DOI: http://doi.org/10.4038/agrieast.v16i2.115

Cinnamon (*Cinnamomum verum* J. Presl) bush architecture as affected by modified planting systems

H.N. Aluthgamage[1*], D.L.C.K. Fonseka[1], C.K. Benaragama[2]

[1]*Department of Crop Science, Faculty of Agriculture, University of Ruhuna, Sri Lanka*

[2]*Department of Crop Science, Faculty of Agriculture, University of Peradeniya, Sri Lanka*

Abstract

Cinnamon (Cinnamomum verum J. Presl) is a spice crop native to Sri Lanka which plays a vital role in the country's export earnings. Bark being the harvestable portion, the production of cinnamon can be affected by its bush architecture. Hence, this study was conducted to identify the impact of harvesting interval, spatial pattern, and type of planting material on some essential aspects of cinnamon bush architecture, namely, the number of stems per plant, stem height, stem diameter, straightness of the stem, percentage of branches in upper, middle and lower levels of the stem, number of branches per unit length, branch length and angle. Seedlings and vegetatively propagated plants (VP) of cinnamon variety Sri Gemunu were planted under three different spatial patterns such as (A) 1.2×0.6 m with three plants per hill, (B) 1.2×0.4 m with two plants per hill, and (C) 1.2×0.2 m with one plant per hill while maintaining an equal plant density. Two main plots were maintained with the above treatment combinations, harvested according to two harvesting intervals (6 and 8 months). The study was conducted two years after the first harvest. According to the results, seedlings established in the spatial pattern C produced a significantly higher ($p < 0.05$) number of longer stems with fewer branches per unit length. Similarly, seedlings harvested in eight months intervals produced significantly longer stems ($p < 0.05$). The stem diameter of VP was significantly higher than seedlings ($p < 0.05$). Similarly, stem diameter was significantly higher when harvested in eight months intervals than six months intervals ($p < 0.05$). Seedlings were straighter than VP. Therefore, a preferable bush architecture can be obtained in cinnamon plants by selecting an optimum combination of harvesting interval, spatial pattern, and planting material.

Keywords: *Bush architecture, cinnamon, harvesting interval, seedlings, vegetatively propagated plants*

INTRODUCTION

Cinnamon (*Cinnamomum verum* J. Presl) is an evergreen woody perennial tree that belongs to the family Lauraceae. *Cinnamomum* comprises about 250 species of evergreen trees and shrubs found in Asia and Australia (Jayaprakasha *et al*., 2003). The tree can be grown up to 10 - 18 m in height under natural conditions (Pasiecznik, 2009; Rawat *et al*., 2019). Though cinnamon has been vastly recognized as a spice for centuries, it is a multifaceted plant with numerous uses (Suriyagoda *et al*., 2021). The history of the Sri Lankan cinnamon trade goes up to the 13th century, according to Dewasiri *et al*., 2020.

At the beginning of the cinnamon trade, wildly grown cinnamon plants were harvested through a risky and laborious process. With increasing demand, cinnamon plantations were established during the Dutch era in the 17th century (Weiss, 2002). Simultaneously, some important training and pruning methods were introduced to the industry, which proved to enhance the productivity of

*Corresponding author: hnayananjalee@gmail.com https://orcid.org/0000-0002-7442-4258

Received: 30.09.2022 Accepted: 08.12.2022

cinnamon plants. Through those training and pruning methods, single-stemmed cinnamon trees were converted into bushes with many stems, changing their architecture. Simultaneously, the number of plants established per hill has increased under cultivations up to about five plants which appear as a single dense, bushy plant about 2-3 m in height.

The overall size and shape of a plant and the spatial arrangement of its canopy, stem, branches, and leaves can be described as its architecture (Poorter *et al*., 2003). Bark being the unique harvestable portion, some aspects of the cinnamon bush architecture play a vital role in its productivity and quality. The most important aspects are the number of stems per plant, stem height, stem diameter, straightness of the stem, percentage of branches in upper, middle and lower levels of the stem, number of branches per unit length, branch length and angle.

Processed cinnamon bark is arranged into pipe-like structures called quills which has worldwide recognition for its unique structure. Characteristics of the cinnamon stem such as length, girth, straightness, and number of knots, act as determinant factors in quill processing (Weerasinghe and Pushpitha, 2020). Therefore, studying the cinnamon bush architecture related to stem characteristics is crucial to exploit it to maximize the productivity and quality of cinnamon quills.

Though various studies have been conducted on the morphological characteristics of cinnamon (Abeysinghe *et al*., 2020), there needs to be more information on the behaviour of cinnamon bush architecture under different conditions. For all plant species, morphological characteristics, including bush architecture, are determined by both genetic and environmental factors. Availability of radiation is largely associated with the plant architecture, while it is a critical contributor to plant performance under stress conditions (Yang *et al*., 2015). Due to superficially induced bush architecture in cultivated cinnamon, the impact of environmental factors should be prominent. Hence, this study was conducted to identify the impact of harvesting interval, spatial pattern and type of planting material on some selected aspects of cinnamon bush architecture, namely, the number of stems per plant, stem height, stem diameter, straightness of the stem, percentage of branches in upper, middle and lower levels of the stem, number of branches per unit length, branch length and angle.

MATERIALS AND METHODS

This study was conducted in the Mapalana area of Matara district at the Faculty of Agriculture, University of Ruhuna, Sri Lanka. The area belongs to the low county wet zone (WL2), with annual rainfall above 2,500 mm and red-yellow podzolic and low humic gley soils as major soil types.

Planting material

Two planting material types were used namely, seedlings (SD) and vegetatively propagated plants (VP) of the cinnamon variety *Sri Gemunu* (Wijesinghe, 2011). Vegetatively propagated plants were obtained through rooted cuttings. Uniformly grown healthy plants were selected for the study to maintain uniformity throughout the research.

Field establishment

Plants were established in 2.4×3.0 m plots after the initial land preparation. Three spatial patterns were used 1.2×0.6 m with three plants per hill (A), 1.2×0.4 m with two plants per hill (B), and 1.2×0.2 m with one plant per hill (C). There were three plant rows in each plot, and the middle plants of the middle row were used for the data collection to prevent the border effect. The plant density was equal (41,666 plants/ha) for all treatment combinations.

Field management
The field was maintained according to the recommendations of the Department of Export Agriculture throughout the study (Technical Bulletin, 2015). Two harvesting intervals were maintained as six months and eight months.

Data collection and analysis
The first harvest was collected two years after the field establishment, and the study was conducted two years after the first harvest. The number of stems per plant was recorded on the field just before harvesting. Once harvested, height, top diameter, bottom diameter, and diameter every 30 cm along the stem were recorded in each stem. A digital vernier calliper was used to measure diameters to ensure accuracy. The average diameter of stems was calculated with data obtained from every 30 cm along stems.

The straightness of the stems was measured by categorizing them into groups (erect stems, slightly curved stems, stems with irregular bends, and stems with bends and knots) based on erectness (Figure 1 (A)). Because erect and slightly curved stems were more beneficial during processing, the percentage of erect and slightly curved stems was calculated and used for statistical analysis.

Three levels along the length of stems as upper, middle and lower, were considered for the data collection regarding branches (Figure 1 (B)). The number of branches per level and lengths and angles of branches were recorded. The percentage of branches in a level and the number of branches per unit length were calculated.

Lengths of branches were evaluated by categorizing them into groups as a percentage under 50 cm, 50 – 100 cm, and above 100 cm. Simultaneously, angles were evaluated by categorizing into groups as a percentage of branches under 30°, 30° - 60°, and above 60°.

Because the number of branches in the lower level was considerably low, only the upper and middle levels were considered for descriptive data analysis in the number of branches per unit length and lengths and angles of branches.

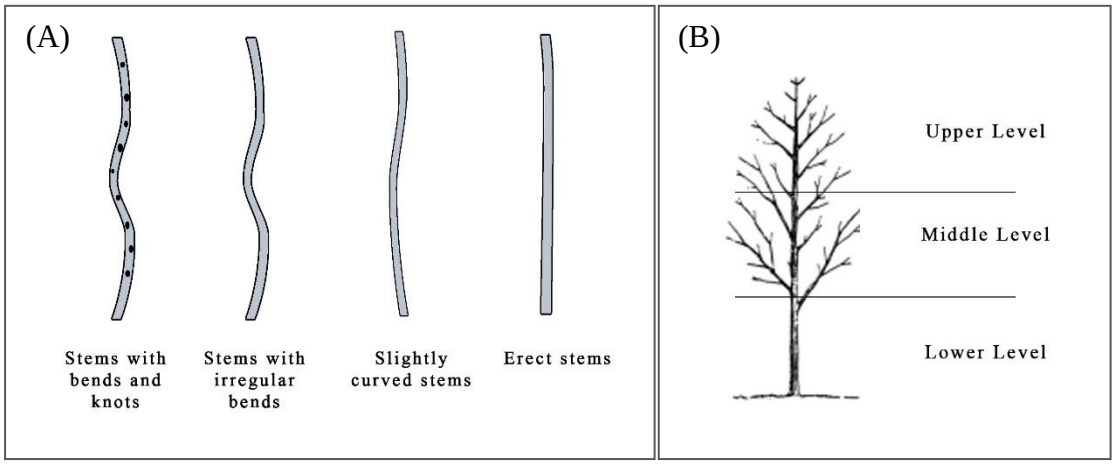

Figure 1: (A) - Categories of stems based on straightness, (B) - Upper, middle and lower levels of cinnamon stems

The experiment was conducted as a three-factor factorial (three spatial patterns, two planting material types, and two harvesting intervals) split plot design (Table 1) with four replications. The collected data were statistically analyzed using the analysis of variance (ANOVA), and the means were separated with Duncan's Multiple Range Test (DMRT). All the tests were performed at the 5% probability level.

Table 1: Treatment combinations tested during the study for the impact on selected aspects of cinnamon bush architecture (SD: Seedlings; VP: Vegetatively propagated plants)

Harvesting interval	Spatial pattern	Planting material
6 months	(A) 1.2×0.6 m with three plants per hill	SD
		VP
	(B) 1.2×0.4 m with two plants per hill	SD
		VP
	(C)1.2×0.2 m with one plant per hill	SD
		VP
8 months	(A) 1.2×0.6 m with three plants per hill	SD
		VP
	(B) 1.2×0.4 m with two plants per hill	SD
		VP
	(C)1.2×0.2 m with one plant per hill	SD
		VP

RESULTS AND DISCUSSION

According to the results, the interaction effect between planting material and the spatial pattern was significant ($p < 0.05$) for the number of stems per plant. The seedlings established under spatial pattern C recorded the highest number of stems per plant (3.6). The value was significantly higher ($p < 0.05$) than all other values. The lowest number of stems per plant (2.3) was recorded in the vegetatively propagated plants established under spatial patterns B and C. The value was not significantly different ($p < 0.05$) from the vegetatively propagated plants established under spatial pattern A (2.6). (Figure 2 (A)).

Since cinnamon trees have been converted into bushes with multiple stems through continuous coppicing, the number of stems per plant tends to be increased with the increasing number of coppicing cycles. Therefore, plant age has been identified as a significant factor affecting the number of stems in a single plant (Pathiratna, 2007). With the current findings, spatial pattern also proved to be an essential factor in producing stems in seedlings. Availability of space in the entire perimeter of the coppiced main stem to produce new stems may be the reason for the increased number of stems in seedlings established under spatial pattern C. As vegetatively propagated plants tend to produce a rather bushy structure compared to seedlings, spatial patterns may not affect the number of new stems produced.

Simultaneously, the results revealed that the interaction effect between planting material and harvesting interval (Figure 2 (B)) and the interaction effect between planting material and spatial pattern (Figure 2 (C)) were significant ($p < 0.05$) for stem height of cinnamon plants. Considering the interaction effect between planting material and harvesting interval, significantly long ($p < 0.05$) stems were produced in seedlings harvested during eight months harvesting interval (235.2 cm). Stems were significantly shorter ($p < 0.05$) in vegetatively propagated plants harvested in 6 months harvesting interval (99.1 cm). When considering the interaction effect between planting material and spatial pattern, significantly long ($p < 0.05$) stems were produced in seedlings established under spatial pattern C (222.9 cm). Stems were significantly shorter ($p < 0.05$) in vegetatively propagated plants established under spatial patterns B (111.5 cm) and C (103.8 cm).

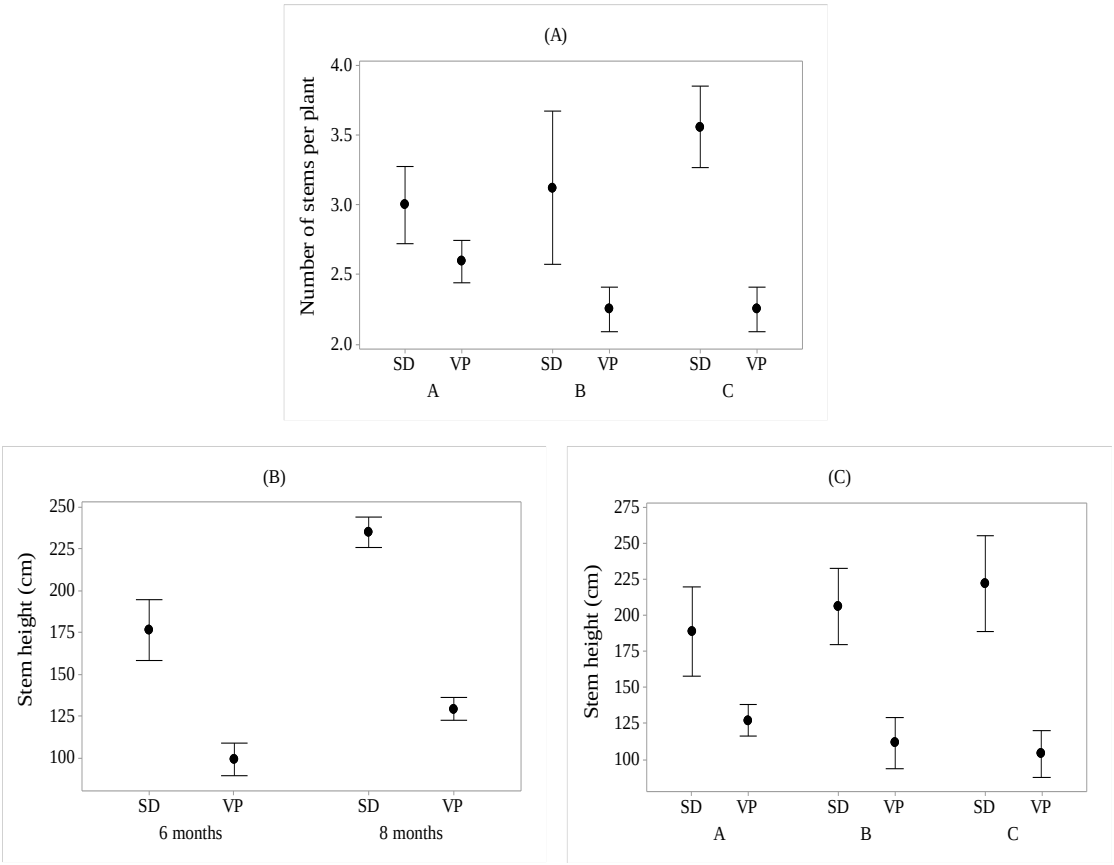

Figure 2: (A) - Number of stems per plant as affected by planting material and spatial pattern, (B) - Stem height of cinnamon plants as affected by planting material and harvesting interval, (C) - Stem height of cinnamon plants as affected by planting material and spatial pattern (SD: Seedlings; VP: Vegetatively propagated plants; A: 1.2×0.6, 3 plants/hill; B: 1.2×0.4, 2 plants/hill, C: 1.2×0.2, 1 plant/hill).

Generally, stems can grow taller with longer coppicing cycles. Similarly, the lack of shoot and root meristems demotes the elongation of vegetatively propagated plants due to the reduced levels of auxins (Leyser, 2010; Massoumi *et al*., 2017). Hence, the stems of seedlings have been taller in both harvesting intervals than vegetatively propagated plants.

On the other hand, the height of sun-loving plants such as cinnamon is highly affected by shade levels. Close planting of crops always causes mutual shading, which influences changes in light intensity and spectrum (Wherley *et al*., 2005). According to Pathiratna and Perera (2006), the length of cinnamon stems has been affected by the mutual shading, which occurred due to the reduction of the Red: Far Red ratio within canopies. The results revealed that the optimum spatial pattern for developing longer stems in seedlings differs from vegetatively propagated plants.

Stem girth is another crucial factor, as well as stem height in cinnamon. Hence, the impact of harvesting interval, spatial pattern and planting material on different aspects of stem girth were tested.

Neither interaction effects nor main effects were significant ($p < 0.05$) for the top diameter of cinnamon stems. The average value was 14.8 mm (Figure 3 (A)). Nevertheless, bottom diameter and average diameter of cinnamon stems were significantly affected by harvesting interval and planting material ($p < 0.05$).

When considering the harvesting interval, both bottom diameter and average diameter

were significantly higher ($p < 0.05$) when harvested in 8 months harvesting interval (Bottom diameter: 31.8 mm, Average diameter: 27.9 mm) than harvested in 6 months harvesting interval (Bottom diameter: 29.6 mm, Average diameter: 25.8 mm). (Figure 3 (B) and (D))

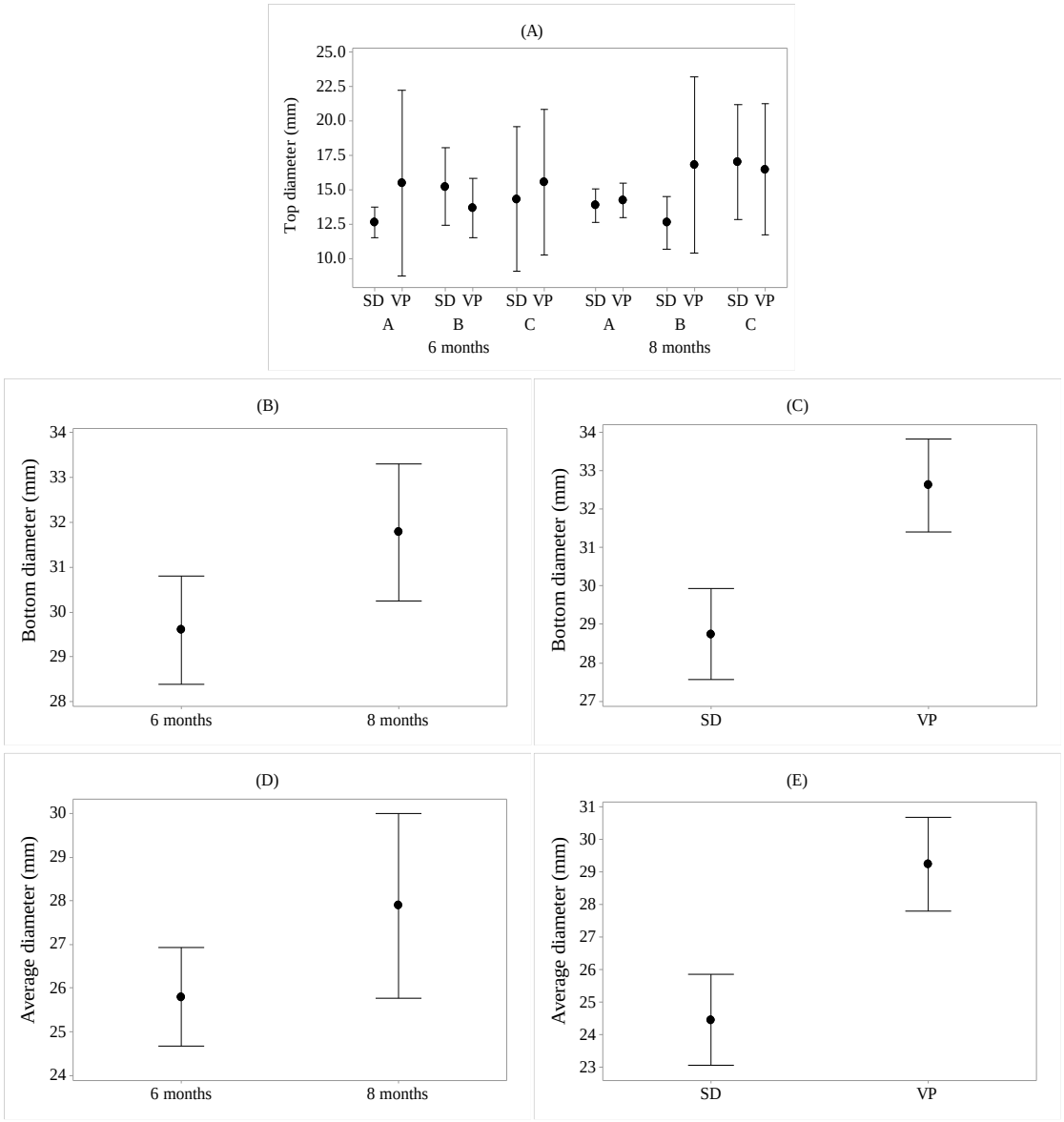

Figure 3: (A) - Top diameter of cinnamon stems as affected by harvesting interval, spatial pattern and planting material, (B) - Bottom diameter of cinnamon stems as affected by harvesting interval, (C) - Bottom diameter of cinnamon stems as affected by planting material, (D) - Average diameter of cinnamon stems as affected by harvesting interval, (E) - Average diameter of cinnamon stems as affected by planting material (SD: Seedlings; VP: Vegetatively propagated plants; A: 1.2×0.6, 3 plants/hill; B: 1.2×0.4, 2 plants/hill, C: 1.2×0.2, 1 plant/hill; 6 months: 6 months harvesting interval; 8 months: 8 months harvesting interval).

Simultaneously, considering the planting material, both bottom diameter and average diameter were significantly higher ($p < 0.05$) for vegetatively propagated plants (Bottom diameter: 32.6 mm, Average diameter: 29.2 mm) than for seedlings (Bottom diameter: 28.7 mm, Average diameter: 24.5 mm). (Figure 3 (C) and (E))

A direct relationship can be identified between the age and stem diameter of woody perennial plants (Perryman and Olson, 2000). Similarly, longer harvesting intervals provide more time to assimilate dry matter in their stems. Hence, the stem girth of cinnamon stems harvested in 8 months intervals were higher than that stems harvested in 6 months intervals. Simultaneously, vegetatively propagated plants appeared to produce stout structures with shorter stems and higher diameters than seedlings.

Like stem height and girth, the straightness of cinnamon stems also highly affects the processing ability and quill grade of cinnamon. According to the results, the planting material significantly affected the straightness of cinnamon stems ($p < 0.05$). The percentage of erect and slightly curved stems of seedlings (93.75%) was significantly higher than vegetatively propagated plants (35.5%) (Figure 4).

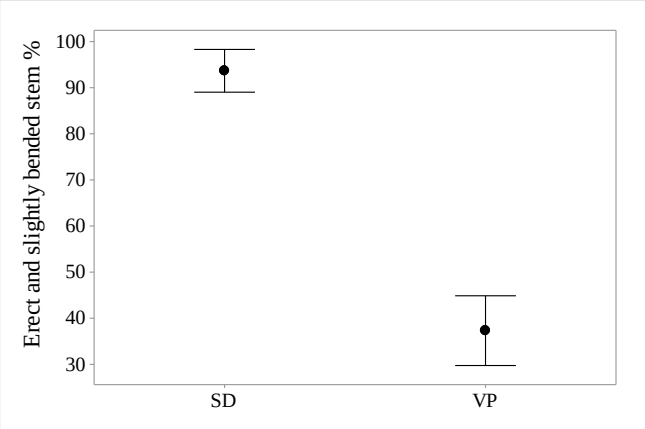

Figure 4: Percentage of erect and slightly curved cinnamon stems as affected by the planting material (SD: Seedlings; VP: Vegetatively propagated plants).

Stem malformations such as bending can be occurred due to genetic, ecological and silvicultural factors in woody perennial species (Del Rio *et al.*, 2004). Similarly, higher plant densities tend to produce higher rates of straight stems (Malinauskas, 1999). Characteristics and deformations also proved to affect the straightness of stems due to the relationship between stem stability and root system (Danjon, 1999; Lindström, 1999). In the current study, seedlings produced more straight stems than vegetatively propagated plants. The comparatively less stable root system of vegetatively propagated plants can be a reason for the above results. On the other hand, auxin promotes cell growth and elongation of the plant which alters the plant wall plasticity making it easier for the plant to grow upwards (Place, n.d.). As previously mentioned, the auxin concentration of vegetatively propagated plants is lower than seedlings, which can be another reason for the comparatively bent nature of the stems.

Some aspects of branches were tested in order to gain an overall image of bush architectures under tested conditions. When considering the percentage of branches in the upper (Figure 5 (A)), middle (Figure 5 (B)), and lower (Figure 5 (C)) levels of the cinnamon stems, neither interaction effects nor main effects were shown any significant effect ($p < 0.05$). The average percentages of branches in upper, middle

and lower levels of cinnamon stems are 63.83%, 29.50%, and 6.67%, respectively.

According to the results, a comparatively higher proportion of branches were in the upper level of stems, while a comparatively lower proportion was in the lower level. Because of that, only the upper and middle levels were considered when analyzing the number of branches per unit length, branch length, and angle.

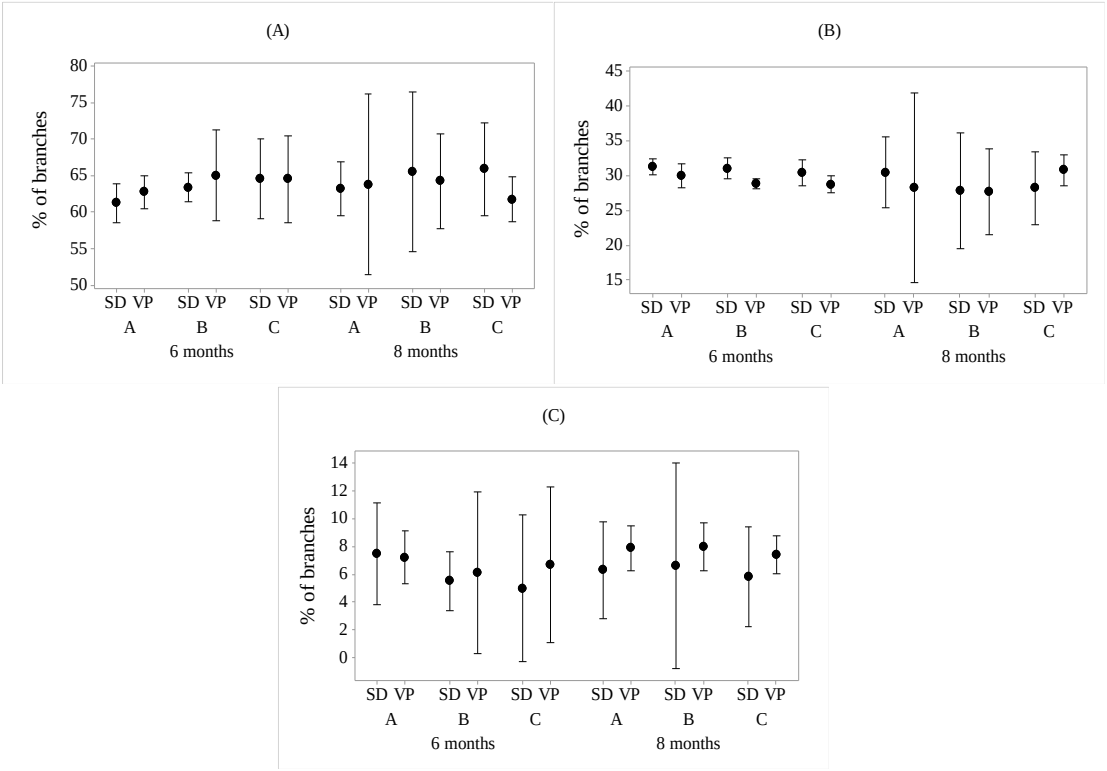

Figure 5: (A) - Percentage of branches in the upper level of cinnamon stems, (B) - Percentage of branches in the middle level of cinnamon stems, (C) - Percentage of branches in the lower level of cinnamon stems (SD: Seedlings; VP: Vegetatively propagated plants; A: 1.2×0.6, 3 plants/hill; B: 1.2×0.4, 2 plants/hill, C: 1.2×0.2, 1 plant/hill; 6 months: 6 months harvesting interval; 8 months: 8 months harvesting interval).

Though the percentage of branches in each level of cinnamon stems was not significantly affected ($p < 0.05$) by treatments, there were some significant effects ($p < 0.05$) on the number of branches in a unit length of a stem.

The interaction effect between planting material and the spatial pattern was significant ($p < 0.05$) for the number of branches per meter in the upper level of cinnamon stems. The highest number of branches per meter (21.0) was recorded in the vegetatively propagated plants established under spatial pattern C, which was significantly higher ($p < 0.05$) than all other values. The seedlings established under spatial pattern C recorded the lowest number of branches per meter (13.1). The value was not significantly different ($p < 0.05$) from the seedlings established under spatial pattern A (13.6). (Figure 6 (A)).

The effect of planting material was significant ($p < 0.05$) for the number of branches per meter in the middle level of cinnamon stems. The number of branches per meter in vegetatively propagated plants (9.5) was significantly higher ($p < 0.05$) than in seedlings (6.8). (Figure 6 (B)).

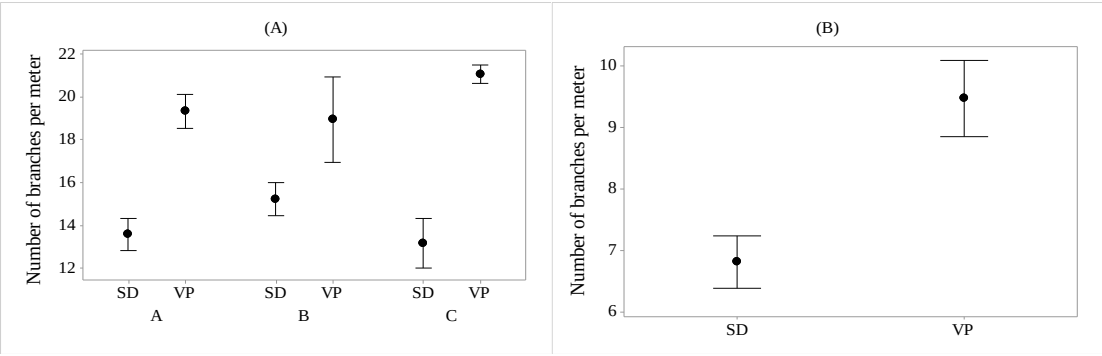

Figure 6: (A) - Number of branches per meter in the upper level of cinnamon stems as affected by the planting material and the spatial pattern, (B) - Number of branches per meter in the middle level of cinnamon stems as affected by the planting material (SD: Seedlings; VP: Vegetatively propagated plants; A: 1.2×0.6, 3 plants/hill; B: 1.2×0.4, 2 plants/hill, C: 1.2×0.2, 1 plant/hill).

When considering branch length, main effects or interaction effects were not significant ($p < 0.05$) for the percentages of branches under each length category (< 50 cm, 50 - 100 cm, >100 cm) in both upper and middle levels of cinnamon stems (Table 2).

Table 2: Percentages of branches under each length category in upper and middle levels of cinnamon stems*.

Planting material	Spatial pattern	Harvesting interval	Upper %			Middle %		
			< 50 cm	50 – 100 cm	>100 cm	< 50 cm	50 – 100 cm	>100 cm
SD	A	6 months	62.40^a	29.43^a	8.17^a	63.65^a	29.06^a	7.29^a
		8 months	64.09^a	28.38^a	7.53^a	58.23^a	27.76^a	10.35^a
	B	6 months	65.03^a	28.08^a	6.90^a	57.81^a	33.96^a	8.23^a
		8 months	67.39^a	25.46^a	7.14^a	64.81^a	28.19^a	7.00^a
	C	6 months	64.53^a	29.80^a	5.67^a	59.48^a	32.33^a	8.19^a
		8 months	65.90^a	26.79^a	7.32^a	54.38^a	27.76^a	8.15^a
VP	A	6 months	67.41^a	25.27^a	7.32^a	60.35^a	30.45^a	9.20^a
		8 months	64.91^a	30.82^a	4.28^a	58.37^a	30.92^a	10.71^a
	B	6 months	64.66^a	26.83^a	8.52^a	59.65^a	31.84^a	8.51^a
		8 months	63.24^a	27.23^a	9.54^a	67.29^a	23.02^a	9.69^a
	C	6 months	63.40^a	30.70^a	5.90^a	55.83^a	33.75^a	10.42^a
		8 months	66.52^a	26.72^a	6.77^a	61.98^a	29.79^a	8.23^a

**Values in the same column followed by the same letter do not differ significantly ($p<0.05$); Length categories: < 50 cm, 50 - 100 cm, >100 cm; SD: Seedlings; VP: Vegetatively propagated plants; A: 1.2×0.6, 3 plants/hill; B: 1.2×0.4, 2 plants/hill, C: 1.2×0.2, 1 plant/hill.*

On the other hand, the impact of planting material was significant ($p < 0.05$) for all of the angle categories in both the upper and middle levels of cinnamon stems (Table 3).

Table 3: Percentages of branches under each angle category in upper and middle levels of cinnamon stems*.

Planting material	Upper %			Middle %		
	< 30°	30°- 60°	>60°	< 30°	30°- 60°	>60°
SD	17.33^a	69.21^a	13.46^b	18.10^a	69.15^a	12.73^b
VP	14.97^b	53.80^b	31.23^a	15.07^b	48.76^b	36.17^a

**Values in the same column followed by the same letter do not differ significantly ($p<0.05$); Angle categories: < 30°, 30°- 60°, and 60° <; SD: Seedlings; VP: Vegetatively propagated plants.*

The light environment is an essential factor in the branch development of woody perennial plants (Suzuki and Suzuki, 2008). Branches are developed to facilitate optimum conditions to capture light by leaves. Hence, the stem heights are different in seedlings and vegetatively propagated plants; branching habits may vary according to the type of planting material.

Apical dominance is another major factor determining growth of branches and development. The apical portion of the shoot carries the ability to prevent the outgrowth of lateral branches (Jacyna, 2002). Because the stem cuttings were used as vegetatively propagated plants for the study, the apical portion was absent at the initial age. This could be another reason for having a higher number of branches per unit length of stems than the plants produced by seedlings.

CONCLUSIONS

New modified planting systems were tested on cinnamon bush architecture by altering spatial patterns, planting material, and harvesting interval. The interaction effect between planting material and the spatial pattern was significant for the number of stems per plant, height, and the number of branches per unit length. The interaction effect between planting material and harvesting interval was significant for the stem height. Simultaneously, the impacts of planting material and harvesting interval were significant for the stem diameter as the main factor effects. The impact of planting material was significant for the stem straightness and branch angle. When considering the entire results section, seedlings established in 1.2×0.2 m with one plant per hill proved to develop a beneficial bush architecture. Hence, when establishing seedlings, the spatial pattern 1.2×0.2 m with one plant per hill can be used to obtain preferred stems for high-quality quill production. As eight months harvesting interval produces longer stems while six months harvesting interval produces thinner stems, when considering the bush architecture, the harvesting interval can be selected according to the availability of cinnamon peelers.

Acknowledgement

The authors acknowledged Mrs. DABN Amarasekera and Mr. HKMS Kumarasinghe from the Department of Crop Science, Faculty of Agriculture, University of Ruhuna, for their immense support and guidance throughout the study.

REFERENCES

Abeysinghe, P.D., Bandaranayake, P.C.G. and Pathirana, R. (2020) Botany of Endemic Cinnamomum Species of Sri Lanka. pp. 85–118. In: *Cinnamon: Botany, Agronomy, Chemistry and Industrial Applications* (Eds. R. Senaratne and R. Pathirana), Springer, Cham.

Danjon, F., Sinoquet, H., Godin, C., Colin, F. and Drexhage, M. (1999) Characterisation of structural tree root architecture using 3D digitising and AMAPmod software. *Plant and soil* 211(2): 241–258.

Del Rio, M., Bravo, F., Pando, V., Sanz, G. and de Grado, R.S. (2004) Influence of individual tree and stand attributes in stem straightness in *Pinus pinaster* Ait. stands. *Annals of forest science* 61(2): 141–148.

Dewasiri, N.R., Wagenaar, L.J. and Uyangoda J. (2020) Historical, Ethno-Botanical and Social Aspects of Cinnamon Cultivation in Sri Lanka. pp. 39–6 In: *Cinnamon: Botany, Agronomy, Chemistry and Industrial Applications* (Eds. R. Senaratne and R. Pathirana), Springer, Cham.

Jacyna, T. (2002) Factors influencing lateral-branch formation in woody plants. *Acta Agrobotanica* 55(2): 5–25

Jayaprakasha, G.K., Jagan Mohan Rao, L. and Sakariah K.K. (2003) Volatile constituents from *Cinnamomum zeylanicum* fruit stalks and their antioxidant activities. *Journal of agricultural and food chemistry* 51(15):4344–4348.

Leyser, O. (2010) The power of Auxin in plants. *Plant physiology* 154(2): pp. 501-505.

Lindström, A. and Rune, G. (1999) Root deformation in plantations of container-grown Scots pine trees: effects on root growth, tree stability and stem straightness. *Plant and soil* 217(1): 29–37.

Malinauskas, A. (1999) The influence of the initial density and site conditions on Scots pine growth and wood quality. *Baltic Forestry [en línea]* 5(2): 8–19.

Massoumi, M., Krens, F.A., Visser, R.G.F. and De Klerk, G.M. (2017) Etiolation and flooding of donor plants enhance the capability of Arabidopsis explants to root. *Plant Cell, Tissue and Organ Culture* 130:531–541.

Pasiecznik, N. (2009) *Cinnamomum verum* (cinnamon), Invasive Species Compendium, [accessed 2022 Mar 21]. https://www.cabi.org/isc/datasheet/13573.

Pathiratna, L.S.S. (2007) Factors affecting bark yield components of cinnamon. *Bulletin of the Rubber Research Institute of Sri Lanka* 48: 43-48.

Pathiratna, L.S.S. and Perera, M.K.P. (2006) Effect of plant density on bark yield of cinnamon intercropped under mature rubber. *Agroforestry Systems* 68(2): 123-131.

Perryman, B.L. and Olson, R.A. (2000) Age-stem diameter relationships of big sagebrush and their management implications. *Rangeland Ecology & Management/Journal of Range Management Archives* 53(3): 342–346.

Place, M., (n.d.) Auxin: The Functions, Effects, and Applications of a Plant Growth Hormone. Available at: https://www.ndsu.edu/pubweb/chiwonlee/plsc211/student%20papers/articles00/mplace/mplace.htm (Accessed: 28 Nov 2022).

Poorter, L., Bongers, F., Sterck, F.J. and Wöll, H. (2003) Architecture of 53 rain forest tree species differing in adult stature and shade tolerance. *Ecology* 84(3):602–608.

Rawat, I., Verma, N. and Joshi, K. (2019) Cinnamon (*Cinnamomum zeylanicum*). In: Medicinal Plants in India: Importance and Cultivation (Eds: Ghosh, S.N., Nath, A. and Bakshi, P.), Jaya Publishing House, New Delhi, pp. 164-177

Suriyagoda, L., Mohotti, A.J., Vidanarachchi, J.K., Kodithuwakku, S.P., Chathurika, M., Bandaranayake, P.C., Hetherington, A.M. and Beneragama, C.K. (2021) "Ceylon cinnamon": Much more than just a spice. *Plants, People, Planet* 3(4), pp.319-336.

Suzuki, A.A. and Suzuki, M. (2008) Why do lower order branches show greater shoot growth than higher order branches? Considering space availability as a factor affecting shoot growth. *Trees* 23(1): 69–77.

Technical bulleting (2015) Cinnamon cultivation and processing. Department of Export agriculture, Sri Lanka.

Weerasinghe, K.D.N. and Pushpitha, N.P.G. (2020) Cinnamon Process Technology. pp. 233–250. In: *Cinnamon: Botany, Agronomy, Chemistry and Industrial Applications* (Eds. R. Senaratne and R. Pathirana), Springer, Cham.

Weiss, E.A. (2002) Spice crops. CABI Publishing, Oxford.

Wherley, B.G., Gardner, D.S. and Metzger, J.D. (2005) Tall fescue photomorphogenesis as influenced by changes in the spectral composition and light intensity. *Crop Science* 45(2):562–568.

Wijesinghe, K. G. G., (2011) Cinnamon improvement programmes through selection and breeding, International Symposium: Technology to reach future aspirations of Ceylon Cinnamon, Matara, Sri Lanka, 18-19 July, 2011, pp 25-27

Yang, X.D., Yan, E.R., Chang, S.X., Da, L.J. and Wang, X.H. (2015) Tree architecture varies with forest succession in evergreen broad-leaved forests in Eastern China. *Trees* 29(1):43–57.