

Short communication

## Meshball-driven air-pruning offers a resource efficient strategy for containerized cultivation in urban horticulture

Savitha Dhandapani<sup>1</sup>, Gandhimathi Chinnasamy<sup>1</sup>, Shaik Anwar Ahamed Nabeela Nasreen, Vidya Susan Philip, Bong Soo Park<sup>\*</sup>, Somika Bhatnagar<sup>\*</sup>

Temasek Life Sciences Laboratory, 1 Research Link, National University of Singapore, Singapore 117604, Singapore

### ARTICLE INFO

#### Keywords:

Air-pruning  
Root architecture  
Urban greening  
Ornamental shrubs  
Container cultivation  
Sustainable horticulture  
Meshball system

### ABSTRACT

Containerized plant cultivation is central to urban greening, horticulture, nurseries, and small-scale food production but is often limited by root circling, poor aeration, and inefficient resource use. Conventional air-pruning pots alleviate circling but cause water loss, nutrient leaching, and lack adaptability to diverse root systems. To address these limitations, we developed meshball-mediated air-pruning, a scalable method embedding stainless-steel spheres into soil to create localized aeration pockets, enabling targeted root pruning while minimizing water and soil loss. Testing across four species revealed strong benefits for ornamental shrubs: in dwarf ixora (*Ixora coccinea*), shoot fresh weight increased by 120 %, branch number by 55 %, and root biomass by 139 %, while firebush (*Hamelia patens*) showed 87 % greater height and 59 % higher root biomass compared with controls. These effects were linked to early disruption of apical dominance, stimulation of lateral roots, and improved root–shoot signaling. By contrast, pak choi (*Brassica rapa* var. *chinensis*) showed no measurable change, and white teak (*Gmelina arborea*) seedlings displayed reduced root biomass, underscoring species-specific responses. Structural evaluation confirmed meshballs provided stable aeration for six months without corrosion or soil intrusion. Overall, meshball-mediated air-pruning represents a resource-efficient alternative to conventional containers, particularly effective for ornamental shrubs in urban landscapes, and offers a sustainable approach to enhance root architecture, plant vigor, and survival in horticulture, forestry, and greening applications.

### 1. Introduction

As cities expand and temperatures rise, urban landscapes face increasing pressure to provide both livability and ecological stability. Green spaces are now recognized as essential infrastructure that deliver ecosystem services, mitigate urban heat islands, and support biodiversity (Norton et al., 2015; Tzoulas et al., 2007). From large botanical gardens to community and rooftop gardens, such initiatives not only enhance aesthetic and recreational value but also improve air quality, regulate stormwater, and sustain pollinator habitats.

The success of greening strategies depends strongly on efficient seedling establishment, which determines plant survival, growth, and long-term ecological contributions (Grossnickle, 2012). Root system architecture plays a central role: fibrous, well-branched roots enhance soil exploration, nutrient acquisition, water uptake, and shoot vigor (Trubat et al., 2010). In contrast, containerized cultivation often causes

root circling, girdling, and poor aeration, leading to reduced transplant success and limited long-term growth (Marshall and Gilman, 1998; Ortega et al., 2006; Tsakalidimi et al., 2005). For ornamental shrubs and fast-growing species, root quality also influences plant stability, aesthetic appeal, and delivery of ecosystem services (Sánchez-Gómez et al., 2006).

Root air-pruning provides a promising solution to these challenges. By exposing root tips to air, apical dominance is disrupted, stimulating lateral root initiation and enhancing fibrous root density (Elsy and Einhorn, 2022; Marler and Musser, 2016). These changes improve water and nutrient uptake (Lynch, 2019) and promote shoot development through root–shoot signaling (Aloni et al., 2006; Vysotskaya et al., 2001; Werner et al., 2010). Conventional air-pruning containers have shown benefits in seedling quality and transplant performance (Marshall and Gilman, 1998; Ortega et al., 2006). However, their reliance on continuous sidewall perforations accelerates water loss, promotes nutrient

<sup>\*</sup> Corresponding authors.

E-mail addresses: [bongsoo@tll.org.sg](mailto:bongsoo@tll.org.sg) (B.S. Park), [somika@tll.org.sg](mailto:somika@tll.org.sg) (S. Bhatnagar).

<sup>1</sup> Co-first authors

leaching, and restricts adaptability across species and production systems. This highlights the need for simpler, resource-efficient approaches that enable localized air exposure without compromising water-use efficiency.

In this study, we evaluated a novel method of embedding stainless-steel meshballs into soil to create localized aeration pockets that promote root air-pruning. We tested the system in four contrasting species: dwarf ixora (*Ixora coccinea*), firebush (*Hamelia patens*), pak choi (*Brassica rapa* var. *chinensis*), and white teak (*Gmelina arborea*). These were chosen to represent distinct functional categories. Dwarf ixora, a popular ornamental with compact growth and vibrant flowers, is widely used in urban gardens and streetscapes (Baliga and Kurian, 2012). Firebush is valued for its striking blooms and ecological role as a nectar source for butterflies and hummingbirds (Lasso and Naranjo, 2006; Palathoti et al., 2022). Pak choi, a staple leafy vegetable in Asian diets, exemplifies the urban farming sector where rapid and healthy seedling establishment is essential (Niето et al., 2025; Wang et al., 2023). White teak, a fast-growing tropical hardwood, is important for reforestation, timber production, and ecological restoration, where root vigor underpins long-term survival (Dvorak, 2004).

By systematically comparing species with diverse growth habits and ecological roles, this study demonstrates how meshball-mediated air-pruning can overcome the limitations of conventional containers. Current practices often waste water, restrict root development due to the extreme root circling, and limit adaptability—factors that undermine the success of urban greening and sustainable horticulture. Our work positions meshballs as a scalable, resource-efficient strategy to improve seedling quality, accelerate establishment, and strengthen resilience in both food and ornamental systems.

## 2. Materials and methods

### 2.1. Plant material and propagation

Dwarf ixora (*Ixora coccinea*), firebush (*Hamelia patens*), pak choi (*Brassica rapa* var. *chinensis*), and white teak (*Gmelina arborea*) were used in this study. Dwarf ixora cuttings were rooted in IAA and transplanted after one month. Firebush plants were directly transplanted. Pak choi seedlings were germinated and maintained under controlled conditions (22 °C, 60 % RH, 16 h light/8 h dark). In addition, no additional fertilizer was supplied during pak choi cultivation, as the commercial soil substrate contained nutrient levels sufficient to support growth throughout the short four-week experimental period. White teak seedlings were collected from natural regeneration, acclimatized, and grown under greenhouse conditions. Dwarf ixora, firebush, and white teak were harvested six months after transplanting, while pak choi was harvested at four weeks.

### 2.2. Air-pruning treatment

Dwarf ixora, firebush, and white teak were grown in 7.5 L pots, while pak choi was cultivated in 0.3 L pots. The commercial BVB substrate was mixed with sand at a 15:1 ratio to improve drainage.

For the control treatment, the substrate mixture was filled directly into the pots. For the air-pruning treatment, the bottom layer of each pot was filled with the substrate mixture, followed by placement of three stainless-steel mesh balls. The mixture was then added to cover the mesh balls completely, after which three additional mesh balls were positioned at mid-depth to establish aeration pockets (Supplementary Figure S1). Each pot contained about 4 Kg of substrate mixture.

Mesh ball sizes were adjusted based on species: 9 cm for dwarf ixora, firebush, and white teak, and 5 cm for pak choi (Supplementary Figure S2). For all plant species, a minimum of 6 replicates were used per condition in each experiment, and the study was repeated three times.

After transplanting, dwarf ixora, firebush, and white teak plants were grown for six months and received monthly applications of NPK

15–15–15 granular fertilizer at a concentration of 4 g per pot. Pak choi plants were grown for four weeks without application of fertilizers.

### 2.3. Growth and physiological measurements

Dwarf ixora, firebush, and white teak plants were grown for six months, whereas pak choi was cultivated for four weeks prior to harvesting. Plants were imaged, and shoot and root traits—including biomass, plant height, leaf or branch number, and root morphology—were recorded (Supplementary Fig. S1).

### 2.4. Statistical analysis

All statistical analyses were performed using Microsoft Excel. Data are presented as mean  $\pm$  standard deviation. Treatment comparisons were conducted using two-tailed Student's *t*-tests. Statistical significance was defined as \*\*\**p* < 0.001, \*\**p* < 0.01, \**p* < 0.05.

## 3. Results and discussion

### 3.1. Structural and functional assessment of meshball-mediated air-pruning

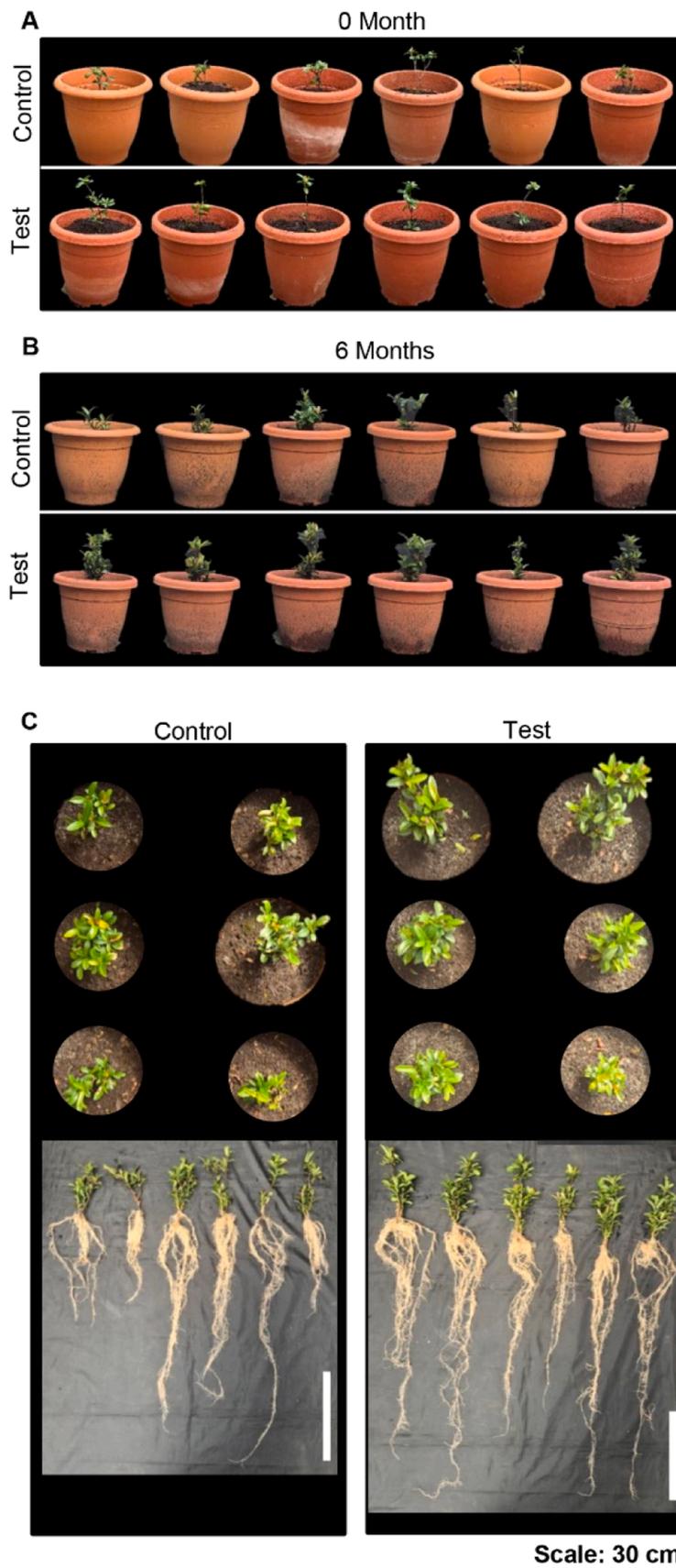
Upon harvesting, soil removal revealed that meshballs remained unfilled, confirming maintenance of localized air pockets for root pruning. Roots entering the meshballs were predominantly pruned, with multiple lateral roots emerging from these sites (Supplementary Figure S3), forming denser root systems adjacent to the meshballs. No corrosion was observed on stainless-steel meshballs after prolonged exposure to wet soil, although corrosion-resistant plastics could be considered for long-term applications. These findings demonstrate that meshballs effectively maintain air pockets, stimulate lateral root proliferation, and provide durable performance in soil environments.

### 3.2. Species-Specific responses

Meshball-mediated air-pruning effectiveness varied among species due to differences in growth habit and responsiveness to root pruning. Dwarf ixora and firebush exhibited marked growth enhancements under air-pruning conditions. In dwarf ixora, shoot fresh weight increased by 120 %, branch number by 55 %, and root biomass by 139 % (Fig. 1, Table 1). Firebush showed an 87 % increase in plant height and a 59 % increase in root biomass (Fig. 2, Table 2). The stronger response observed in dwarf ixora is likely attributable to early-stage transplantation into air-pruning pots, which enabled root system reshaping from the onset of establishment. In contrast, firebush plants were transplanted at an adult stage from conventional pots, where existing root structures were already formed. This likely limited the degree to which air-pruning could redirect root growth, resulting in a moderate but still substantial improvement in shoot height and root biomass.

These findings underscore the importance of transplantation timing as a determinant of air-pruning efficacy. The improvements observed in firebush, although significant, may not represent the upper limit of achievable benefits. Future studies that systematically vary the developmental stage at transplantation—from seedlings to progressively mature plants—will be essential to identify the optimal window for meshball introduction in this species. Such optimization has practical relevance for ornamental horticulture and landscape management, where maximizing root health and shoot vigor is critical for performance under field conditions. A species-specific approach to transplant timing may therefore enhance the broader applicability and economic value of meshball-based air-pruning systems.

The observed growth enhancements align with the effects of root apical pruning, which disrupts apical dominance, redistributes auxin locally, and stimulates lateral root initiation (Aloni et al., 2006; Fukaki and Tasaka, 2009; Lavenus et al., 2013; Miller and Graves, 2019;



(caption on next page)

**Fig. 1.** Growth and root responses of dwarf ixora seedlings under control and meshball-mediated air-pruning conditions. (A) Six representative seedlings per treatment immediately after transplanting. (B) The same treatments six months post-transplanting, where meshball-mediated air-pruning promoted greater height and biomass than controls. (C) Shoot and root morphology at six months post-transplanting. Top: representative shoots; Bottom: corresponding root systems. Plants exposed to meshball-mediated air-pruning displayed longer shoots and larger root systems compared with controls, highlighting the role of localized root pruning in enhancing overall growth.

**Table 1**

Effect of meshball-mediated air-pruning treatment on growth parameters of dwarf ixora seedlings.

Parameter	Control	Test
Shoot Fresh Weight (g)	7.54 ± 2.09	16.61 ± 3.13***
Number of Branches	3 ± 0.63	4.67 ± 0.82**
Plant Height (cm)	16.54 ± 2.34	20.94 ± 1.33**
Root Fresh Weight (g)	3.28 ± 1.67	7.84 ± 1.11***
Root Length (cm)	56.47 ± 23.39	86.02 ± 15.49*
Whole Plant Dry Weight (g)	3.41 ± 1.08	6.97 ± 1.07***

Data are presented as mean ± standard deviation. Treatment comparisons were conducted using two-tailed Student's *t*-tests. Statistical significance was defined as \*\*\**p* < 0.001, \*\**p* < 0.01, \**p* < 0.05. *p*-values are given in Supplementary Table S1.

Overvoorde et al., 2010; Roy et al., 2025). Dense, fibrous root systems likely improved nutrient and water uptake, while strengthened root-to-shoot signaling facilitated vegetative branching and shoot elongation. In firebush, increased plant height may involve cytokinin-mediated responses, as reported in Arabidopsis, tobacco, and wheat (Aloni et al., 2006; Werner et al., 2010; Zhang et al., 2024).

In contrast, pak choi showed no measurable improvement in shoot or root biomass or leaf number (Supplementary Figure S4, Table S3), and white teak seedlings exhibited reduced root biomass in air-pruning pots (Supplementary Figures S5, S6, Table S4). Fast-growing tree species

typically allocate biomass to dominant roots for anchorage and water acquisition (South and Mitchell, 1999). Air-pruning may disrupt this developmental strategy, reducing overall root biomass without compensatory lateral root proliferation. Similar effects have been observed in Pinus and Eucalyptus nursery seedlings, where constrained root development compromised transplant performance (Lindström and Rune, 1999; Löf et al., 2012; Ortega et al., 2006).

### 3.3. Limitations of conventional air-pruning pots and advantages of the meshball design

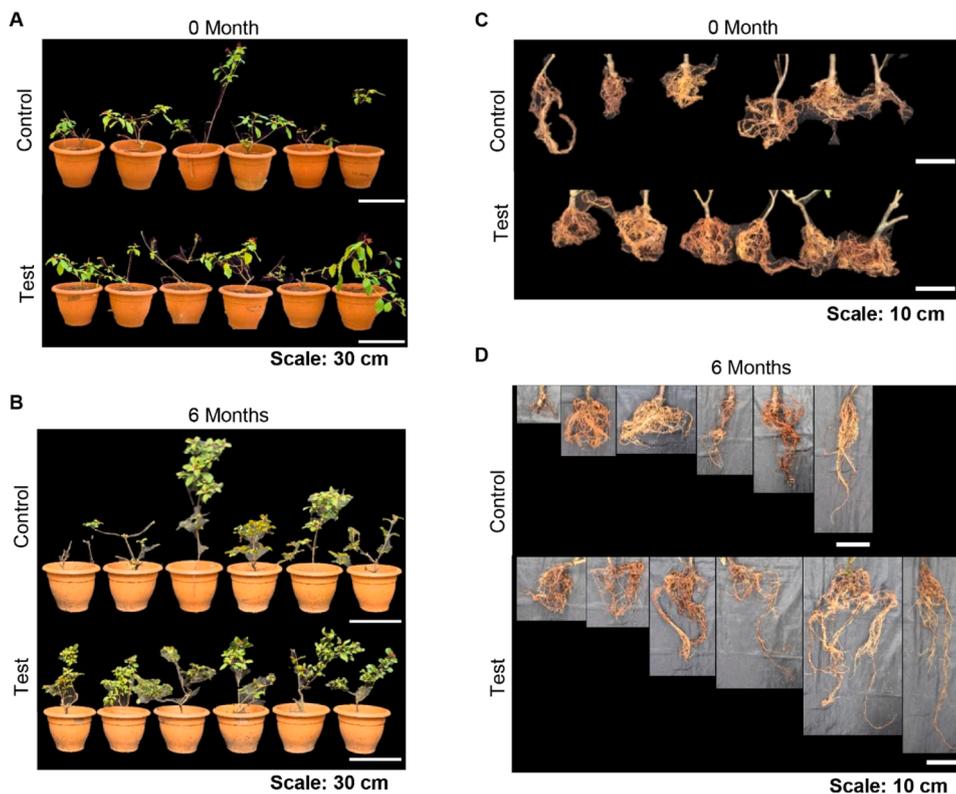
Conventional air-pruning pots reduce root circling and promote

**Table 2**

Effect of meshball-mediated air-pruning treatment on growth parameters of firebush plants.

Parameter	Control	Test
Shoot Fresh Weight (g)	41.45 ± 13.92	40.52 ± 14.56
Increase in Plant Height (%)	14.92 ± 13.43	27.97 ± 11.62*
Root Fresh Weight (g)	5.34 ± 3.68	8.49 ± 4.93*
Root Length (cm)	22.86 ± 9.73	33.1 ± 16.13
Whole Plant Dry Weight (g)	15.89 ± 5.39	15.05 ± 4.15

Data are presented as mean ± standard deviation. Treatment comparisons were conducted using two-tailed Student's *t*-tests. Statistical significance was defined as \**p* < 0.05. *p*-values are given in Supplementary Table S2.



**Fig. 2.** Growth and root responses of firebush plants under control and meshball-mediated air-pruning conditions. (A) Six representative seedlings per treatment immediately after transplanting. (B) The same treatments six months post-transplanting, where meshball-mediated air-pruning promoted greater shoot height compared with controls. (C) Root morphology at the start of the experiment (immediately before transplanting). (D) Root systems six months post-transplanting, showing increased root fresh weight in plants subjected to meshball-mediated air-pruning.

lateral root branching, but sidewall perforations accelerate water loss, delaying effective pruning during early seedling development (Marshall and Gilman, 1998; Ortega et al., 2006). Traditional pots can also induce spiraled or girdling roots, impairing nutrient uptake and long-term stability (Marshall and Gilman, 1998; Tsakaldimi et al., 2005), a critical concern for ornamental shrubs with aesthetic and commercial value (Gilman and Beeson, 1996; Topic et al., 2006).

The meshball system overcomes these limitations by providing localized aeration that minimizes water loss while enabling early and effective root pruning. Sequential pruning points at mid- and basal depths reduce root circling and stimulate lateral root formation (Fig. 3, Supplementary Figure S7). Meshball size and placement can be customized: central placement benefits straight-growing roots, whereas side-aligned meshballs enhance adventitious root development. This approach promotes uniform and timely pruning while reducing soil volume requirements, enhancing resource efficiency without compromising growth.

Meshball feasibility varies by plant type, requiring tailored configurations for optimal performance. Herbaceous species benefit from shallow meshball placement (5–10 cm), which stimulates lateral root proliferation in fibrous root zones. Slower-rooting herbs or transplant-sensitive species warrant further evaluation (Leskovar and Stoffella, 1995).

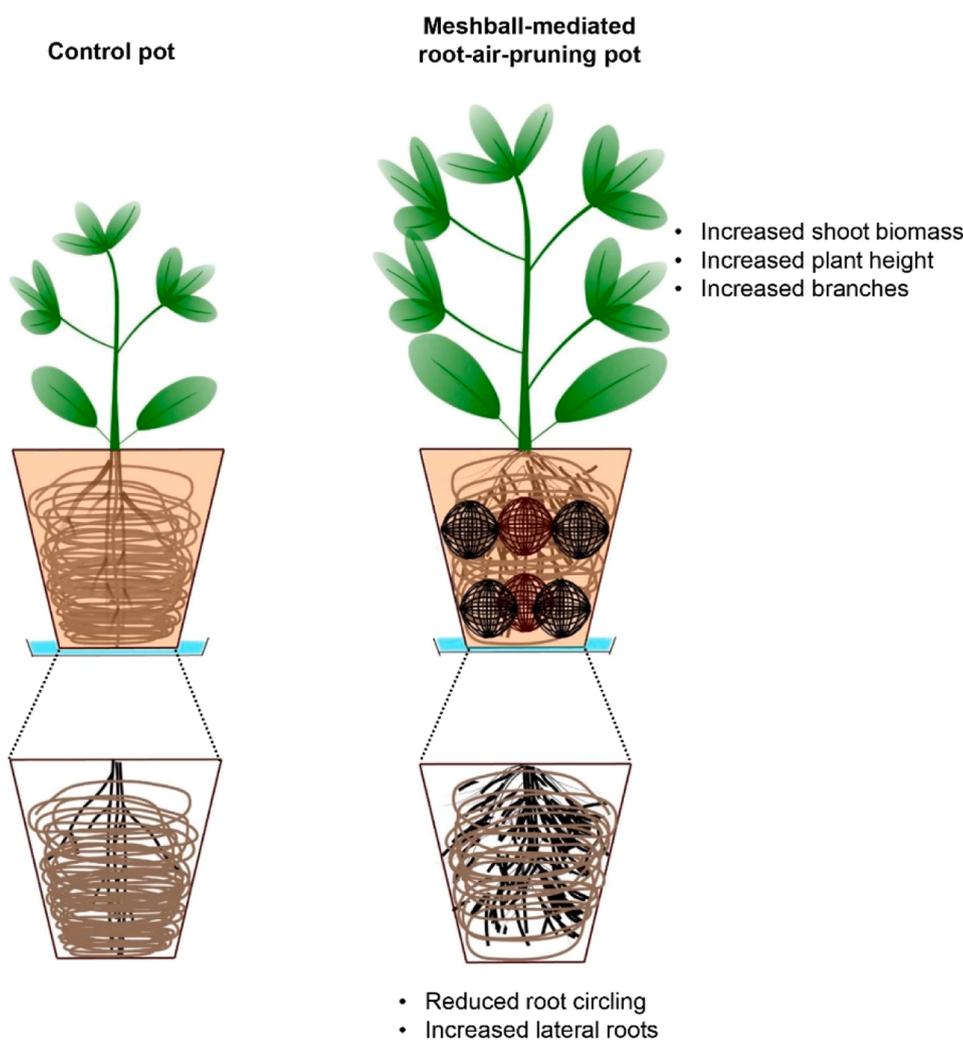
Ornamental shrubs respond favorably to centrally positioned

meshballs at multiple depths. This configuration prevents root circling, promotes fibrous architecture, and improves transplant establishment—key requirements for nursery production (Marshall and Gilman, 1998; Gilman and Beeson, 1996). Dwarf ixora and firebush demonstrated substantial growth enhancement, suggesting moderate-growth shrubs are ideal candidates. Early-stage meshball introduction maximizes architectural benefits (Burdett, 1990).

Climbing plants gain advantages from peripherally distributed meshballs, which trigger adventitious rooting along stems. This supports vertical growth habits and provides stable anchorage in constrained volumes (Stuepp et al., 2018), making the approach suitable for living walls and container-based vertical systems.

Tree seedlings present challenges, as white teak exhibited reduced root biomass under air-pruning. Species investing heavily in tap roots for anchorage and water access may experience developmental disruption rather than improvement (South and Mitchell, 1999; Lindström and Rune, 1999). Meshball application to woody seedlings requires species-specific assessment of natural root strategies and end-use requirements.

Beyond functional advantages, meshballs offer scalable and sustainable solutions for diverse contexts, including household gardening, commercial nurseries, and urban greening projects. By improving water-use efficiency and reducing soil requirements, meshballs provide practical, economically viable strategies for sustainable cultivation.



**Fig. 3.** Conceptual model illustrating the effect of meshball-mediated air-pruning on ornamental plants at the end of the experiment. Plants grown in control pots were shorter, had lower shoot and root biomass, and exhibited root circling. In contrast, meshball-mediated air-pruning promoted taller growth, increased biomass, more branches, and reduced root circling, highlighting the proposed mechanism by which localized root pruning enhances overall plant development.

Overcoming the structural and functional limitations of conventional pots, the meshball system represents a versatile, scalable, and sustainable advancement in containerized plant cultivation.

#### 4. Conclusion

This study shows that meshball-mediated air-pruning enhances growth and root architecture in ornamental shrubs, though species responses vary. The meshball design addresses limitations of conventional air-pruning pots by enabling customizable aeration, reducing soil and water use, and improving root quality without issues like root circling. While particularly beneficial for ornamental horticulture and urban greening, limited effects in leafy vegetables and negative impacts on tree seedlings highlight the need for species-specific optimization. Overall, meshballs offer a versatile, sustainable approach to containerized cultivation, with strong potential to improve plant quality, survival, and ecological performance.

#### Funding sources

This research was supported by A\*STAR under its Industry Alignment Fund Prepositioning (IAF-PP), Grant No A19E4a0101 and the core fund (3085,3110) in Temasek Life Sciences Laboratory.

#### Data availability

The data supporting the findings of this study are available from the corresponding authors upon reasonable request.

#### Ethics approval and consent to participate

Not applicable.

#### Consent for publication

Not applicable.

#### CRedit authorship contribution statement

**Savitha Dhandapani:** Writing – original draft, Validation, Methodology, Investigation, Data curation, Conceptualization. **Gandhimathi Chinnasamy:** Validation, Methodology, Investigation, Data curation. **Shaik Anwar Ahamed Nabeela Nasreen:** Investigation. **Vidya Susan Philip:** Investigation. **Bong Soo Park:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization. **Somika Bhatnagar:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization.

#### Declaration of competing interest

The authors declare no competing interests.

#### Acknowledgements

Not applicable.

#### Supplementary materials

Supplementary material associated with this article can be found, in the online version, at [doi:10.1016/j.scienta.2025.114575](https://doi.org/10.1016/j.scienta.2025.114575).

#### References

Aloni, R., Aloni E Fau - Langhans, M., Langhans, M., Fau - Ullrich, C.I., Ullrich, C.I., 2006. Role of cytokinin and auxin in shaping root architecture: regulating vascular differentiation, lateral root initiation, root apical dominance and root gravitropism. *Ann. Bot.*

Baliga, M.S., Kurian, P.J., 2012. *Ixora coccinea* Linn.: traditional uses, phytochemistry and pharmacology. *Chin J Integr Med* 18, 72–79.

Burdett, A.N., 1990. Physiological processes in plantation establishment and the development of specifications for forest planting stock. *Can. J. For. Res.* 20, 415–427.

Dvorak, W., 2004. World view of *Gmelina arborea*: opportunities and challenges. *New For.* 28, 111–126.

Elsysy, M., Einhorn, T.C., 2022. Air-Pruning Contain. *Modify Root Scion Growth Alter Resour. Alloc. Bench-Gr. Apple Plants Hortic.*

Fukaki, H., Tasaka, M., 2009. Hormone interactions during lateral root formation. *Plant Mol. Biol.* 69, 437–449.

Gilman, E.F., Beeson, R.C., 1996. Nursery production method affects root growth. *J. Env. Hortic* 14, 88–91.

Grossnickle, S.C., 2012. Why seedlings survive: influence of plant attributes. *New For.* 43, 711–738.

Lasso, E., Naranjo, M., 2006. Effect of pollinators and nectar robbers on nectar production and pollen deposition in *Hamelia patens* (Rubiaceae). *Biotropica* 35, 57–66.

Lavenus, J., Goh, T., Roberts, I., Guyomarc'h, S., Lucas, M., De Smet, I., Fukaki, H., Beeckman, T., Bennett, M., Laplaze, L., 2013. Lateral root development in *Arabidopsis*: fifty shades of auxin. *Trends Plant Sci* 18, 450–458.

Leskovar, D.I., Stoffella, P.J., 1995. Vegetable seedling root systems: morphology, development, and importance. *HortScience* 30, 1153–1159.

Lindström, A., Rune, G., 1999. Root deformation in plantations of container-grown Scots pine trees: effects on root growth, tree stability and stem straightness. *Plant Soil* 217, 29–37.

Löf, M., Dey, D.C., Navarro, R.M., Jacobs, D.F., 2012. Mechanical site preparation for forest restoration. *New For.* 43, 825–848.

Lynch, J.P., 2019. Root phenotypes for improved nutrient capture: an underexploited opportunity for global agriculture. *New Phytol.* 223, 548–564.

Marler, T., Musser, C., 2016. Chemical and air pruning of roots influence post-transplant root traits of the critically endangered *Serianthes nelsonii*. *Plant Root* 10, 21–25.

Marshall, M.D., Gilman, E.F., 1998. Effects of nursery container type on root growth and landscape establishment of acer rubrum L. *J. Env. Hortic* 16, 55–59.

Miller, B., Graves, W., 2019. Root pruning and auxin alter Root morphology of hickories. *HortScience* 54, 1517–1520.

Nieto, J.A., Hellín, P., Valverde, M., Pérez, B., Viadel, B., Agudelo, A., 2025. Pak choi (*Brassica rapa* ssp. *Chinensis*) glucosinolates profile and bioaccessibility through in vitro dynamic digestion model. *Eur. Food Res. Technol.* 251, 205–212.

Norton, B.A., Coutts, A.M., Livesley, S.J., Harris, R.J., Hunter, A.M., Williams, N.S.G., 2015. Planning for cooler cities: a framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes. *Landsc Urban Plan* 134, 127–138.

Ortega, U., Majada, J., Mena-Petite, A., Sanchez-Zabala, J., Rodriguez-Iturrizar, N., Txarterrina, K., Azpitarte, J., Duñabeitia, M., 2006. Field performance of *Pinus radiata* D. Don produced in nursery with different types of containers. *New For.* 31, 97–112.

Overvoorde, P., Fukaki, H., Fau - Beeckman, T., Beeckman, T., 2010. Auxin control of root development. *Cold Spring Harb Perspect Biol* 2.

Palathoti, S., Karyamsetty, H., Raju, A.J., 2022. Flower-insect interact. spec. ref. honey bees some plant species (*Albizia lebbek* *Calliandra brevipes* *Calliandra haematocephala* *Mimosa pudica* *Pithecellobium dulce* *Hamelia patens* *Mitragyna parvifolia* *Hugonia mystax*) 23, 285–296.

Roy, D., Mehra, P., Clark, L., Mukkavar, V., Bellande, K., Martin-Arevalillo, R., Ghosh, S., Ingole, K.D., Bhagat, P.K., Brown, A., Sue-ob, K., Jones, A., Vermeer, J.E.M., Vernoux, T., Lilley, K., Mullineaux, P., Bechtold, U., Bennett, M.J., Sadanandom, A., 2025. Redox-regulated Aux/IAA multimerization modulates auxin responses. *Science* 389, eadu1470.

Sánchez-Gómez, D., Valladares, F., Zavala, M.A., 2006. Performance of seedlings of Mediterranean woody species under experimental gradients of irradiance and water availability: trade-offs and evidence for niche differentiation. *New Phytol.* 170, 795–806.

South, D., Mitchell, R., 1999. Determining the "optimum" slash pine seedling size for use with four levels of vegetation management on a flatwoods site in Georgia, U.S.A. *Can. J. For. Res.-rev. Can. Rech. For. - CAN J FOR. RES* 29, 1039–1046.

Stuepp, C.A., Wendling, I., Xavier, A., Zuffellato-Ribas, K.C., 2018. Vegetative propagation and application of clonal forestry in Brazilian native tree species. *Pesqui. Agropecu. Bras.* 53, 985–1002.

Topic, V., Butorac, L., Jelic, G., Peric, S., 2006. Influence of container type on growth and development of holm oak (*Quercus ilex* L.) seedlings in a nursery. *Period. Biol* 108, 643–648.

Trubat, R., Cortina, J., Fau - Vilagrosa, A., Vilagrosa, A., 2010. Root architecture and hydraulic conductance in nutrient deprived. *Pist. lentiscus* L. seedl., *Trees*.

Tsakalidimi, M., Zagas, T., Tsitsoni, T., Ganatsas, P., 2005. Root morphology, stem growth and field performance of seedlings of two Mediterranean evergreen oak species raised in different container types. *Plant Soil* 278, 85–93.

Tzoulas, K., Korpela, K., Venn, S., Yli-Pelkonen, V., Kazmierczak, A., Niemela, J., James, P., 2007. Promoting ecosystem and human health in urban areas using Green Infrastructure: a literature review. *Landsc Urban Plan* 81, 167–178.

Vysotskaya, L.B., Timergalina, L.N., Simonyan, M.V., Veselov, S.Y., Kudoyarova, G.R., 2001. Growth rate, IAA and cytokinin content of wheat seedling after root pruning. *Plant Growth Regul* 33, 51–57.

- Wang, J., Hu, T., Wang, Y., Wang, W., Hu, H., Wei, Q., Yan, Y., Bao, C., 2023. Metabolic and transcriptomic analyses reveal different metabolite biosynthesis profiles between purple and green Pak Choi. *Int J Mol Sci*.
- Werner, T., Nehnevajova, E., Köllmer, L., Novák, O., Strnad, M., Krämer, U., Schmölling, T., 2010. Root-Specific Reduct. Cytokinin Causes Enhanc. Root Growth Drought Toler. Leaf Miner. *Enrich. Arab. Tob. Plant cell* 22, 3905–3920.
- Zhang, Y., Li, J., Xu, Q., Chen, C., Nie, S., Lei, J., Duan, L., 2024. Cytokinin modulates the inhibitory effect of shade stress on photosynthesis, antioxidant capacity and hormone homeostasis to regulate the grain yield in wheat. *Front Plant Sci* 15, 1498123.