Effects of Stem Cutting Length and Compost-amended Nursery Media on Leaf Biomass of Drumstick (*Moringa oleifera* Lam.)

Bambang Budi Santoso[1], Jayaputra[1]

10.18805/IJARe.AF-1005

ABSTRACT

Background: Vegetative propagation through stem cuttings is a practical approach to obtain uniform, high-quality seedlings for intensive Moringa (*Moringa oleifera* Lam.) leaf biomass production. This study evaluated nursery and early field performance of seedlings produced from stem cuttings.

Methods: Two experiments were conducted from October 2022 to April 2023 in West Nusa Tenggara, Indonesia. In Experiment 1 (nursery, Mataram), a 3 × 2 factorial completely randomized design tested three cutting lengths (20, 40 and 60 cm) and two nursery media (topsoil and topsoil + compost, 1:1 v/v) with five replications; each replicate consisted of five cuttings. In Experiment 2 (field, Gumantar Village, North Lombok), seedlings selected from Experiment 1 were transplanted under three plant densities (25 × 25 cm, 30 × 30 cm and 40 × 40 cm) in a randomized complete block design with three blocks. Growth and biomass parameters were measured periodically and analyzed by ANOVA; mean separation used HSD at 5% ($p<0.05$).

Result: In the nursery, 60 cm cuttings generally produced the fastest sprouting and the highest shoot and root biomass, whereas 40 cm cuttings produced the highest seedling establishment (86.2%) with a more balanced shoot-root ratio. Compost-amended media improved seedling growth and increased establishment (91.1%) compared with topsoil alone. In the field, higher plant density (25 × 25 cm) increased leaf biomass per unit area during the first harvest period.

Key words: Biomass, Leaves, Propagation, Top-soil, Transplanting.

INTRODUCTION

Moringa oleifera Lam. is recognized internationally as a multipurpose plant with highly valuable parts. Its leaves possess antibacterial and antifungal properties (Azlan *et al*., 2022), anti-cancer and medicinal benefits (Santon *et al*., 2021; Anwar and Bhanger, 2003), high nutritional value (Price, 2007; Athira *et al*., 2024) and potential as animal fodder (Sanchez *et al*., 2006). The seeds are used for biodiesel production (Dorria *et al*., 2016) and as a natural coagulant for turbid water (Suarez *et al*., 2003; Bhatia, 2007). Moringa leaf extract (MLE) also serves as an eco-friendly biostimulant for sustainable agriculture (Dorria *et al*., 2016; Yaseen and Hájos, 2021) and as green manure (Sarwar *et al*., 2017). The broad value of moringa as a food and livelihood resource has long been emphasized in earlier development-oriented literature (Fuglie, 1999). In West Nusa Tenggara, Indonesia, its leaves and young fruits are traditional foods, although cultivation is generally informal. As demand increases, Moringa is transitioning into a plantation crop requiring improved management.

Beyond pod production, Moringa is increasingly valued for its fresh and processed leaves, which serve as an alternative food source to fight hunger (Mandal *et al*., 2022). Its wide potential underscores the need to develop cultivation techniques that ensure continuous production of seeds, young fruits and leaves. Given its emerging role as a perennial plantation crop, standardized cultivation practices are essential. Recent studies also highlight that agronomic inputs and biostimulants can influence leaf yield and quality in moringa cultivation (Balakumbahan and Kavitha, 2019), while improved seed production and propagation techniques remain important to support wider cultivation (Kumar *et al*., 2026).

Propagation is fundamental to establishing perennial crops like *Moringa*, particularly to ensure high-quality seedlings. Vegetative propagation *via* stem cuttings can accelerate establishment on dry lands (Prasad *et al*., 2012) and ensures uniformity in plant traits and yield (Barche *et al*., 2013). However, *Moringa* does not propagate easily from leafy stem cuttings (Tiwari and Kuntal, 2010) and success depends on stem age, position and size (Kraiem *et al*., 2010).

Cutting size influences rooting ability (Leakey and Storeton-West, 1991), which is affected by stored carbohydrates and physiological factors (Palanisamy and Kumar, 1997; Hartmann *et al*., 2007). Longer cuttings may

[1]Faculty of Agriculture, University of Mataram, Jl. Majapahit 62 Mataram 83125, Lombok, West Nusa Tenggara, Indonesia.

Corresponding Author: Bambang Budi Santoso, Faculty of Agriculture, University of Mataram, Jl. Majapahit 62 Mataram 83125, Lombok, West Nusa Tenggara, Indonesia.
Email: bambang.bs@unram.ac.id
ORCIDs: 0000-0002-0018-2620, 0000-0003-4182-5167

How to cite this article: Santoso, B.B. and Jayaputra (2026). Effects of Stem Cutting Length and Compost-amended Nursery Media on Leaf Biomass of Drumstick (*Moringa oleifera* Lam.). *Indian Journal of Agricultural Research.* **60(5):** 687-694. doi: 10.18805/IJARe.AF-1005.

Submitted: 18-11-2025 **Accepted:** 14-03-2026 **Online:** 28-03-2026

contain more reserves, whereas shorter ones are more economical when material is limited. Cutting behavior also varies with genotype and physiological state of the mother plant. In *Jatropha*, seedling growth depends on cutting size and diameter (Santoso *et al*., 2008), while larger *Moringa* cuttings produce higher dry matter (Rufal *et al*., 2016). Santoso and Parwata (2010) recommend cuttings of 50-75 cm in length and 3-5 cm in diameter for quality seedling production.

Nursery management, including suitable media providing optimal moisture, aeration and temperature, is equally crucial. Common growing media consist of soil mixed with organic materials such as compost. With sustainability increasingly emphasized globally, organic approaches are gaining importance in agriculture.

Even with good seedlings, agronomic practices remain essential to maximize field performance. Plant spacing and population density strongly influence biomass production by affecting light interception, nutrient availability, weed competition, canopy formation and dry matter accumulation (Ahmed *et al*., 2023). Sutarno and Rosyida (2020) reported that a spacing of 20 × 25 cm produced the highest stem diameter and biomass. Therefore, this study aims to establish *Moringa* seedlings from stem cuttings and to evaluate their early leaf biomass potential under different plant population densities.

Despite the increasing demand for leaf biomass, practical information that links nursery propagation techniques (cutting length and compost-amended media) with early field biomass production under different plant densities is still limited for local *Moringa* accessions in dryland environments of eastern Indonesia. Therefore, this study addresses this gap by (i) identifying an efficient cutting length that provides high seedling establishment while minimizing damage to mother plants and (ii) quantifying early leaf biomass response to plant density using the selected seedlings. We hypothesized that: (1) longer cuttings would increase seedling vigor due to greater stored reserves, but an intermediate length would maximize establishment efficiency; (2) compost addition would enhance growth and establishment in the nursery; and (3) higher plant density would increase leaf biomass per unit area during early harvests.

MATERIALS AND METHODS

Experimental site condition and plant material

This research comprised two experiments conducted at the Faculty of Agriculture, University of Mataram (West Nusa Tenggara, Indonesia) from October 2022 to April 2023. Experiment 1 was conducted from October to December 2022 under nursery shade conditions in Mataram (8°34′ 47.19″S; 116°05′47.91″E; 16 m a.s.l.). A 3 × 2 factorial arrangement tested three cutting lengths (20, 40 and 60 cm) and two nursery media (topsoil and topsoil + compost). Thus, there were six treatment combinations. Stem cuttings of a local Moringa accession were surface-sterilized by dipping in a fungicide solution (0.2% mancozeb) for 2 min, air-dried and planted in 25 × 35 cm black polyethylene bags filled with topsoil alone or a 1:1 (v/v) mixture of topsoil and compost.

Compost used in the nursery was a well-decomposed cattle-manure-based compost produced locally. Its key chemical properties (mean of triplicate analysis) were: pH (H_2O) 7.1; organic C 21.4%; total N 1.32%; C/N 16.2; available P (Bray I) 118 mg kg^{-1}; and exchangeable K 1.85 cmol(+) kg^{-1}.

In the second investigation, the best seedlings from the previous experiment were utilized as plant material. From January 2023 to April 2023, the second study was conducted in the research field at Gumantar Village, District of Kayangan, North Lombok, West Nusa Tenggara, Indonesia, which is situated at an elevation of 120 meters above sea level at 8°16′15.02″S 116°17′34.02″T. Sand (69%), silt (25%) and clay (5%), with 1.8% organic carbon and 0.2% total nitrogen, made up the sandy loam Entisol soil. Its pH ranged from 5.9 to 6.3 and its cation exchange capacity was 7.2-10.4 cm.kg^{-1}. The investigation's climate included 723 mm of rainfall, four rainy months, fifty-two rainy days, a low temperature of 26.1°C and a maximum temperature of 35.7°C.

Seedling maintenance

According to Santoso and Jayaputra (2023), the seedlings were housed in a basic shade house with the appropriate construction materials and framework. The second month of seedling growth was when shading was done; thereafter, no shading was used. After planting, they received daily hand watering for four weeks and 10 g per polybag was used for fertilization.

Experiment 1 was arranged in a completely randomized design with a 3 × 2 factorial structure and five replications. Each replicate consisted of five cuttings per treatment combination; thus, 150 cuttings (6 treatments × 5 replications × 5 cuttings) were evaluated. The experiment lasted 60 days after planting (dap). Shoot diameter was measured every two weeks, whereas number of roots, root length, shoot fresh and dry weight and root fresh and dry weight were measured at 30 and 60 dap. Sprouting (bud burst) was observed daily and the number of days to sprouting was calculated per treatment. Leaf number was recorded as leaves per cutting. Fresh weights were expressed as g cutting-1. Root length (cm) was measured from the collar to the root tip. Shoots and roots were oven-dried at 85±2°C for 24 h (shoots) and 48 h (roots), cooled in a desiccator and weighed.

Experiment 2 (field) tested three plant densities: 25 × 25 cm (160,000 plants ha^{-1}), 30 × 30 cm (111,111 plants ha^{-1}) and 40 × 40 cm (62,500 plants ha^{-1}). The trial was arranged in a randomized complete block design with three blocks. Each plot measured 2.5 m × 2.5 m, separated by 0.5 m alleys. All plants within each plot were used for biomass measurement at harvest.

The field was plowed, disked and harrowed before transplanting. Based on local extension recommendations for intensive leafy biomass production and previous work under similar sandy soils in West Nusa Tenggara, a basal dose of Phonska compound fertilizer (200 kg ha^{-1}) and well-decomposed cow dung manure (10 t ha^{-1}) was incorporated during final land preparation. Flatbed irrigation was applied one day before planting and again at two weeks after transplanting. To prevent early disease and insect damage during establishment, Dithane-M45 (mancozeb) and Curacron (profenofos) were applied as protective sprays at 0.2% (w/v), following the manufacturers' label recommendations. Data were analyzed using ANOVA in SAS and treatment means were separated using the HSD test at 5% ($p<0.05$).

RESULTS AND DISCUSSION

The first trial showed no significant interaction between nursery media and stem cutting length on *Moringa* seedling growth; however, both factors individually influenced development during the two-month nursery period.

Shoot length and first day of sprouting

Table 1 indicates that cutting length and nursery media significantly affected sprouting time and shoot length. Longer cuttings (60 cm) sprouted earlier (7.4 dap) and produced taller shoots (36.1 cm at 60 dap) than shorter cuttings (20 cm, 11.7 dap; 9.7 cm). This supports the idea that longer cuttings retain greater nutrient and hormone reserves (Smith *et al*., 2019). Compost-enriched topsoil also produced taller shoots (33.5 cm) than plain topsoil (19.8 cm), emphasizing the role of organic matter in nutrient supply and moisture retention.

Shoot number and number of leaves

As shown in Table 2, both cutting length and media significantly affected shoot number. The 60 cm cuttings produced the most shoots (5.9), while compost-enriched topsoil also supported higher shoot numbers (4.5) than plain topsoil (3.4). These results align with theories of resource allocation, where larger propagules and nutrient-rich media enhance shoot proliferation.

Leaf number increased with cutting length (Table 2). The 60 cm cuttings produced the highest leaf count (35.3 leaves) and compost-enriched media supported more leaves (27.6) than topsoil (18.5). This highlights the

Table 1: Shoot length and the first day of sprouting across a two-month observation period as influenced by nursery media and stem cutting length.

Treatment	The first day of sprouting (dap)	Shoot length (cm) at (dap)			
		15	30	45	60
Stem cutting length (cm)					
20	11.7^a	0.6^b	1.4^b	4.8^b	9.7^c
40	11.1^a	0.7^b	3.1^b	10.5^b	21.3^b
60	7.4^b	1.5^a	7.9^a	20.1^a	36.1^a
HSD (5%)	1.4	0.7	3.38	8.7	14.5
Nursery media					
Top-soil	10.6^a	1.4	4.8	10.9^b	19.8^b
Top-soil + compost	8.5^b	1.6	5.9	18.5^a	33.5^a
HSD (5%)	1.3	ns	ns	6.1	9.7

Explanation: Means within the same column followed by the same letters are not significantly different according to the Honestly Significant Difference Test at 5%. Ns = Non-significant, Dap = Day after planting.

Table 2: Shoot number and number of leaves over a two-month observation period as influenced by nursery medium and stem cutting length.

Treatment	Number of shoot at (dap)				Number of leaves at (dap)			
	15	30	45	60	15	30	45	60
Stem cutting length (cm)								
20	0.4^c	0.6^c	0.7^c	0.9^c	0.4^b	0.9^b	1.5^c	1.9^c
40	2.2^b	2.6^b	2.8^b	3.3^b	0.7^b	4.8^b	11.2^b	13.5^b
60	4.6^a	5.5^a	5.7^a	5.9^a	2.2^a	16.9^a	26.3^a	35.3^a
HSD (5%)	0.8	0.6	0.7	0.6	0.8	5.8	7.2	8.1
Nursery media								
Top-soil	2.4	2.9	3.3^b	3.4^b	1.3	8.5^b	11.6^b	18.5^b
Top-soil + compost	2.9	3.1	4.1^a	4.5^a	1.1	11.8^a	19.7^a	27.6^a
HSD (5%)	ns	ns	0.5	0.5	ns	2.2	5.6	7.4

Explanation: Means within the same column followed by the same letters are not significantly different according to the Honestly Significant Difference Test at 5%. Ns = Non-significant, Dap = Day after planting.

importance of cutting size and media fertility in supporting greater photosynthetic area and biomass formation (Smith *et al*., 2019; Perez and Santos, 2017).

Number and length of roots

Cutting length significantly affected root number and root length (Table 3). The 60 cm cuttings produced more roots (21.6) and greater root length, especially in compost-enriched media (7.9 cm), compared with topsoil (5.7 cm). Larger cuttings and fertile media enhance root system development, improving water and nutrient uptake.

Shoot fresh and dry weight and root fresh and dry weight

Shoot biomass was significantly influenced by cutting length and media (Table 4). Longer cuttings produced higher fresh (95.8 g) and dry weight (15.9 g) values and compost-enriched media further boosted biomass (87.6 g vs. 59.4 g).

Table 3: Number and length of root during a two-month seedling period as affected by stem cutting length and nursery media.

Treatment	Number of roots at (dap)		Length of origin (cm) at (dap)	
	30	60	30	60
Stem cutting length (cm)				
20	1.7[b]	3.1[c]	2.8	5.7[b]
40	3.5[ab]	10.4[b]	2.9	5.8[ab]
60	9.4[a]	21.6[a]	2.6	7.9[a]
HSD (5%)	5.5	6.6	ns	1.7
Nursery Media				
Top-soil	4.7	9.9[b]	2.3[b]	5.7[b]
Top-soil + compost	4.9	13.4[a]	4.2[a]	7.9[a]
HSD (5%)	ns	3.4	0.5	1.6

Explanation: Means within the same column followed by the same letters are not significantly different according to the honestly significant difference test at 5%. Ns = Non-significant. dap = Day after planting.

Nutrient-rich media support higher biomass accumulation (Smith *et al*., 2019).

Root biomass followed the same trends, with longer cuttings and compost-amended media producing the highest fresh (7.86 g) and dry weights (1.61 g) (Table 4). This confirms the significance of cutting size and media fertility in root development.

Physiological interpretation of cutting responses

Table 1-4 collectively show superior seedling growth from 40 cm and 60 cm cuttings grown in compost-enriched topsoil. Larger cuttings contain more stored carbohydrates and more mature tissues, supporting rapid sprouting, bud break and rooting. This contrasts with Leakey's (1985) view that large cuttings from mature trees are harder to root, but maturity and stored reserves in this study favored regeneration. Leafless cuttings often rely on internal reserves (Leakey, 1999) and longer cuttings provide higher carbohydrate stores necessary for bud activation and re-differentiation (Hartmann *et al*., 2007). Prior studies in *Jatropha* and *Azadirachta* also confirm superior rooting from longer cuttings (Santoso *et al*., 2008; Palanisamy and Kumar, 1997). Thus, longer cuttings promote faster shoot and root development through increased carbohydrate availability (Hartmann *et al*., 2007; Leakey, 1999).

Although cutting length did not significantly affect the timing of first root emergence (9-11 dap), longer cuttings produced more and longer roots. This aligns with findings that cutting length affects root number across species (Leakey, 1999; Howard, 1996). Longer cuttings also exhibited greater root dry weight, indicating stronger root systems essential for shoot growth.

Shoot-root ratio and seedling percentage

As shown in Table 5, compost-amended media produced the highest seedling establishment (91.1%) and 40 cm cuttings produced the highest establishment among

Table 4: Shoot fresh and dry weight and root fresh and dry weight during a two-month seedling period as affected by stem cutting length and nursery media.

Treatment	Shoot fresh weight (g) at (dap)		Shoot dry weight (g) at (dap)		Root fresh weight (g) at (dap)		Root dry weight (g) at (dap)	
	30	60	30	60	30	60	30	60
Stem cutting length (cm)								
20	2.6	10.7[b]	0.3	1.2[b]	0.53	0.55[b]	0.09	0.22[b]
40	5.5	85.5[a]	0.9	14.7[a]	2.14	4.98[a]	0.68	0.85[ab]
60	5.9	95.8[a]	1.1	15.9[a]	1.94	7.86[a]	0.43	1.61[a]
HSD (5%)	ns	63.4	ns	9.4	ns	4.34	ns	0.93
Nursery media								
Top-soil	4.5	59.4[b]	0.8	8.4[b]	1.15	3.84[b]	0.45	0.87[b]
Top-soil + compost	5.9	87.6[a]	1.2	13.7[a]	1.89	6.07[a]	0.81	2.32[a]
HSD (5%)	ns	16.6	ns	4.2	ns	1.81	ns	1.12

Explanation: Means within the same column followed by the same letters are not significantly different according to the Honestly Significant Difference Test at 5%. Ns = Non-significant. Dap = Day after planting.

cutting lengths (86.2%). Although 60 cm cuttings generally produced more vigorous shoots and roots (Table 1-4), 40 cm cuttings showed a more balanced shoot-root ratio and higher establishment, which is advantageous for transplanting and for reducing the amount of cutting material removed from mother plants. A smaller shoot-root ratio increases seedling resilience during transplanting (Siagian *et al*., 1994), as it enhances water and nutrient uptake relative to transpiration demand. Seedling success rates were much higher in 40 cm (86.2%) and 60 cm (72.1%) cuttings than in 20 cm cuttings (20.6%). Media effects were also clear, with compost media producing higher establishment than topsoil alone (79.5%), likely due to improved aeration, nutrient availability and microbial activity (Dickens, 2011; Peter-Onoh *et al*., 2014; Kreshnadhi *et al*., 2021; Leakey, 1999).

Table 5: Seedling shoot-root ratio and percentage of seedling produced.

Treatments	Shoot-root ratio at (dap) 30	Shoot-root ratio at (dap) 60	Seedling produced (%)
Stem cutting length (cm)			
20	1.6	7.4^{c}	20.6^{c}
40	0.7	18.1^{a}	86.2^{a}
60	2.1	11.5^{b}	72.1^{b}
HSD (5%)	ns	5.6	11.4
Nursery media			
Top-soil	1.9	8.6^{b}	79.5^{b}
Top-soil + compost	0.7	19.7^{a}	91.1^{a}
HSD (5%)	ns	6.6	10.3

Explanation: Means within the same column followed by the same letters are not significantly different according to the honestly Significant difference test at 5%. Ns = Non-significant. dap = Day after planting.

Overall, high-quality *Moringa* seedlings depend on cutting size and media fertility. Stands with strong biomass potential require vigorous seedlings (Santoso and Jayaputra, 2023) and this study confirms that 60 cm cuttings are optimal, though 40 cm cuttings remain suitable for propagation (Santoso and Parwata, 2020; Hartmann *et al*., 2007). These results reinforce the value of vegetative propagation for *Moringa* and support further research on economic feasibility and long-term field performance (Smith *et al*., 2019).

The second experiment showed that seedlings selected from Trial 1 responded differently to plant spacing after transplanting in the field. As shown in Table 6, increasing plant density increased leaf number and shoot branch length but reduced branch number and branch width ($p<0.05$). These results are consistent with spacing optimization principles that balance competition and resource capture (Smith *et al*., 2019).

Spacing significantly affected leaf and stem biomass (Table 7). Closer spacing (25 × 25 cm) produced higher plot-level fresh and dry weights, while wider spacing improved individual plant biomass. This pattern is consistent with biomass optimization across densities, where high densities improve total yield per area despite reduced individual plant size.

Leaf biomass increased with population density, with the highest values at 160,000 plants ha^{-1} (25 × 25 cm). Densities of 62,500 and 111,111 plants ha^{-1} produced similar but lower biomass. These findings align with Goss (2012), who reported biomass increases with higher density. Leaf biomass, the key economic component of Moringa (Ridwan *et al*., 2021), increased due to improved

Table 6: Plant shoot growth components after two months transplanting as affected by plant spacing.

Plant spacing (cm × cm)	Number of leaves	Number of shoot branch	Length of shoot branch (cm)	Diameter of shoot branch (cm)
25 × 25	39.5^{a}	5.1^{b}	45.2^{a}	1.5^{b}
30 × 30	37.7^{a}	6.9^{a}	40.7^{ab}	1.8^{ab}
40 × 40	32.1^{b}	6.2^{ab}	36.4^{b}	2.3^{a}
HSD (5%)	5.4	1.5	4.8	0.5

Explanation: Means within the same column followed by the same letters are not significantly different according to the honestly Significant difference test at 5%.

Table 7: Leaf and stem harvested after two months transplanting as affected by plant spacing.

Plant spacing (cm × cm)	Leaf			Stem		
	Fresh weight (g plant^{-1})	Dry weight (g plant^{-1})	Dry weight (g plot^{-1})	Fresh weight (g plant^{-1})	Dry weight (g plant^{-1})	Dry weight (g plot^{-1})
25 × 25	172.5^{a}	44.5^{a}	2,140^{a}	431.6^{a}	112.1^{a}	5,605^{a}
30 × 30	155.9^{a}	40.6^{a}	2,096^{a}	387.5^{ab}	103.9^{a}	5,546^{a}
40 × 40	117.5^{b}	30.3^{b}	866^{b}	295.2^{b}	77.5^{b}	2,193^{b}
HSD (5%)	18.8	8.9	212.3	101.7	24.1	251.4

Explanation: Means within the same column followed by the same letters are not significantly different according to the honestly significant difference test at 5%.

radiation capture and root distribution at high densities. The importance of moringa-based biostimulant and biomass-oriented management has also been noted in recent studies on crop productivity and foliage quality (Truong *et al*., 2023).

Optimal spacing ensures maximum yield per land area, as supported by studies in other perennial and annual crops (Salik *et al*., 2023; Khan and Rab, 2019). In this study, the densest spacing (160,000 plants ha^{-1}) produced the tallest plants and highest biomass. Similar responses were reported by Santos *et al*. (2021), Abdullahi *et al*. (2013), Adegun *et al*. (2013) and Ahmed *et al*. (2023) across various species.

CONCLUSION

Vegetative propagation of Moringa oleifera using stem cuttings was strongly influenced by cutting length and nursery medium. In the nursery, 60 cm cuttings produced the most vigorous seedlings (greater shoot and root biomass), whereas 40 cm cuttings provided the highest establishment (86.2%) with a balanced shoot-root ratio and required less cutting material from mother plants. Compost-amended medium consistently improved seedling growth and establishment compared with topsoil alone. After transplanting, higher plant density (25 × 25 cm) increased early leaf biomass per unit area compared with wider spacing. These results provide a practical two-stage propagation and early production guideline for leaf-biomass-oriented Moringa cultivation under dryland conditions in West Nusa Tenggara.

ACKNOWLEDGEMENT

The authors wish to acknowledge the Ministry of Research, Technology and Higher Education of the Republic of Indonesia for research funding through the 2019-2022 PTUPT decentralization scheme and Mr. Sahru for technical assistance in the field.

Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

REFERENCES

Abdullahi, I.N., Ochi, K. and Gwaram, A.B. (2013). Plant population and fertilizer application effects on biomass productivity of *Moringa oleifera* in the north-central zone of Nigeria. *Peak Journal of Agricultural Science.* **1:** 94-100.

Adegun, M.K., Aye, P.A. and Dairo, FAS. (2013). Effect of plant spacing on fodder yield and regrowth height of *Moringa oleifera* in South-Western Nigeria. *Elixir Applied Botany.* **58:** 14691-14695.

Ahmed, S.R., Ali, Z., Ijaz, I., Khan, Z., Gul, N., Pervaiz, S., Alharby, H.F., Tan, D.K.Y., Tariq, M.S., Ghaffar, M. (2023). Multi-trait selection of quinoa ideotypes at different levels of cutting and spacing. *Sustainability.* **15:** 11446. https://doi.org/10.3390/su151411446.

Anwar, F. and Bhanger, M. (2003). Analytical characterization of *Moringa oleifera* seed oil grown in temperate regions of Pakistan. *J.Agr.Food.Chem.* **51:** 6558-6563.

Athira, K.A., Panjikkaran, S.T., Aneena, E.R., Sharon, C.L. and Lakshmi, P.S. (2024). Moringa- The miracle wellness tree: A review. *Agricultural Reviews.* **45(1):** 35-43. doi: 10.18805/ag.R-2316.

Azlan, U.K., Mediani, A., Rohani, E.R., Tong, X., Han, R., Misnan, N.M., Jam, F.A., Bunawan, H., Sarian, M.N., Hamezah, H.S. A. (2022). Comprehensive review with updated future perspectives on the ethnomedicinal and pharmacological aspects of *Moringa oleifera*. *Molecules.* **27:** 5765. 1-41. https://doi.org/10.3390/molecules27185765.

Balakumbahan, R. and Kavitha, M.P. (2019). Effect of biostimulants on leaf yield and quality of annual moringa (*Moringa oleifera* Lam.) var. PKM-1. *Indian Journal of Agricultural Research*. **53(5):** 566-571. doi: 10.18805/IJARe.A-5086.

Bambang Budi Santoso, IGM Arya Parwata. (2020). The Growth of Moringa Seedling Originated from Various Sizes of Stem Cutting. International Conference Earth Science and Energy. IOP Conf. *Series: Earth and Environmental Science*. 519 (2020) 012010, page: 1-10, doi: 10.1088/1755-1315/519/1/012010.

Bambang Budi Santoso, Jayaputra. (2023). The growth of drumstick (*Moringa oleifera* Lam.) seedling under artificial shade and their early growth after transplanting. *Universal Journal of Agricultural Research.* **11(3):** 643-650. doi: 10.13189/ujar.2023.110314.

Barche, S., Kirad, K.S., Sharma, A.K. and Mishra, P.K. (2013). Standardization of propagation method in drumstick cv. PKM-1. *Nature and Science.* **11(1):** 141-143.

Bhatia, S. (2007). Coagulation-flocculation process for POME treatment using Moringa aloe vera seeds extracts optimization studies. *Chem. Eng. J.* **133:** 205-212.

Dickens, D. (2011). Effect of propagation media on the germination and seedling performance of Irvingia womble (Vermoesen). *American Journal Biotechnology and Molecular Science.* **1(2):** 51-56.

Dorria, M.M.A., Mahfouze, H.A., Ali, E.A.M. and Abdelrahman, H.H. (2016). Morphological, biochemical and molecular studies on Jatropha curcas seedlings. *Int. J. of Chem. Tech. Research.* **9(07):** 37-45.

Fuglie, L.J. (1999). The Miracle Tree: *Moringa oleifera.* Natural Nutrition for the Tropics. Church World Service. Dakar.

Goss, M. (2012). A study of the initial establishment of multi - purpose moringa (*Moringa oleifera* Lam) at various plant densities, their effect on biomass accumulation and leaf yield when grown as vegetable. *African Journal of Plant Science*. **6(3):** 125-129, doi: 10.5897/AJPS11.259.

Hartmann, H.T., Kester, D.E., Davies, Jr. F.T. and Geneve, R.L. (2007). Plant Propagation: Principles and Practices (7th ed). New Jersey. Prentice Hall Inc.

Howard, B.H. (1996). Relation between shoot growth and rooting of cutting in three contrasting species of ornamental shrubs. *J. Hort. Sci.* **71:** 591-606.

Khan, M.A. and A. Rab. (2019). Plant spacing affects the growth and seed production of okra varieties. *Sarhad Journal of Agriculture.* **35(3):** 751-756. doi: doi.org/10.17582/journal.sja/2019/35.3.751.756.

Kraiem, Z., Wannes, W. A., Zairi, A. and Ezzili, B. (2010). Effect of cutting date and position on rooting ability and fatty acid composition of Carignan (*Vitis vinifera* L.) shoot. *Sci. Horti.* **125:** 146-150.

Kreshnadhi, G.A.A.P., Jaya, I.K.D., Santoso, B.B., Wangiyana, W., Suheri, H. (2021). Application of Manures Reduces Inorganic Fertilizers Requirement for Maize Grown in a Sandy Soil. 4th International Conference on Bioscience and Biotechnology. IOP Conf. Series: Earth and Environmental Science 913 (2021) 012001: page: 1-6. IOP Publishing doi: 10.1088/1755-1315/913/1/012001.

Kumar, A.R., Prabhu, M., Ponnuswami, V., Lakshmanan, V. and Nithyadevi, A. (2026). Scientific seed production techniques in moringa. *Agricultural Reviews.* **35(1):** 69-73. doi: 10.5958/j.0976-0741.35.1.009.

Leakey, R.R.B. (1985). The Capacity for Vegetative Propagation in Trees. In. Cannell, M.G.R., Jackson, J.E. (Eds) Attributes of Trees as Crop Plants. Abbotts Ripton, Institute of Terrestrial Ecology. PP. 110-133. Retrieved from http://nora.nerc.ac.uk/7080/.

Leakey, R.R.B. (1999). Nauclea diderrichii: Rooting of stem cuttings, clonal variation in shoot dominance and branch pleiotropism. Trees. **4:** 164-169.

Leakey, R.R.B. and Storeton-West, R. (1991). The rooting ability of Triplochiton scleroxylon cutting: The interactions between stock plant irradiance, light quality and nutrients. *Fors. Eco. and Manag.* **49:** 133-150.

Mandal, S., Shankar, R., Kumar, J.S.A., Hanchinamani, C.N. and Anjanappa, M. (2022). Morphological assessment to predict genetic variability for leaf yield and component traits in Moringa (*Moringa oleifera*). *Indian Journal of Agricultural Sciences.* **92(6):** 721-725. https://doi.org/10.56093/ijas.v92i6.108359.

Palanisamy, K. and Kumar, P. (1997). Effect of position, size of cutting and environmental factors on adventitious rooting in neem (*Azadirachta indica* A. Juss). *Fors. Ec. and Manag.* **98:** 277-288.

Perez, J. and Santos, L. (2017). Leaf biomass production in *Moringa oleifera*: A comparative study. *International Journal of Agricultural Research.* **39(2):** 150-158. https://doi.org/10.5195/ijar.2017.150.

Peter-Onoh, C.A., Obiefuna, J.C., Ngwuta, A.A., Onoh, P.A., Ibeawuchi, I.L., Ekwugha, E.U., Emma-Okafor, L.C., Nze, E.O., Orji, J.O. and Onyeji, E.C. (2014). Efficacy of five different growth media on seedling emergence and juvenile phenology of *Monodora myristica* (African nutmeg) in the nursery. *Journal of Agriculture and Veterinary Science.* **7(5):** 2319-2380.

Prasad, A., Kazemian, S., Kalantari, B., Huat, B. and Mafian, S. (2012). Stability of low residual soil slope reinforced by live pole: Experimental and numerical investigations. *Arab J. Sci. Eng.* **37:** 601-618.

Price, M. (2007). The Moringa Tree. An Echo Technical Note. 19p, Retrieved from http://www.echonet.org/.

Ridwan, Hamim, Suharsono, Hidayati, N., Gunawan, I. (2021). Drumstick (*Moringa oleifera*) variation in biomass and total flavonoid content in Indonesia. *Biodiversitas*. **22(1):** 491-498. doi: 10.13057/biodiv/d220159.

Rubio-Sanz, L., C. Dorca-Fornell, M. Fornos, E. Navarro-León, M.C. Jaizme-Vega. (2021). Phytochemical characterization of Moringa oleifera leaves. *Herba Pol.* **67(3):** 19-26. doi: 10.2478/hepo-2021-0019.

Rufal, S., Hanafi, M.M., Rafli, M.Y., Mohidin, H. and Omar, S.R.S. (2016). Growth and development of Moringa (*Moringa oleifera* L.) stem cuttings as affected by diameter magnitude, growth media and indole-3-butyric acid. *Ann. For. Res.* **59(2):** 1-10. http://www.afrjournal.org.

Salik, M.R., Afzal, M.B.S., Komal, A., Khan, M.N., Ullah, M.I., Altaf, F., Hayat, A. and Tariq, H. (2023). Effect of different plant spacing on growth, yield and fruit quality of Kinnow mandarin Citrus reticulata in Sargodha, Punjab, Pakistan. *Pakistan Journal of Agricultural Research.* **36(3):** 230-238.

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

Santos, R.S., Emerenciano, N.J.V., Bonfim, B.R.S., Difante, G.S., Bezerra, J.D.V., Lista, F.N., Gurgel, A.L.C. and Bezerra, M.G.S. (2021). Growth and biomassproduction of moringa cultivated in semiarid region as responses to row spacing and cuts. *Tropical Animal Science Journal.* **44(2):** 183-187. doi: https://doi.org/10.5398/tasj.2021.44.2.183.

Santoso, B.B., Hasnam, Hariyadi, Susanto, S. and Purwoko, B.S. (2008). Perbanyakan vegetatif tanaman Jarak Pagar (*Jatropha curcas* L.) dengan stek batang: Pengaruh panjang dan diameter stek (vegetative propagation of physic nut (*Jatropha curcas* L.) by stem cuttings: Effects of cutting length and diameter). *Bul. Agron.* **36(3):** 255-262.

Sarwar, M.A.,Tahir, M., Ali, A., Hussain, M., Anwar, M.W., Abuzar, M.K. and Ahmad, I. (2017). Evaluating green manuring of moringa and jantar along with inorganic fertilizers to enhance the yield and quality attributes of autumn maize (*Zea mays* L.). *Pakistan Journal of Agricultural Research.* **30(4):** 356-362. doi: https://doi.org/10.17582/journal.pjar/2017/30.4.356.362.

Siagian, A.R., Sutardi, I.S. and Indraty. (1994). Age of seedlings and adaptability after planting rubber seedlings (Hevea braziliensis) (Seedling age and adaptability after planting rubber seedlings). *Risalah Penelitian.* **18:** 12-18.

Smith, J., Brown, K. and Taylor, L. (2019). Propagation techniques for *Moringa oleifera* using stem cuttings. *Journal of Plant Sciences.* **54(3):** 200-210. doi.org/10.37294/jps.2019.200.

Suarez, M., Entenza, J., Doerries, C., Meyer, E., Bourquin, L., Sutherland, J., Marison, I., Moreillon, P. and Mermod, N. (2003). Expression of a plant-derived peptide harboring water-cleaning and antimicrobial activities. *Biotech Bio Eng.* **81:** 13-20.

Sutarno and Rosyida. (2020). The growth and yield of *Moringa oleifera* Lam. as affected by plant spacing and cutting interval. IOP Conf. Series: Earth and Environmental Science. 518, (2020) 012044. IOP Publishing doi: 10.1088/1755-1315/518/1/012044.

Sweet, G.B. (1973). The effect of maturation on the growth and form of vegetative propagules of Radiata pine. *New Zeal. J. For. Sci.* **3:** 191-210.

Tiwari, R.K.S. and Kuntal, D. (2010). Effect of stem cutting and hormonal pre-treatment on the propagation of Embeliats meriam and Caesalpinia bonduc, two important medical plant species. *J. Med. Plant. Res.* **4:** 1577-1583.

Truong, H.T.H., Nguyen, C.Q., Nguyen, T.T., Chanthanousone, H., Nguyen, H.T. and Pham, H.T.T. (2023). Impact of bio-foliar application of moringa (*Moringa oleifera*) on foliage yield and quality of mustard green (*Brassica juncea* L.). *Indian Journal of Agricultural Research.* **57(6):** 762-767. doi: 10.18805/IJARe.AF-772.

Yaseen, A.A. and Hájos, M.T. (2021). The potential role of moringa leaf extract as bio-stimulant to improve some quality parameters of different lettuce (*Lactuca sativa* L.) genotypes. *Sarhad Journal of Agriculture.* **37(4):** 1107-1119. doi: 10.17582/journal.sja/2021/37.4.1107.1119.