. and Nazli, Z. H. 2015. Biomass production and nutritional composition of *Moringa oleifera* under different cutting frequencies and planting spacings. *Int. J. Agric. Biol.,* **17**:1055-1060. https://doi.org/10.17957/IJAB/15.0076

Chaimala, A., Jogloy, S., Vorasoot, N., Toomsan, B., Jongrungklang, N., Kesmala, T., Holbrook, C. C., and Kvien, C. K. 2020. Responses of total biomass, shoot dry weight, yield and yield components of Jerusalem Artichoke (*Helianthus tuberosus* L.) varieties under different erminal drought duration. *Agriculture*, *10*(6), 198. https://doi.org/10.3390/agriculture10060198

Farahzety, A. M., Singh, A., Yap, L.V., Muhammad, N. O. G., Wan, R. W.E. and Rosniza, K. 2024. Yield and phytonutrient content of Moringa leaves as influenced by plant spacings and fertilizer application. *Food Res.*, **8**: 1-12.

Gomez, A. K. and Gomez, A. A. 1984. Statistical procedure for agricultural research 2nd Ed. John.

Goss, M. 2007. A study on initial establishment of multi-purpose moringa (*Moringa oleifera* Lam) with focus on stand densities, nitrogen, phosphorus, ph, media type and seed priming. Ph.D. Thesis. University of Zimbabwe, Zimbabwe.

Goss, M. 2012. A study of the initial establishment of multipurpose moringa (*Moringa oleifera* Lam) at various plant densities, their effect on biomass accumulation and leaf yield when grown as vegetable. *African. J. Plant Sci.,* **6**:125-129. https://doi.org/10.5897/AJPS11.259

Islam, Z., Islam, S. M. R., Hossen, F., Mahtab-Ul-Islam, K., Hasan, M. R. and Karim, R. 2021. *Moringa oleifera* is a prominent source of nutrients with potential health benefits. *Int. J. Food Sci*., 6627265.

Joshi, M. R. and Pandit, S. 2020. *Moringa oleifera*: A boon to agriculture. *J. Inst. Agric. Animal Sci.***,** **37**: 113-120.

Kumalasari, N. R., G. P. Wicaksono, and L. Abdullah. 2017. Plant growth pattern, forage yield, and quality of *Indigofera zollingeriana* influenced by row spacing. *J. Exotic Pet Med.,* 40:14 19. https://doi.org/10.5398/medpet.2017.40.1.14

Mabapa, M. P., Ayisi, K. K. and. Mariga, I. K. 2018. Seasonal effect on *Moringa oleifera* gaseous exchange and water use efficiency under diverse planting densities. *J. Applied Bot. and Food Quality.,* 91: 219 – 225. DOI:10.5073/JABFQ.2018.091.029

Mahaveerchand, H. and Salam, A. A. A. 2024. Environmental, industrial, and health benefits of *Moringa oleifera*. *Phytochem. Rev.,* 1: 2-60.

Mai, H., Chau, M., Hoang, A. and Sam, V. 2021. Effect of varieties and spacing on the growth and leaf yield of *Moringa oleifera* Lam. *Plant Cell Biotech. Mole. Bio.*, **22** (61 & 62): 81-92.

Mendieta-Araica, B., Spörndly, E., Reyes-Sánchez, N., Salmerón-Miranda, F. and Halling, M. 2013. Biomass production and chemical composition of *Moringa oleifera* under different planting densities and levels of nitrogen fertilization. *Agroforestry Syst.,* 87: 81-92. DOI 10.1007/s10457-012-9525-5

Moyo, B., Oyedemi, S., Masika, P. J. and Muchenje, V. 2012. Polyphenolic content and antioxidant properties of *Moringa oleifera* leaf extracts and enzymatic activity of liver from goats supplemented with *Moringa oleifera* leaves or sunflower seed cake. *Meat Sci.,* 91:441-447. https://doi. org/10.1016/j.meatsci.2012.02.029

Nouman, W., Siddiqui, M.T., Basra, S. M. A., Farooq, H., Zubair, M. and Gull, T. 2013. Biomass production and nutritional quality of *Moringa oleifera* as field crop. *Turkish J. Agric. For.,* **37**: 410 – 419.

Olawepo, T. F., Akanbi. W. B., Asaolu, V. O. and Olayiwola, S. A. 2020. Effect of different spacing on biomass yield of Moringa in Ogbomoso, Oyo State, Nigeria. *Nigerian J. Hort. Sci.*

Pandey, P. and Khan, F. 2022. *Moringa oleifera* plant as a potent alternative to chemical coagulant in water purification. *Brazilian J. Pharma. Sci.,* 58: e201158.

Ponnuswami, V. and Rani, E. A. 2019. Organic leaf production of Moringa (*Moringa oleifera* Lam) cv. PKM-1 for higher leaf yield and quality parameters under Ultra High-Density planting system. *Adv. Plants Agric. Res.,* **9**(1):206–214.

Rajamanickam, C. and Arokiamary, S. 2022. Assessment of Moringa varieties for growth and yield characters. *J. Krishi Vigyan*., 11(1): 7-10.

Sánchez, N. R., Ledin, S. and Ledin, I. 2006. Biomass production and chemical composition of *Moringa oleifera* under different management regimes in Nicaragua. *Agroforestry Syst.* 66: 231-242.

Santos, W. R., D. B. Matos, B. M. Oliveira, T. M. Santana, M. M. Santana, & G. F. Silva. 2011. Estudo do tratamento e clarificação de água com torta de sementes de *Moringa oleifera* Lam. Ver. *Bras. Prod. Agroind.*, 13:295-299. https://doi. org/10.15871/1517-8595/rbpa.v13n3p295-299

Takase, M., Essandoh, P. K., Asare, R. K. and Nazir, K. H. 2022. The value chain of *Moringa oleifera* plant and the process of producing its biodiesel in Ghana. *The Sci. World J.,* 1827514.

Valdez-Solana, M. A., Mejía-García, V. Y., Téllez-Valencia, A., García-Arenas, G., SalasPacheco, J., Alba-Romero, J. J. and Sierra-Campos. E. 2015. Nutritional content and elemental and phytochemical analyses of *Moringa oleifera* grown in Mexico. *J. Chem.*, pp:1-9. https://doi. org/10.1155/2015/860381