Pak. J. Bot., 57(4): 1273-1279, 2025. DOI: http://dx.doi.org/10.30848/PJB2025-4(8)

SOILLESS MEDIA SOLUTIONS FOR MANGO NURSERY INVOLVE THE SYNERGISTIC USE OF BIOCHAR AND POT SIZE TO ENHANCE GROWTH

MUHAMMAD SHAHZAD ZAFAR[1], ISHTIAQ AHMAD RAJWANA[1*], KASHIF RAZZAQ[1], TANVEER UL HAQ[1] AND HAMEED ULLAH[2]

[1]Department of Horticulture, Muhammad Nawaz Shareef University of Agriculture, Multan, Punjab, Pakistan
[2]Mango Research Institute, Multan, Punjab, Pakistan
**Corresponding author's ishtiaq.rajwana@mnsuam.edu.pk; shahzadvh@gmail.com*

Abstract

Mango is Pakistan's second most important fruit crop, facing escalating health issues, mainly from unhealthy nursery plants. To address challenges like poor seedling growth and high mortality rates, a study was conducted to investigate the effects of various media on the growth and performance of mango nursery plants, focusing on four soilless media: M1(Compost-15%+ Coir 30% + Bagasse 65%), M2 (Coir 5%+ Bagasse 30%+ Compost-2 65%), M3(Compost-25%+ Coir 30% + Bagasse 65%), and M4(Biochar-25% + Coir 30% + Bagasse 65%); a soil-based media recipe M0 (Coir 5% + Silt 30% + Bagasse 65%) as control and three sizes of black polythene pots: S1 (35.56 cm x 22.86 cm), S2 (40.64 cm x 22.86 cm), and S3 (45.72 cm x 22.86 cm). The findings exhibited that media M4 and pot size S3 significantly enhanced plant height (42.97%), No. of leaves (30.21), leaf area (1.51 folds), stem girth (1.59 times), volume of root (2.53 folds), volume of shoot (1.42 folds), seedlings fresh biomass (39.68%), seedlings dry biomass (50.77%), fresh root weight (2.16 times) and dry root weight (2.36 times) as compared to control. However, compared to the control, a significant reduction was observed in days to first flush (10.64 days) and plant mortality (77.42%) in media M4 and pot size S3. The study reveals that soilless media M4 with larger pots S3 significantly improves the growth and vigor of mango nursery plants and reduces mortality compared to soil-based pot media and smaller pots. The research underscores the innovative potential of biochar-based media as a sustainable option, which enhances nursery practices and fosters healthier seedling growth in mango production.

Key words: Biochar, Mango nursery, Mortality, Biomass, Pot size.

Introduction

Mango (*Mangifera indica* L.) is an important fruit crop in tropical and subtropical countries, particularly in Asia, where it is adored as the "king of fruits" (Grewal *et al*., 2020). Mango orchard health difficulties are growing more prevalent by the day, and the primary cause of poor output can be traced to mango nursery plants. Mango nurseries are grown in mango orchards beneath the canopy of huge trees in Pakistan, as opposed to established mango-producing countries where nurseries are grown in standardized container medium in green rooms isolated from mango orchards. These potted nurseries are kept separate from other pests and illnesses (Haq *et al*., 2017). Orchard soil is frequently a source of insects, pests, root-borne diseases, and, most critically, weed seeds, which harm nursery plants by competing for nutrients and space. Initially, the Australia-Pakistan Agriculture Sector Linkages Program (ASLP) developed potting material, a game changer in the mango nursery sector in Pakistan. As part of the project, the nurseryman was trained on the importance of a potted nursery under an isolated shaded house. The developed media has three ingredients: 5% coconut coir, 30% silt, and 65% sugarcane bagasse by volume. High EC of fresh coir has a detrimental effect on plant growth (Hongpakdee & Ruamrungsri, 2015). In contrast, silt is mostly brought from local canals, and it has been discovered that canal water frequently mixes with sewerage and industrial waste, resulting in polluted silt and deleterious effects that ultimately affect seedling growth and development (Salemaa & Uotila, 2001). Whereas, fresh sugarcane bagasse decomposes rapidly (Thiessen *et al*., 2023), and shrinkage of media disrupted the ratio of aeration and water in media, resulting in stunted growth and even seedling death (Agarwal *et al*., 2023).

The most critical input for optimal seedling production is the potting medium. It is in charge of producing healthy, uniform seedlings. In order to create an optimal environment for plant growth, it is important to modify the growing media by adding necessary amendments. Field soils are typically unsuitable for container plant production due to their inherent limitations.

The value of plant material for use in a growing medium is primarily determined by the type of plant material and the extent of its decomposition. In the past few years, growing environmental concerns (Barkham, 1993) and the rising cost of peat have led to increased attention to discovering alternative, organic, and cost-effective materials to serve as partial or entire substitutes for peat in nursery plant production. Coir is one such substance, made from the husks of coconut fruits (*Cocos nucefera* L.) produced in several tropical regions of the world (Evans & Stamps, 1996). Coir is a sustainable and readily available resource that offers a balanced ratio of air and water, akin to peat (Barret *et al*., 2016). However, coir obtained from coastal regions requires treatment to lower toxic sodium and potassium levels and be effectively used as a soilless medium (Poulter, 2014). In nursery production, coir has proven to be an effective potting medium (Mariotti *et al*., 2020). Compost and biochar can positively affect plant growth by improving water retention and aeration, promoting better plant growth (Baronti *et al*., 2014). Some composts may not be suitable for potting media due to high salt content, pH levels, phytotoxicity, rapid shrinkage, or excessive heavy metal content. However, depending on the composition of the feedstock, they can still be a vital source of nutrients (Hue & Sobieszczyk, 1999). Biochar added to rooting media in a 2:1:1 ratio increased the germination percentage, germination rate, seedling vigor, seedling height, girth, number of leaves, and leaf area (Jasmitha, *et al*., 2018). Similarly, Al-Toobi *et al*., (2023) claimed that mango wood biochar incorporation in growing media improved plant growth; however, the physiological effects of biochar at higher rates had detrimental effects on plant development and overall performance (Regmi *et al*., 2022). The challenge of maintaining the necessary equilibrium between air and water in the soil, especially in limited quantities, has led to the development of soilless growth media. These media have emerged as a transformative solution, enabling producers to effectively regulate water, air, and nutrient availability to plant roots. Additionally, soilless growth media offer the advantage of mitigating soil-borne diseases. (Fussy & Papenbrock, 2022).

In Pakistan, currently (35.56 cm × 25.4 cm) pot size is used for potted silt-based mango nurseries (Iqbal *et al*., 2022). Mango is a fast-growing fruit crop with a deep taproot system. When plants are sold, it is usual for their roots to have broken through the plastic bags. As a result, such plants take longer to establish themselves in the field after transplantation, and their growth remains slow. Mango nursery plants that are healthy and have a robust, undisturbed root system, on the other hand, establish themselves more quickly and resume growth shortly after being planted in the field. (Denovan *et al*., 2016).

In Egypt and Israel, mango nursery plants are prepared in larger-sized bags, which have been shown to enhance adequate root development and improve graft establishment in the field. Container size positively affects tap root length, secondary root quantity, and root spread in general. Compared to tiny containers, larger containers produced healthier plants (Haldankar *et al*., 2014).

Container-grown nurseries have several benefits over field-grown nurseries, including same-site utilization annually, prevention of harmful pests, less requirement of tools and equipment, and a partially controlled microenvironment (Maxwell & Lyons, 1979). The combined effect of plant growing media and container size on *Cajanus cajan* and *Sesbania sesban* seedling growth demonstrates that growing media and container size substantially affect seedling growth. When roots are restricted within a container, inhibiting their growth, they engage in a competition for vital resources. This competition arises due to the increased mass of the roots and the limited space available for root expansion, resulting in a scarcity of essential oxygen for their survival (Peterson *et al*., 1991). Using soilless media-based nurseries on a commercial scale is an established nursery practice in quality mango producing countries. Therefore, we anticipated using soilless media enriched with biochar and larger polythene bags to enhance the seedling's growth by curtailing the tap root and handling root volume could be a revolutionary step for mango nursery production.

Considering the importance of potting media and pot size, this study aimed to identify and choose the ideal potting media and pot size for mango nursery plants. Using agricultural solid waste as potting media could considerably help with waste management, farming approaches, and environmental sustainability in the region. Developing a superior potting medium from waste products and appropriate pot size was prioritized to reduce the plant mortality ratio and produce healthy and vigorous mango nursery plants.

Material and Methods

The present study was conducted at MNS-University of Agriculture, Multan, during 2023 and 2024. To prepare soilless pot media recipes, ingredients including Compost-1 (Rice husk+Wheat straw+Corn cob), Compost-2 (Bagasse), Biochar-1 (Corn Cob), Biochar-2 (Mango wood), Bagasse (one-year-old), Coconut Coir (washed with fresh water) were mixed by volume in 5:30:65 ratio. The experiment evaluated four soilless media recipes: M1 (Compost-1 5% + Coir 30% + Bagasse 65%), M2 (Coir 5% + Bagasse 30% + Compost-2 65%), M3 (Compost-2 5% + Coir 30% + Bagasse 65%), and M4 (Biochar-2 5% + Coir 30% + Bagasse 65%) against a traditional soil-based potting mix (M0) comprised Coir 5% + Silt 30% + Bagasse 65%. The experiment utilized black polythene pots in three sizes: S1 (35.56 cm x 22.86 cm), S2 (40.64 cm x 22.86 cm), and S3 (45.72 cm x 22.86 cm). The physical and chemical properties of media combinations under study are given in (Table 1). The media mixing ratio (5:30:65), pot media M0 (Coir 5% + Silt 30% + Bagasse 65%), and pot size S1 (35.56 cm x 22.86 cm) were taken as a control since this combination is already in practice (Haq *et al*., 2017).

Each treatment received NPK fertilizer (20:20:20, 5-g per pot) in mid-February and mid-July. The pots were designed with 24 drainage holes (12 mm each) in the lower half. Mango stones were sown on July 15th under tree shade, and seedlings were transplanted in mid-August when they had four light green leaves. Cleft grafting was conducted in March at a height of 9 inches using mango cv. Sufaid Chaunsa as scion. The plants were grown under a 65% black shading net, with transparent polythene covering them during winter from mid-October to mid-January to protect them from cold temperatures. Compost was prepared according to the method described by Ali *et al*., (2015), and a pit measuring 10 ft in length, 7 ft in width, and 4 ft in depth was prepared. It was enclosed by walls and covered with a roof. The raw materials for each type of compost were mixed. The mixture was then layered in the pit to a depth of 0.5 ft, and the accelerator was sprinkled over it repeatedly until the pit was filled. A plastic sheet was used to cover the pit. The entire compost mixture was mixed every two weeks to facilitate rapid aerobic decomposition. After a couple of weeks, the compost was ready to use. It was then air-dried, sieved, and stored for the experiment. Two types of biochar were prepared, one from shelled corn cobs and the second from mango wood looping having leaves using the kon-tiki Flame Curtain Pyrolysis technique (Cornelissen *et al*., 2016). The data for various attributes were recorded after 365 days of seedlings transplanting, and an average was taken.

Plant height was measured from pot media to the terminal bud of the plant using meter rods and expressed in cm. From a straightforward count, the total number of leaves was ascertained. Leaf area was measured using a leaf area meter and expressed in cm2. Using a vernier caliper, the stem girth of mango nursery plants was measured and expressed in cm. The volume of root and shoot was measured by the method described by

Harrington *et al*., 1994. The fresh and dry weight of seedlings and roots was determined according to Gebregiorgs *et al*., (2021). The number of days from transplanting seedlings into pots to the appearance of a leaf that was L: 9 mm and W: 3.5 mm in size was counted to access days to the first flush. The seedling mortality percentage was calculated after 365 days of seedling transplanting by using the following formula;

$$Mortality\ (\%) = \frac{\text{No. of dead seedlings}}{\text{Total No. of seedlings after transplanting}} X\ 100$$

The survival percentage was calculated after 4 months of sowing based on the below mentioned formula:

The experimental data were analyzed for analysis of variance (Steel *et al*., 1997) using statistix® 8.1 software (Tallahassee, Florida, USA) based on four replications under a 2-factor factorial (media treatments and pot size) configuration. Prior to statistical analysis, the data of two years were pooled since the year effect was not statistically significant. Least Significant Differences Fisher's test (LSD Fisher's test) was used to compare the means at a 5% probability level ($p \leq 0.05$).

Results

The findings revealed that the growth attributes of mango nursery plants were significantly affected by the combination of various growing media and pot sizes. The most significant increase in plant height was observed in media M4 with pot size S3, showing a 42.97% rise compared to the control treatment (M0) in pot size S1 (Fig. 1-A). The data exhibited that No. of leaves was significantly improved, as media M4 in pot size S3 yielded an average of 30.21 leaves, contrasting sharply with the 11.96 leaves found in the control treatment (M0) in pot size S1 (Fig. 1-B). Leaf area measurements showed a 1.51-fold significant increase in media M4 when paired with pot size S3 compared to the control (M0) in pot size S1 (Fig. 1-C). Furthermore, stem girth was significantly larger in plants grown in media M4 and pot size S3, measuring 1.59 times more than the control (M0) in pot size S1 (Fig. 1-D). The combination of M4 media and pot size S3 constantly outperformed others, achieving the highest plant height, leaf count, leaf area, and stem girth. This highlights the superiority of biochar-based media (M4) and larger pot size (S3) for optimal mango nursery growth.

The data exhibited significant enhancement in the volume of the root of the mango nursery plant, increasing by 2.53 folds in media M4 with pot size S3 compared to the control (M0) in pot size S1 (Fig. 2-A). Similarly, the shoot volume demonstrated a maximum increase of 1.42 folds in media M4 with pot size S3 compared to the control (M0) in pot size S1 (Fig. 2-B). The data depicted the highest increase (39.68%) in fresh weight of seedlings in media M4 when grown in pot size S3 as compared to the plant grown in control (M0) with pot size S1 (Fig. 2-C). Similarly, the data showed significantly higher (50.77 %) dry weight of seedlings when grown in pot size S3 than when the plant was grown in control (M0) with pot size S1 (Fig. 2-D). Maximum root and shoot volume, along with fresh and dry seedling weight were achieved in pot size S3 (45.72 cm x 22.86 cm) with M4 media underlining the efficacy of biochar.The fresh weight of root in media M4 with pot size S3 was 2.16 times greater than that of the control (M0) with pot size S1 (Fig. 3-A), and the dry weight of roots was 2.36 times higher when compared with the control (M0) with pot size S1 (Fig. 3-B). The days until the first flush post-transplanting was found to be minimum in media M4 with pot size S3, recorded at 10.64 days, compared to 22.05 days for the control (M0) in pot size S1 (Fig. 3-C). The data exhibited that mortality rates of mango nursery plants dropped significantly by 77.42% in media M4 when combined with pot size S3 compared to the control (M0) with pot size S1 (Fig. 3-D). The synergistic effect of biochar-based media (M4) and S3 pot size resulted in in early flush emergence, maximum fresh and dry weight of roots, and minimum mortality percentage.

Table 1. Physical and chemical properties of various media combinations.

Media	Ingredients combination	pH	EC (µS/cm)	Air filled porosity (%)	Water holding capacity (%)	Comparative summary
M0	Coir 5% + Silt 30% + Bagasse 65%	7.8	1300.3	15.0	51.3	Highest pH, EC, and WHC; lowest compost incorporation
M1	Compost-1 5% + Coir 30% + Bagasse 65%	6.5	1044.0	13.5	42.3	Moderate pH; lower WHC and EC than M_0
M2	Coir 5% + Bagasse 30% + Compost-2 65%	6.4	1082.3	13.7	44.0	Lowest pH; balanced WHC; EC higher than M_1, lower than M_0
M3	Compost-2 5% + Coir 30% + Bagasse 65%	6.5	1056.3	14.7	43.0	Similar to M_1, but with slightly higher WHC and porosity
M4	Biochar-2 5% + Coir 30% + Bagasse 65%	6.7	1012.0	12.3	40.3	Lowest WHC, porosity and EC; moderate pH; biochar inclusion

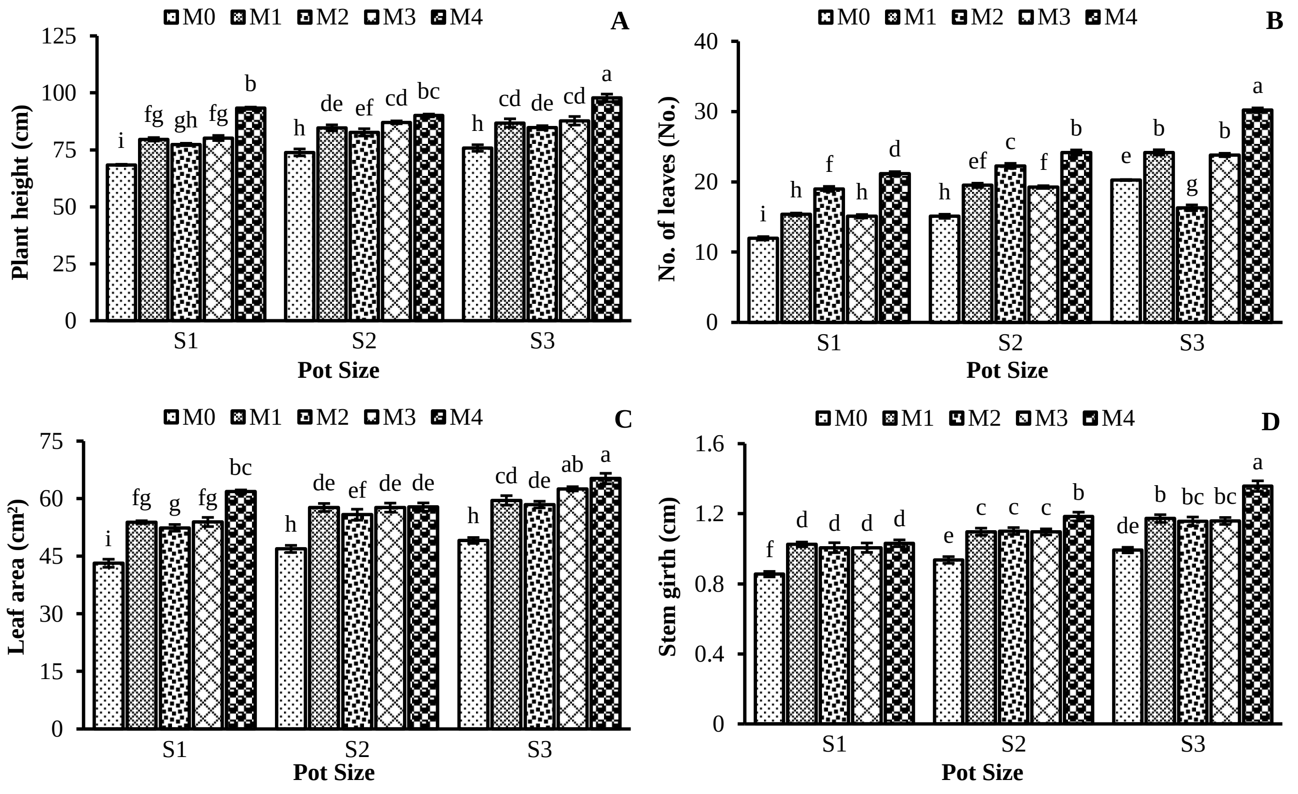

Fig. 1. Effect of growing media and pot size on plant height (A), No. of leaves (B), Leaf area (C) and Stem girth (D) of mango nursery plants. The different letters show a significant difference at $p \leq 0.05$. Vertical bars indicate ± S.E & means and are invisible when the values are negligibly small. LSD value at $p \leq 0.05$, (A) MxS: 3.4961**(n=4), (B) MxS: 0.8414***(n=4), (C) MxS: 2.8688***(n=4), (D) MxS: 0.0615***(n=4).

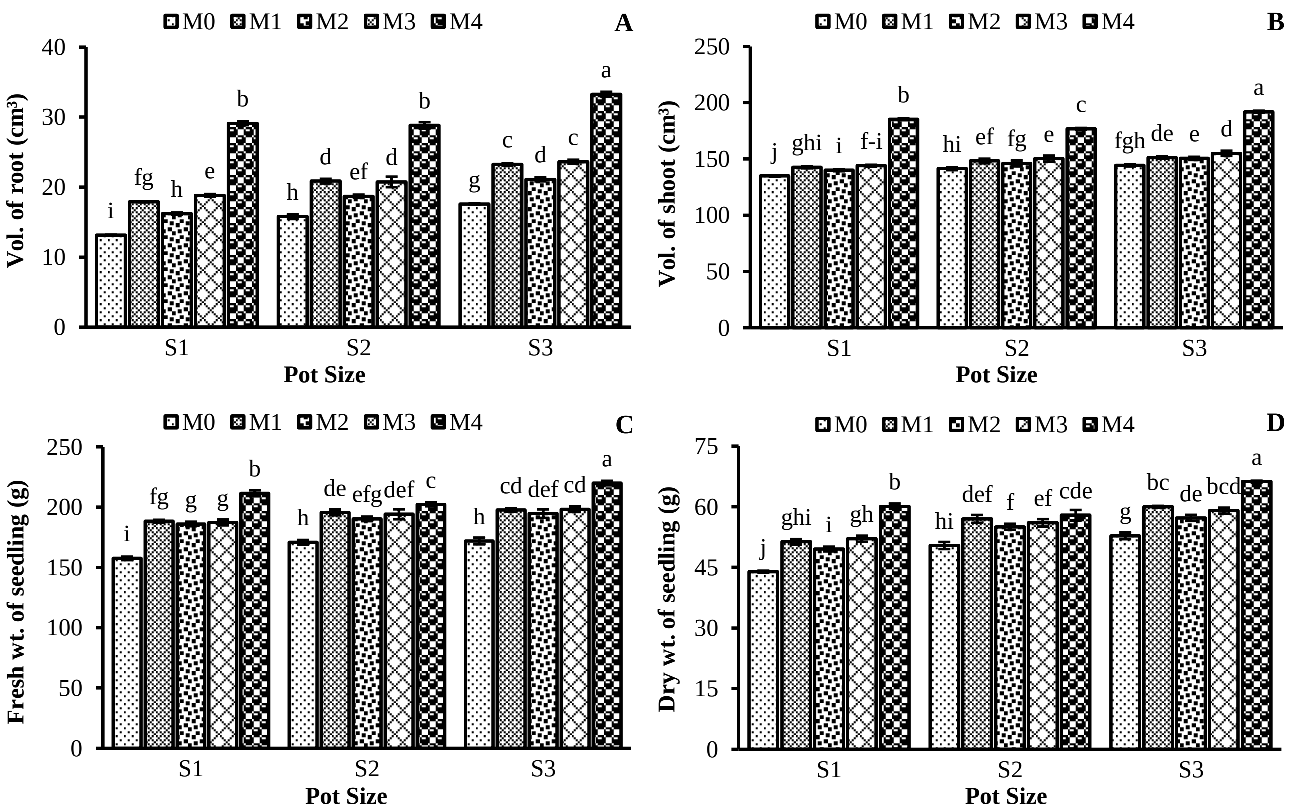

Fig. 2. Effect of growing media and pot size on vol. of root (A), vol. of shoot (B), fresh wt. of seedling (C), dry wt. of seedlings (D) of mango nursery plants. The different letters show a significant difference at $p \leq 0.05$. Vertical bars indicate ± S.E & means and are invisible when the values are negligibly small. LSD value at $p \leq 0.05$, (A) MxS: 0.8915***(n=4), (B), MxS: 4.2121***(n=4), (C) MxS: 6.6121***(n=4), (D) MxS: 2.1541***(n=4).

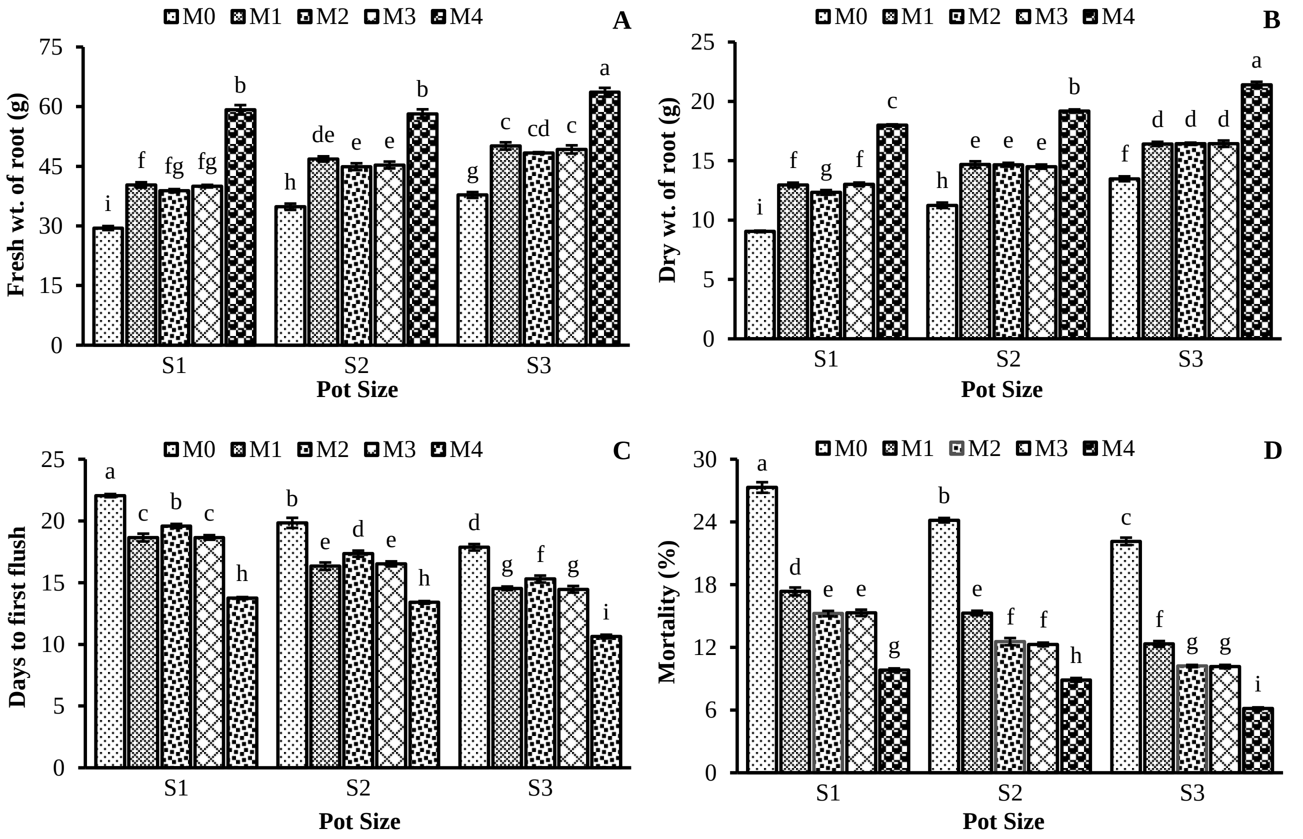

Fig. 3. Effect of growing media and pot size on fresh wt. of root (A), dry wt. of root (B), days to first flush (C), mortality (D) of mango nursery plants. The different letters show a significant difference at $p \leq 0.05$. Vertical bars indicate ± S.E & means and are invisible when the values are negligibly small. LSD value at $p \leq 0.05$, (A) MxS: 2.3052***(n=4), (B) MxS: 0.5276*(n=4), (C) MxS: 0.6664***(n=4), (D) MxS: 0.7699**(n=4).

Discussion

The mango nursery seedlings' quality is determined by the pot's size and the potting material being used (Desai *et al*., 2020). Thus, the type of media and the components utilized to prepare the media influence the quality of the nursery plants (Sahin *et al*., 2005). Using biochar in the agriculture to improve crop productivity and media fertility is a well-established strategy (Major *et al*., 2010). Its role in enhancing the growing medium's net surface area is proven scientifically (Baronti *et al*., 2014). Biochar expands plant cells and enhances their leaf area, which, as a result, produces auxin-stimulated growth. The present study reflected that the plants grown under biochar-filled media and larger pots significantly influenced the plant height, number of leaves, leaf area, and stem girth. Moreover, biochar activates microbial activity, improves soil porosity, enhances soil water holding capacity, and hastens the plant's photosynthetic rate, leading to improvement in plant growth. Integrating biochar in growing media enhances the plant height and shoot diameter of *Poncirus trifoliate* (Changxun *et al*., 2016). As it can hold nutrients, biochar has extended benefits on plant nutrition (Lehmann & Joseph, 2015). In our study, the biochar-based media increased the plant height, number of leaves, stem girth, and leaf area by improving media porosity, increasing soil-water retention ability, enhancing photosynthetic rate, and increasing the soil's capacity to store nutrients for longer periods. These results align with the findings of (Jismitha *et al*., 2018), who found that when mango plants were grown in the potting media having biochar, the plant height, number of leaves, stem girth, leaf area, and vigor of the plants were improved. The days to first flush after transplanting the seedlings into the pots were reduced significantly in biochar-based potting media. The reason for developing early first flush could be because biochar speeds up the root development and allows plants to absorb more nutrients through these early developed roots (Backer *et al*., 2017). Moreover, adding biochar in potting mix enhanced the plant biomass of the seedlings as it increased the root and shoot volume, fresh and dry weight, and root biomass (Yang & Zhang, 2022). Similarly, when biochar was added to the growing media, it not only improved soil nutrient availability and soil water retention but also optimized root structure (Cheysargyris *et al*., 2020). Primarily, acidified carbon drops the media's pH and fosters a conducive environment for the microorganism's growth (Sultan *et al*., 2020) and increased soil aeration, which promotes plant growth by supplying the plant's roots with the required water and oxygen. The current research results align with the findings of Shahzad *et al*., (2023), who testified the linkage of biochar addition in the growing media with the enhancement of root and shoot fresh and dry weight and root and shoot length. Li *et al*., (2019) reported that aeration of the growing medium can increase the amount of chlorophyll and photosynthetic rate, boosting plant growth and decreasing plant mortality. Biochar lowers the chance of shrinking and reduces growing media's decomposition (Tian *et al*., 2012). In our study, media with biochar showed a minimum mortality percentage of mango plants. This could be due to the low degradation rate of biochar, which also slows down the decomposition of media and maintains good aeration in potting media.

As far as pot size is concerned, larger container sizes improved the plant height, number of leaves, leaf area, stem girth, and plant biomass and minimized the mortality of mango nursery plants. Ouma (2007) reported that an increase in container volume increases plant growth parameters such as the height of plants and stem diameter in rough lemon seedlings. These results could be due to the larger space available for roots to flourish and absorb adequate water and nutrients from media. A larger pot size showed a greater survival rate, plant height, root collar diameter, leaf number, and area, root number and length, fresh and dry plant biomass (NeSmith & Duval, 1998; Argerich & Poggi, 2003; Oagile *et al*., 2016). The aerial parts of the plant depend on the roots for water, nutrition, support, and hormones, whereas the roots depend on the plant aerial parts for photosynthates and different hormones. When the root system is constrained in a narrow rooting volume, the delicate balance between the roots and shoots might be disrupted (NeSmith & Duval, 1998). The growth, productivity, and quality of different fruit crops are significantly impacted by better root development, which is controlled by the size of the pot used (Krezel & Kolota, 2009). Fikre & Boto (2024) reported that larger pot size significantly enhanced early root and shoot growth in *Enset ventricosum*, resulting in improved plant biomass including fresh and dry weight, and promoting robust growth. Haldankar *et al*., (2014) confirm the results of our study that greater root spread, longer tap roots, and more secondary roots were produced by larger pots, which also enhanced plant height, stem girth, number of leaves, and spread of mango nursery plants. Ilyas *et al*., (2014) also confirm that larger pots showed maximum diameter of scion, diameter of stock, scion stock ratio, length of shoot, number of shoots, number of leaves, and height of Kinnow citrus cultivar.

Conclusion

The current study reveals that in comparison with the traditional soil-based media, the integration of biochar into soilless potting media significantly reduces the mango nursery plant's mortality rate while boosting the nursery plants' growth. The research's outcome demonstrates that the biochar's integration into the growing media enhances nutrient retention and root health and creates a plant-growth-conducive environment. Besides, the size of the pots also influences optimal root growth and overall plant health, as the larger pot sizes S3 (45.72 cm x 22.86 cm) were more impactful than medium and smaller (S1) sized pots in the current study. Likewise, the M4 treatment (Biochar-2 5% + Coir 30% + Bagasse 65%) was more successful in developing healthy mango plants and lowering mortality rates. Cu to the chase, the study promises to provide invaluable strategies to improve mango plant nursery-raising methods. Moreover, using larger pots and biochar-integrated growing media, healthy and sustainable nursery management criteria can be developed. These findings aim to open the gateway for future studies in terms of increased biochar integration, in soilless media, leading to healthy growth in mango nursery plants, bringing economic and environmental sustainability to the entire region.

References

Agarwal, P., S. Saha and P. Hariprasad. 2023. Agro-industrial residues as potting media: physicochemical and biological characters and their influence on plant growth. *Biomass Conv. Bioref.,* 13: 9601-9624.

Ali, M., I. Khan, M. Tahir, A. Mahmood, A. Nadeem, U. Ashraf and A. Matloob. 2015. Integrated potassium management through composted straws and inorganic fertilizer in maize. *Maydica.,* 60: 1-8.

Al-Toobi, M., R.R. Janke, M.M. Khan, M. Ahmed, W.M. Al-Busaidi and A. Rehman. 2023. Silica and biochar amendments improve cucumber growth under saline conditions. *Soil Syst.,* 7(1): 26.

Argerich, C.A. and L.M. Poggi. 2003. Seedling establishment: the effect of container size on plant survival and yield of tomatoes for processing. *Acta Hortic.,* 613: 189-192.

Backer, R.G.M., W. Saeed, P. Seguin and D.L. Smith. 2017. Root traits and nitrogen fertilizer recovery efficiency of corn grown in biochar-amended soil under greenhouse conditions. *Plant Soil.,* 415: 465-477.

Barkham, J.P. 1993. For peat's sake: conservation or exploitation? *Biodiv. Conser.,* 2: 556-566.

Baronti, S., F.P. Vaccari, F. Miglietta, C. Calzolari, E. Lugato, S. Orlandini, R. Pini, C. Zulian and L. Genesio. 2014. Impact of biochar application on plant water relations in *Vitis vinifera* (L.). *Eur. J. Agron.,* 53: 38-44.

Chan, K.Y., L. Van Zwieten, I. Meszaros, A. Downie and S. Joseph. 2008. Using poultry litter biochars as soil amendments. *Soil Res.*, 46(5): 437-444.

Changxun, G., P. Zhiyong and P. Shu'ang. 2016. Effect of biochar on the growth of *Poncirus trifoliata* (L.) seedlings in acidic red soil. *J. Soil Sci. Plant Nutr.*, 62(2): 194-200.

Cornelissen, G., N.R. Pandit, P. Taylor, B.H. Pandit, M. Sparrevik and H.P. Schmidt. 2016. Emissions and char quality of flame-curtain "Kon Tiki" kilns for farmer-scale charcoal/ biochar production. *PLoS ONE* 11(5).

Desai, V.S., O.A. Lad, M.M. Kulkarni, S.G. Ragaji, M.S. Gavankar, M.M. Burondkar, N.B. Gokhale, C.D. Pawar, R.G. Khandekar and P.J. Kshirsagar. 2020. Influence of potting mixture on growth and economics of stone graft of mango cv. Alphonso. *J. Hortic. Sci.*, 15(2): 233-237.

Evans, M.R. and R.H. Stamps. 1996. Growth of bedding plants in sphagnum peat and coir dust-based substrates. *J. Environ. Hort.,* 14: 187-190.

Fikre, H. and N. Boto. 2024. Effects of varieties and pot sizes on the early shoot and root growth of enset (*Ensete ventricosum* (Welw) Cheesman). *Cogent Food & Agric.,* 10(1): 2370396.

Fussy, A. and J. Papenbrock. 2022. An overview of soil and soilless cultivation techniques-chances, challenges, and the neglected question of sustainability. *Plants.* 11(9):1153.

Gebregiorgs, G., N. Tekeste and B. Mengesha. 2021. Germination and seedling growth response of mango (*Mangifera indica* L.) cultivars to different nursery potting media. *Agric. Food Secur.* 10: 62.

Grewal, A.G., M.S. Zafar, M. Ahmad, A. Iqbal, A.H. Khan, G. Mustafa, S. Raza and N. Ahmed. 2023. Interactive effect of nitrogen and paclobutrazol on annually pruned sammar bahisht chaunsa. *Pak. J. Bot.,* 55(6): 2119-2129.

Haldankar, P.M., Y.R. Parulekar, M.M. Kulkarni and K.E. Lawande. 2014. Effect of size of polybag on survival and growth of mango grafts. *J. Plant Studies.,* 3: 91-95.

Haq, I.U., A. Ghaffar, H. Umar and I.S.E. Bally. 2017. Evaluation of potting media for rapid growth of mango nursery plants. *Acta Hortic.,* 1183: 133-137.

Harrington, J.T., J.G. Mexal and J.T. Fisher. 1994. Volume displacement provides a quick and accurate way to quantify new root production. *Tree Planters' Notes.,* 45: 121-124.

Hongpakdee, P. and S. Ruamrungsri. 2015. Water use efficiency, nutrient leaching, and growth in potted marigolds affected by coconut coir dust amended in substrate media. *Hortic. Environ. Biotechnol.,* 56: 27-35.

Hue, N.V. and B.A. Sobieszczyk. 1999. Nutritional values of some biowastes as soil amendments. *Compost Sci. Utilization.,* 7: 34-41.

Ilyas, M.K., A. Sharma, V.K. Wali, V.P. Bakshi and S. Rani. 2014. Growth and survival of budded Kinnow plants as influenced by different types of black polybags and soil media. *Afric. J. Agri. Res.,* 9: 1672-1680.

Iqbal, J., S. Kiran, S. Hussain, R. K. Iqbal, U. Ghafoor, U. Younis, T. Zarei, M. Naz, S.G. Germi and S. Danish. 2021. Acidified biochar confers improvement in quality and yield attributes of sufaid chaunsa mango in saline soil. *Horticulturae.,* 7: 418.

Jasmitha, B.G., M.K. Honnabyraiah, S.A. Kumar, G.S.K. Swamy, S.V. Patil and J. Jayappa. 2018. Effect of enriched biochar on growth of mango seedlings in nursery. *Inter. J. of Chem. Stud.,* 6(6): 415-417.

Krezel, J. and E. Kolota. 2009. The influence of seedlings age and pots size on growth and yielding of Chinese cabbage in spring and autumn cultivation. *Vegetable Crops Research Bulletin.,* 71: 25-31.

Lehmann, J. and S. Joseph. 2015. Biochar for environmental management. Routledge. 2nd edition. London.

Li, Y., W. Niu, X. Cao, J. Wang, M. Zhang, X. Duan and Z. Zhang. 2019. Effect of soil aeration on root morphology and photosynthetic characteristics of potted tomato plants (*Solanum lycopersicum*) at different NaCl salinity levels. *BMC Plant Biol.,* 19: 331.

Major, J., J. Lehmann, M. Rondon and C. Goodale. 2010. Fate of soil-applied black carbon: downward migration, leaching and soil respiration. *Glob. Change Biol.,* 16: 1366-1379.

Mariotti, B., S. Martini, S. Raddi, A. Tani, D.F. Jacobs, J.A. Oliet and A. Maltoni. 2020. Coconut coir as a sustainable nursery growing media for seedling production of the ecologically diverse Quercus species. *Forests.,* 11(5): 522.

Maxwell, N.P. and C.G. Lyons. 1979. A technique for propagating container grown citrus on sour orange root stock in Texas. *HortScience.,* 14: 56-57.

NeSmith, D.S. and J.R. Duval. 1998. The effect of container size. *HortTechnology,* 8(4): 495-498.

Oagile, O., P. Gabolemogwe, C. Matsuane and T. Mathowa. 2016. Effect of container size on the growth and development of tomato seedlings. *Int. J. Curr. Microbiol. Appl. Sci.,* 5(4): 890-896.

Ouma, G. 2007. Effect of different container sizes and irrigation frequency on the morphological and physiological characteristics of mango (*Mangifera indica*) rootstock seedlings. *Intern. J. Bot.,* 3: 260-268.

Peterson, T.A., M.D. Reinsel and D.T. Krizek. 1991. Tomato (*Lycopersicon esculentum* Mill., cv. 'Better Bush') plant response to root restriction. *J. of Exp. Bot.,* 42(10): 1241-1249.

Poulter, R. 2014. Quantifying differences between treated and untreated coir substrate. *Acta Hortic.,* 1018: 557-564.

Regmi, A., S. Singh, N. Moustaid-Moussa, C. Coldren and C. Simpson. 2022. The negative effects of high rates of biochar on violas can be counteracted with fertilizer. *Plants.,* 11: 491.

Sahin, U.S., S. Ors, Ercisli, O. Anapali and A. Esitken. 2005. Effect of pumice amendment on physical soil properties and strawberry plant growth. *J. Central Europ. Agric.,* 6(3): 361-366.

Salemaa, M. and T. Uotila. 2001. Seed bank composition and seedling survival in forest soil polluted with heavy metals. *Bas. and Appl. Eco.,* 2: 251-263.

Shahzad, A.S., U. Younis, N. Naz, S. Danish, A. Syed, A. M. Elgorban, R. Eswaramoorthy, S. Huang and M.L. Battaglia. 2023. Acidified biochar improves lead tolerance and enhances morphological and biochemical attributes of mint in saline soil. *Sci. Rep.,* 13: 8720.

Steel, R.G.D., J.H. Torrie and D.A. Dickey. 1997. Principles and Procedures of Statistics: A Biometrical Approach, Subsequent edition. McGraw-Hill College, New York, USA. Sultan, H., N. Ahmed, M. Mubashir and S. Danish. 2020. Chemical production of acidified activated carbon and its influences on soil fertility comparative to thermo-pyrolyzed biochar. *Sci. Rep.,* 10: 595.

Thiessen, M., J.S. Fields, D. Abdi and J. Beasley. 2023. Sugarcane bagasse is an effective soilless substrate amendment in quick-turn Osteospermum production. *Hort Science,* 58(10): 1170-1177.

Tian, Y., X. Sun, S. Li, H. Wang, L. Wang, J. Cao and L. Zhang. 2012. Biochar made from green waste as peat substitute in growth media for *Calathea rotundifola* cv. Fasciata. *Sci. Hortic.,* 143: 15-18.

Yang, W. and L. Zhang. 2022. Biochar and cow dung organic fertilizer additives improve the quality of composted green waste as a growth medium for the ornamental plant *Centaurea cyanus* L. *Environ. Sci. Pollut. Res.,* 29: 45474-45486.

(Received for publication 25 June 2024)