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Growth performance of black pepper raised on *Artocarpus heterophyllus* planted at variable stand densities

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Abstract
Black pepper (*Piper nigrum* L.) is the one of the prominent commercial spice crops grown for culinary and pharmaceutical value. It is trailed on large number of tree species traditionally grown in homegardens and farm lands of humid regions of Kerala. *Artocarpus heterophyllus* is one such promising support trees for cultivation of pepper. Despite the traditional knowledge of trailing pepper on staggered jack trees, such information on optimal tree spacing/density for enhancing the productivity of black pepper when cultivated in blocks in organized manner, is lacking. Considering the utility of Jack as a support for raising black pepper, the jack woodlot was established in 2020 to evaluate the growth performance of black pepper under jack trees managed at different planting spacing (3×3 m, 3×4 m, and 3×5 m). The experimental design followed was randomized block design (RBD) with four replications, at Suhasini hills, Kerala Agricultural University, Thrissur, Kerala. The black pepper was raised after 1 year of establishment of jack woodlot. The results from the study showed variable growth trends for black pepper under different tree spacing regimes, though many of such trends were non-significant. The closely spaced jack woodlots registered lower vine length (21.75 to 83.50 cm) while the trees at wider spacing (18.50 to 111.50 cm; 3×4 m and 20.25 to 92 cm; 3x5m) recorded fairly better vine length for trailed black pepper. The pepper vine collar diameter showed variable trend with better collar diameter associated with closely spaced jack trees (4.83 to 6.28 mm; 3×3 m and 4.67 to 6.22 mm; 3×4 m) while the corresponding range at wider spacing was less (4.84 to 5.54 mm; 3×5 m). Comparable leaf number (6.25 to 17.75 and 6.75 to 18.50) was recorded under 3×4 m and 3×5 m spacing respectively, while low leaf count was observed under 3×3 m spacing (6.50 to 15.50). Although, the best growth has been achieved under 3×4 m spacing, the future predictions cannot be made based on the early results. The present study underscores the need for further investigation to better understand the conditions that favour the growth and emphasize the consideration to other factors such as environmental conditions and management practices, along with tree spacing.

Keywords: Jackwood, black pepper, planting spacing, vines, early growth

Introduction
Black pepper (*Piper nigrum* L.) is an important spice crop trailed on large number of tree species traditionally grown in home gardens and farmlands of Kerala. On account of its unique culinary and pharmaceutical value black pepper is often called black gold and king of spices. Black pepper is believed to have originated from the wet humid regions of the Western ghats of south India. It is largely distributed in Kerala (94%) and Karnataka (5%) while the rest comes from Tamil Nadu, Andhra Pradesh, and NE states, especially Assam (https://agritech.tnau.ac.in). In Kerala, >80% of pepper holdings fall under small (<0.5 acre) and medium (0.5-2.00 acres) categories. The decadal trends (2011-21) of pepper cultivation and production in Kerala are depicted in Fig 1. Black pepper has 40% foreign exchange earnings under spice export (Augustine 2020) [1].

Black pepper is an evergreen and perennial climbing vine (climbs with the aid of aerial or adventitious roots) that grows to a height of 10 m or more. Black pepper requires consistent support called standard which could be inanimate support such as concrete, living and non-living trees (wooden poles).

Living trees have been proven to reduce capital cost along with increase in productivity on long-term basis than concrete or wooden poles (Changthom *et al*. 2017) [2]. Trees are also known to maintain lower temperatures and high relative humidity conducive for pepper growth (Oliveira *et al*. 2018) [3]. It was observed that the rhizosphere of tree species varies considerably in their nutrient availability, enzyme and microbial activities which bring considerable variability in associated pepper growth and yield. For instance, in the plains of humid tropics, the rhizosphere of *Gliricidia sepium* and *Garuga pinnata* was found to have a profound influence on soil properties therefore, species could be preferred for restoring degraded black-pepper plantations (Dinesh *et al*. 2010) [4]. The support trees should be raised 2-3 years in advance to permit trailing of pepper at sufficient height (Sivaraman *et al*. 1999) [5]. Black pepper being perennial starts yielding with full potential from the third year after planting.

The pepper yield is considerably influenced by the choice of tree species. Traditionally, farmers prefer to grow it on a variety of tree species grown in the homesteads and farmlands such as jackfruit, mango, arecanut, coconut, etc. (Dinesh *et al*. 2005) [6]. However, the productivity of black pepper depends on many factors such as support tree attributes and tree spatial geometry. Particularly, regulation of the tree spacing is vital for enhancing the understory light availability and for alleviating the competitive interactions for optimal pepper yield.

Studies also revealed that about 31 tree species are suitable for the cultivation of pepper in the humid tropics such as Kerala (Salam, 1991) [7]. The decadal study of the tree-pepper-based production system revealed that among fast-growing multipurpose tree spp., *Artocarpus heterophyllus* (jack-fruit tree) is a promising support tree for block cultivation of pepper yielding about 1.91 Mg ha^{-1} dry pepper yield (Kunhamu *et al*. 2012) [8]. In Bangladesh also, jackfruit was recommended as the best support tree for the higher yield (1.91 kg dry yield per tree) and quality production of black pepper in climate change scenarios (Faisal *et al*. 2024) [9]. Jack tree fulfills the criteria of shade tree ideotype for trailing black pepper with the desirable characters like deep root system, non-exfoliating bark, fast-growing habit, amenability to lopping, lopped outturn, litter production, nutrient return, long term viability and multifarious utility, etc. as enlisted by Sivaraman *et al*. 1999 [5]; Elevitch and Manner 2006 [10]; Kunhamu *et al*. 2012[8]; Kumar *et al*. 2021 [11].

Despite the traditional knowledge of trailing pepper on staggered jack trees, such information on optimal tree spacing/density for enhancing the productivity of black pepper for establishing large plantations under organized cultivation, is lacking. Considering the utility of Jack as a support for raising black pepper, it would be a desirable strategy to develop stand management protocols for Jack both for timber and black pepper production.

Materials and Methods

Experimental site: Location, climate

The experimental site was located at the Suhashini hills, plantation research area, College of Forestry, Kerala Agricultural University, Vellanikkara, and Kerala. The study was conducted for a period of three years (2021 to 2023). The site experiences a warm humid tropical climate and it is situated at an elevation of 40.29 m above mean sea level and lies at 10°33'11.46'' N latitude and 76°18'00.23'' E longitude, which represents the central agro-climatic zone of the state. Generally, Vellanikkara receives an annual rainfall of 3062 mm (mostly from S-W monsoon), experiences mean maximum temperature from 29.10 to 35.40^{0}C in July-March and mean minimum temperature from 22.19 to 24.83^{0}C in May-December. The meteorological data during the study period is depicted in Fig 3. The field experiment was conducted in an existing *Artocarpus heterophyllus* woodlot established during July 2020 by following RBD design with three spacing treatments *viz*. 3×3 m, 3×4 m, 3×5 m and at four replications. The trees were planted at variable plot size such that each plot maintained equal number of trees (16).

Integration of black pepper

The black pepper variety Panniyur-2 was raised in all the trees managed under variable tree spacing. Black pepper cuttings were trailed on all the jack trees when the trees were one-year-old (2021). For pepper planting, pits of size 50×50×50 cm were prepared at a distance of 15 cm from the tree base in each spacing treatment plot. Well rotten cattle manure at the rate of 500 g, Trichoderma and neem cake at the rate of 50 g each, was added per planting pit. Two rooted cuttings were planted in each pit at 30 cm from tree base in E-W direction. The planting material was procured from the Department of Plantation Crops, College of Agriculture, KAU. The first planting was carried out in the first week of August 2021 but failed with a higher mortality rate (59.63% survival), which was attributed to severe nematode attack which was controlled following nematicide application (KAU, 2021). However, the following summer season marked severe casualty which led to total replacement. The replanting was carried out during the second season (with two-year-old jack trees) in the month of September using new pepper cuttings (var. Panniyur-2; KAU) and the pepper growth was satisfactory (only 12% of causality).

The biometric observations on growth of the pepper under jack trees managed at variable tree spacing, was recorded on monthly intervals for one-year period (during third year growth of trees). Four random pepper seedlings were subjected to growth assessment for each jack plot. The growth parameters such as pepper vine length (cm; using tape, vine length recorded from the base to the tip), collar diameter (mm; using digital vernier caliper; taken at the collar region that separate the stem and the root portion), number of leaves per vine (count of green and functional leaves), number of laterals (laterals are the new shoots arising from the main stem) were evaluated.

Management of pepper vines

The survival rate of black pepper is directly linked to the care and management afforded during the period of establishment phase. The pepper leaves showed yellowing after two months of growth which however could be managed following a foliar spray of N:P: K (19:19:19) at the rate of 10-15 gmL^{-1} of water. The establishment phase of pepper is critical and requires more attention and care. After attaining sufficient vine length, it was tied to tree trunk for facilitation of its anchorage to the tree stem (Figure 2).

Results

The prominent growth parameters of black pepper were recorded on monthly basis for pepper trailed on jack trees managed at three tree spacing regimes *viz*. 3×3 m, 3×4 m and 3× 5m.

Vine length

Vine length is an important determinant of growth rate of pepper plant. The longer and healthier vines can often be considered as good predictor of future yields. Monthly observations reported

consistent increase in pepper vine length over a period of one year. For instance, the vine length increased across all spacing regimes in the range of 21.75 to 83.50 cm (3×3 m), 18.50 to 111.50 cm (3×4 m) and 20.25 to 92 cm (3×5 m) with notable increase in the months from July to September (Fig 3). At the end of one year study, the maximum growth in pepper vine length was reported under moderate tree spacing (111.50 cm; 3×4 m) followed by trees under wider spacing (92 cm; 3×5m) and the lowest vine length at narrow spacing (83.50 cm; 3×3 m).

Collar diameter

Collar diameter is a valuable indicator of plant health and growth potential. The variations in pepper collar diameter across different tree spacing were not conspicuous, though it increased considerably during the one-year period among all the tree spacing levels (Fig 4). The post monsoon period (August to September) recorded pronounced increase in collar diameter. For instance, the collar diameter increased from 4.83 to 6.28 mm under closer spacing (3×3 m) followed by moderate spacing (4.67 to 6.22 mm; 3×4 m) and wider spacing (4.84 to 5.54 mm; 3×5 m) over a period of one year. Nonetheless, the changes in pepper collar diameter among the tree spacing regimes were not appreciable.

Number of leaves

Leaf count is a vital metric to assess the plant growth rate. In general, a higher number of leaves mean higher photosynthetic capacity that contributes to plant's energy production and growth. Leaf number is often related with potential yield especially in fruiting and flowering plants. A consistent increase in leaf count has been noticed over time indicating a healthy growth pattern throughout the year. However, it appears that wider spacing resulted in a higher number of leaves (Fig 5). It is more visible at last sampling period (September) with highest vine leaf number registered for pepper trailed on widely spaced jack (18.50 number; 3×5 m) followed by jack at 3×4 m spacing (17.75 number) and lowest number of leaves (15.50 number) recorded under closely spacing jack trees (3×3 m). The overall patterns indicates that the tree spacing can influence leaf development particularly in certain months.

Number of Laterals

Laterals are the side branches of pepper vines that are vital for fruit production, structural support and propagation. Lateral branches are also called plagiotropic that emerge from the nodes of main stem and are responsible for bearing spikes that produce pepper berries. In the present study, no exact lateral branches have been observed. However, the laterals are observed in the form of runner shoots that emerge from basal portion of main stem and remained restricted to 50 cm from ground. The data recording does not illustrate notable fluctuation in lateral shoot production across spacing and over the months. Over a period of one year, the lateral count varied as 1.06 at 3×3 m, 1.38 at 3×4 m and 0.88 at 3×5 m tree spacing.

Discussion

Black paper prefers moderate light intensity and hence often preferred in the understorey of tree-based production systems. Pepper plants need light intensity of 50-75% for better growth (Wahid 1984) [12]. The top portion of the vine receives more sunlight which declines gradually downwards which is attributes to the mutual shading of the vine (Ramadasan 1987 [13]; Mathai and Chandy 1988) [14]. The productivity of black pepper declines with higher temperatures and low rainfall (Krishnamurthy *et al.* 2011) [15]. It is highly intolerant to dryness and excessive heat. The ideal temperature is 23-32 ℃ (average 28 ℃) with tolerance temperature range of 10-40 ℃. For the optimum growth, about 2000-3000 mm of rainfall is required per year and 90 mm per month (Thangaselvabal *et al.* 2008 [16]; Rosman *et al.* 1996 [17]). The optimum relative humidity required is 60-95% (De Ward 1969 [18]; Wahid and Sitepu 1987) [19]. Among all the environmental factors, rainfall intensity is the more influential factor for the growth and productivity of black pepper (Yudiyanto *et al.* 2015) [20]. Black pepper is a day-neutral plant, subjecting to direct exposure to solar radiation develops physiological disorder even under favorable soil moisture conditions. During the period from November to-march the plant suffers from moisture stress and if rain does not happen for 2-3 weeks, the soil in the top 30 cm reduces to 50% or less (Thangaselvabal *et al.* 2008)[16]. The young seedlings in the field should be given adequate care by providing shade and irrigation until their establishment (Sivaraman *et al.* 1999) [5]. In the present study, a decline in leaf number and collar diameter has been observed from March to June, which is attributed to considerable fluctuations in temperature and rainfall as depicted in Fig 3. The artificial irrigation (weekly intervals in January, two days interval in February to alternate days from March onwards till June) and mulching (Arecanut sheaths and leaves) during the dry period saved the pepper cuttings from mortality with lowering of growth rate. The climatic variations substantially affect the growth of plant during initial stages of development.

The process of vining (elongation of stem) is fundamental adaptation to the environment (Patel *et al.* 2013) [21]. The vine length varies with type of supporting tree and its characteristics, which can correlate with future yields. However, the future predictions cannot be made based on the early results. In the humid tropics of Kerala, the vine length of 6.55 m was recorded with *Artocarpus heterophyllus* (spaced at 3×3 m) at 15 years of the stand age (Kunhamu *et al.* 2012) [8]. Mustakim *et al.* 2022 [22] recorded varying vine length in different media (160.67 cm in biochar > 156.17 cm in vermicompost > 153.54 cm; cowdung and 147.08 cm; field soil) reflecting lower vine growth in field soil. Venkatesh *et al.* 2020[23], observed 4.32% change and 8.53% increase in the leaf number and vine length of black pepper over 30 days interval, respectively. Reyes *et al.* 2009 [24] observed collar diameter of black pepper at the rate of 1.50 cm with *Grevillea* and 1.17 cm with *Gliiricidia* after 6 years of establishment. The variations in lateral count supported the investigations carried out by Ayzenshtat *et al.* 2023 [25] who reported that cytokinin led to morphogenesis and gene-expression events for the adventitious shoot formation in pepper plants. The growth of lateral shoots and photosynthetic rate is higher during peak monsoon in India (June-July) (Mathai 1983) [26]. The field soil was observed to record higher branch/lateral number (1.25) than the growth under other growing media (biochar, vermicompost and cowdung) (Mustakim *et al.* 2022) [22]. In the present study, the increase of vine length, leaves and laterals over a period are in agreement with the Sourabha er al. 2022 [27] wherein, the increasing trends of growth of bush pepper were noticed over a period of 20 months after the application of soil and foliar nutrients.

Correlation between tree and black pepper growth attributes

In addition to the observed variations in pepper growth under tree management regimes, further effort was made to assess any possible correlation between the pepper growth variable and tree

management variables. The correlogram depicted (Fig. 6) that the growth of pepper plants was influenced by tree characters under all the spacing (3×3 m, 3×4 m and 3×5 m). The cross marks in the correlogram shows the non-significant correlation among the tree and black pepper growth attributes. Under closer spacing, the vine length of pepper showed significant and positive correlation with most of the tree growth attributes (tree height; r=0.77, crown height (r=0.61), crown length (r=0.79), crown spread (r=0.92), tree collar diameter (r=0.93), DBH (r=0.90), crown area (r=0.90), and number of branches (r=0.88). However, under 3×4 m spacing vine length exhibits moderate to strong correlations with branches (0.92), tree collar diameter (0.73), and crown height (0.73). In the spacing 3×5, particularly crown area (0.85) and crown spread (0.84), branches (0.87), and tree height (0.67) exhibited correlation with pepper growth, suggesting that vine length is positively influenced by the overall tree size and structure. It suggests that vine length tends to increase as the size and spread of the tree canopy grow.

However, the collar diameter showed a significant but weak positive correlation with crown spread (r=0.55), branches (r=0.61), crown area (r=0.56), and vine length (r=0.54) under closer spacing. While under 3×4 m and 3×5 m, pepper collar diameter showed generally non-significant and weak correlations with tree traits pepper attributes, indicating that it is relatively independent of major tree structure traits.

Under closer spacing, the number of pepper leaves also displays relatively weak correlations with other tree variables, having the highest with vine length (0.66). Similar trends were observed under 3×4 m and 3×5 m spacing, showing pepper leaves had the highest correlation with vine length (0.81 and 0.71) tree branches (0.72 and 0.76), and tree collar diameter (0.6 and 0.52) respectively. This suggests that the size of the tree, especially in terms of branches and canopy area, positively influences the number of pepper leaves along with vine length.

The effective correlation is supported with the results by Sivaraman *et al*. 1999 [5], wherein the growth of black pepper was found to be affected by growth parameters of trees like girth, nature of bark and height. The properties of trees are more important in earlier stages of development of the vines (Nesheim and Okalnd 2007) [28]. The closer spacing (2×2 m) was observed to induce high competition between living standard and black pepper (Kurien *et al*. 1994) [29]. Shade casted by the crowns of living standards regulates the light intensity. The vines if kept under shade, remain green and healthy whereas those exposed to sunlight turns yellow and develop necrotic patches during summer (Vijaykumar and Mammen 1990) [30]. Therefore, the present study gives an idea of optimum shade achieved through living standard (*Artocarpus heterophyllus*) under different spacing and its influence on the pepper growth during initial period of establishment.

Being the early phase of pepper growth, the variation in pepper vine length across planting spacing was not appreciable. However, the present early trends are indicative of possible triggering of competitive interactions among the trees which may be influencing the associated pepper growth. In general, trees managed at wider spacing inflict better resource availability and create non-competitive conditions that facilitate the growth of the associated intercrops. This trend is obvious in the case of black pepper also as represented by better vine length compared to closer spacing where the competitive interaction may have triggered early. However, the trends remained statistically non-significant during this period. Probably, the good soil physico-chemical attributes in the present location under study which enjoy warm humid tropical climate, the competitive interactions between the trees and the associated black pepper may manifest at later stages of the tree growth. The present trends are nevertheless, indicative of possible competitions in future.

Table 1: Details of Pepper plantation with jack trees

Pepper trials	Tree Age	No. of cuttings planted	No. of causality reported (after one week)	Survival Percentage	Trial results
First planting (August-2021)	1 year old	384	155	59.63%	Failure
Second planting (September-2021)	1 years 2 months	384	235	38.80%	Failure
Third planting (September-2022)	2 years 2 months	384	46	88.02%	Success

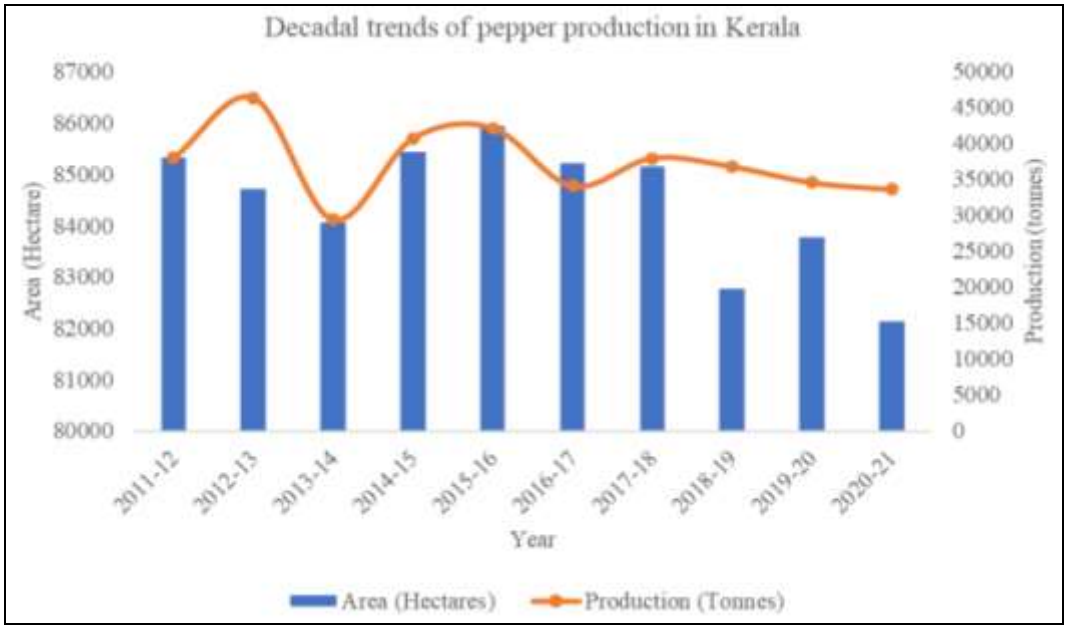

Fig 1: Trends of pepper production in Kerala from 2011-2021 (DES, GoK 2023)

Fig 2: Growth and establishment of black pepper under jack tree canopy

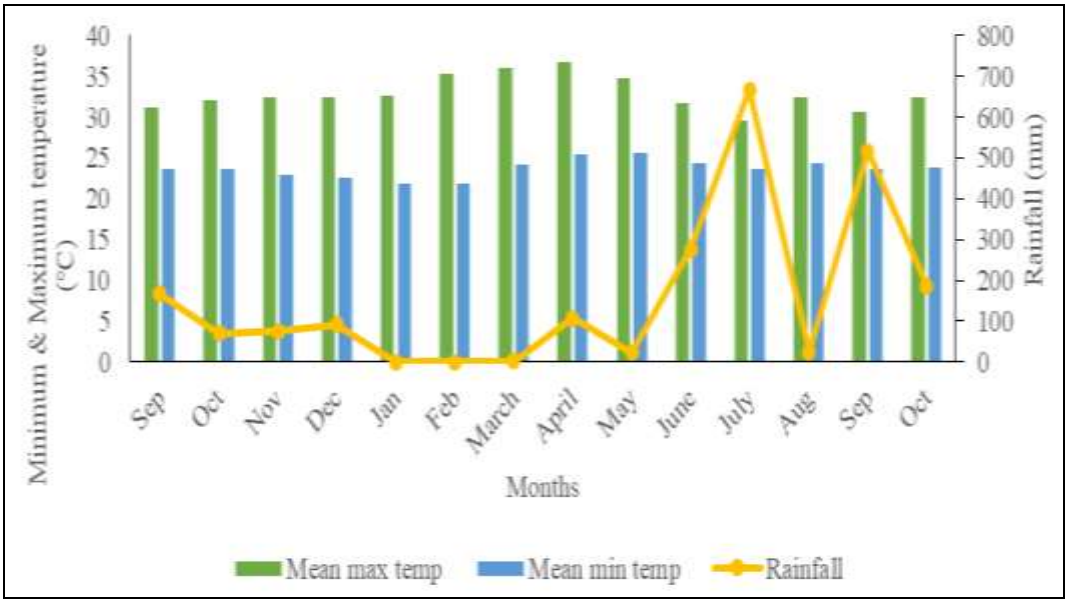

Fig 3: Meteorological data during the study period (Sep 2022-Oct 2023) of experimental site

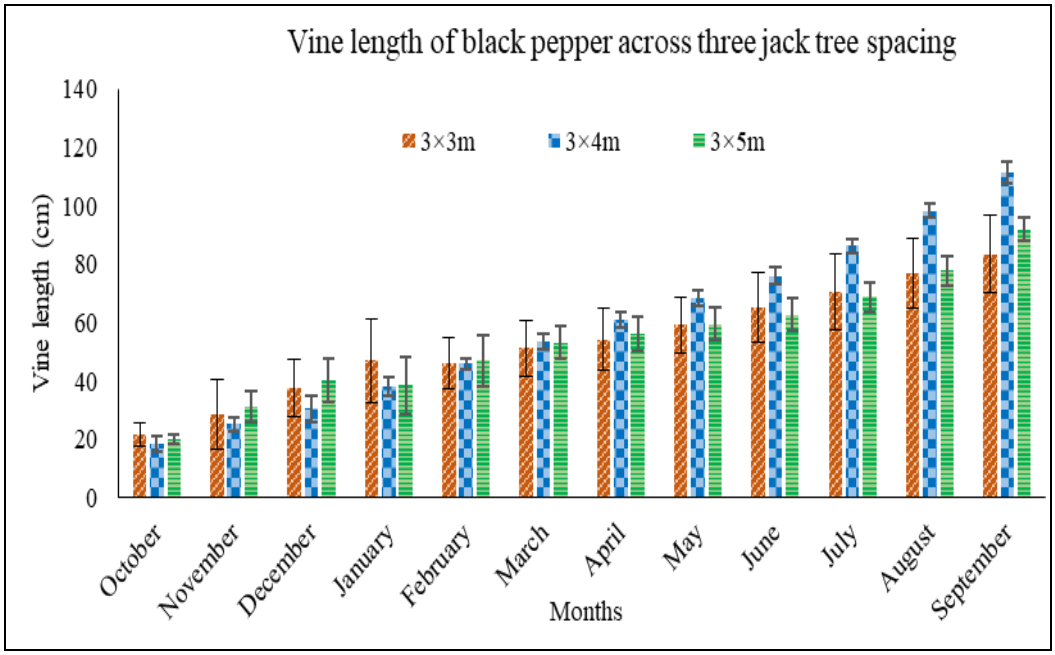

Fig 4: Vine length of black pepper grown under jack trees at three different spacing in Suhasini hills, Vellanikkara, Kerala

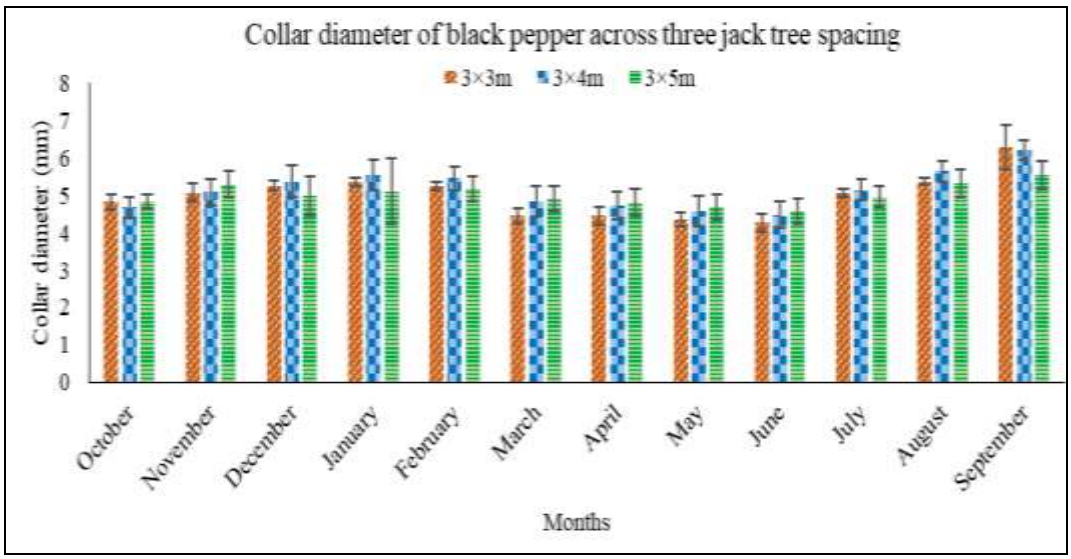

Fig 5: Collar diameter of black pepper grown under jack trees at three different spacing in Suhasini hills, Vellanikkara, Kerala

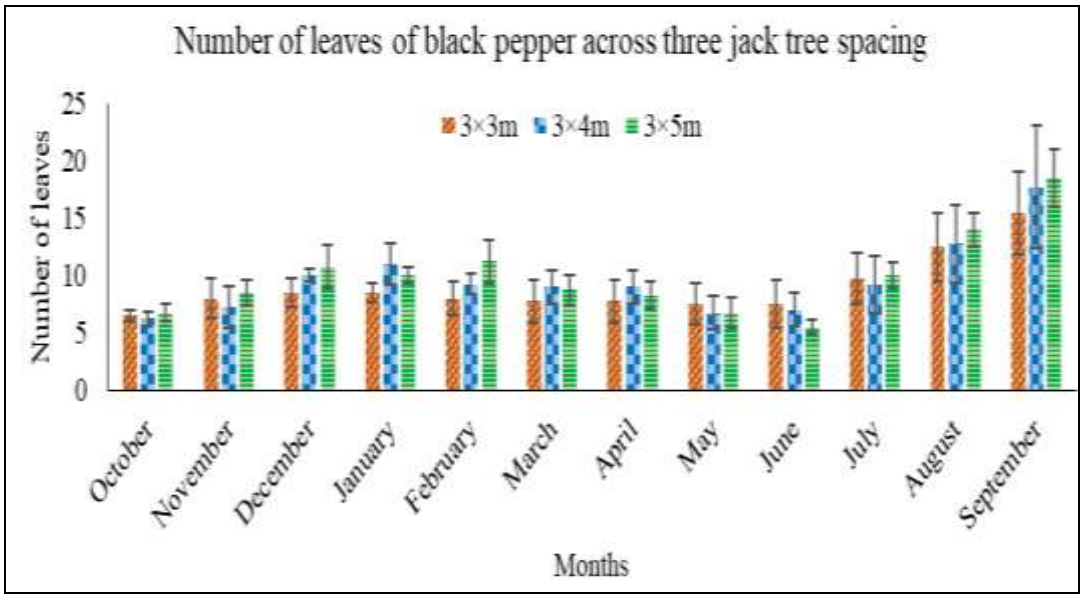

Fig 6: Leaf production of black pepper grown under jack trees at three different spacing in Suhasini hills, Vellanikkara, Kerala

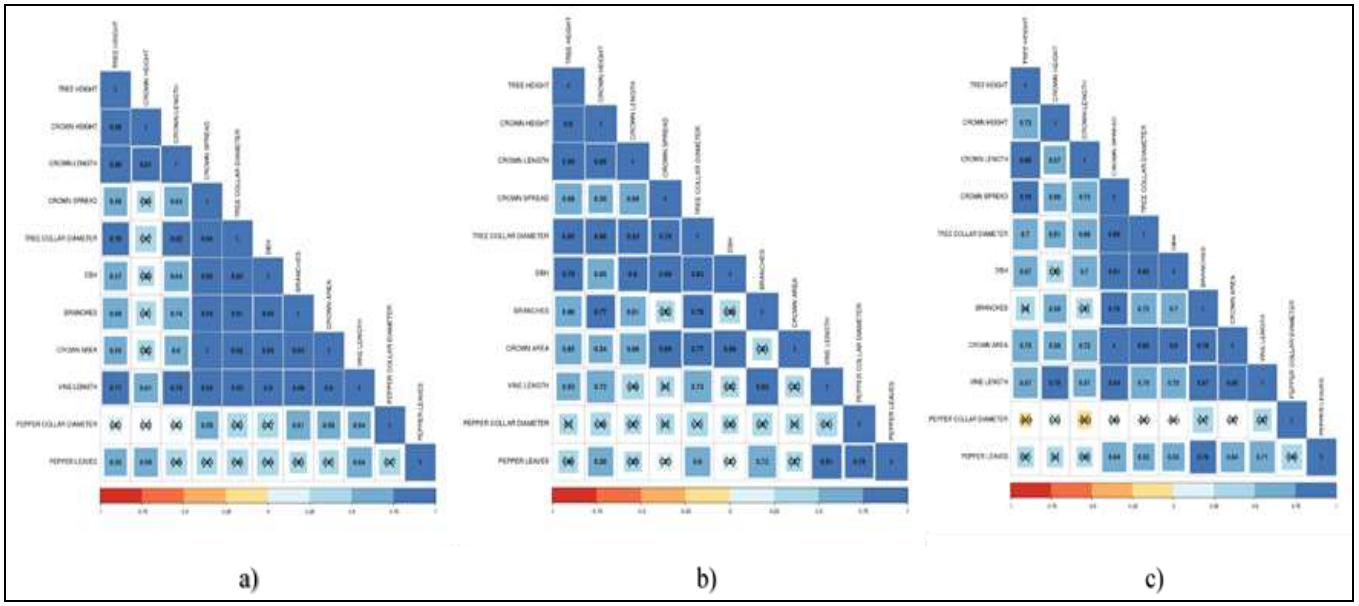

Fig 7: Correlation of pepper and jack growth attributes under 3×3 m (a), 3×4 m (b) and 3×5 m (c) spacing in Suhasini hills, Vellanikkara, Kerala

Conclusion

In the present study, the intercropped black pepper is in the early phase of growth (one year) and the systems may take more time for inflicting competitive interactions for resources in short supply. The plentiful availability of resources including understorey light, may have created a non-competitive growth ambiance for pepper growth which could be the reason for the marginal effect of tree spacing on pepper growth. Often, intercropping studies in crowded stands lead to gross decline in intercrop growth which has not observed in the early stages of the system growth in the present study. However, the overall better performance of black pepper under wider spacing (3×4 m) lead to the possible triggering of future competition for resources, especially understory light regimes contributed by variable spacing. Nevertheless, its too early to make conclusion on the development of jack-pepper system in the early growth phase. Also, there is need to emphasize the consideration to other factors such as environmental conditions and management practices, along with tree spacing.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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