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RESEARCH

Modified Canopy Architecture Enhanced Yield of Black Pepper (*Piper nigrum* L.) through High Absorption and Distribution of Photosynthetically Active Radiation (PAR)

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ABSTRACT

Black pepper (*Piper nigrum* L.), is a woody perennial climbing plant belonging to family *Piperaceae* and the most consumed spice in the world. Although the support tree Gliricidia (*Gliricidia sepium*) is pruned 3 to 4 times per year, pepper vines are not annually pruned in Sri Lanka. The characteristic cylindrical compact canopy of pepper is inefficient in intercepting solar radiation compared to most other vine crops. Therefore, this study was conducted to investigate the effect of different canopy pruning practices on the Photosynthetically Active Radiation (PAR) interception efficiency of the plant canopy and its effect on the yield. Four treatments on pruning practices were compared to each other. Treatments were, T1 – Control (no pruning); T2 - maintaining cone-shaped canopy by pruning only the plagiotropic branches; T3 - partial pruning of lateral branches of only the upper half (layer 1 and layer 2) of the canopy; and T4 - removal of 25% of lateral branches allowing uniform distribution of sunlight all over the canopy (loose canopy). The results revealed that T2 and T4 pruning methods significantly improved the yield (P<0.05) compared to T1 and T3. Hence, both modifying the cone-shaped canopy and maintaining a loose canopy all over the plant are better pruning practices to maximize yield through efficient PAR absorption. Therefore, adopting either of these pruning methods can be recommended as better practices for farmers to maximize their crop yield.

INTRODUCTION

Black pepper (*Piper nigrum* L.), which belongs to the *Piperaceae* family is a highly regarded spice crop, often referred to as the "King of the Spices". Black pepper has diverse applications, ranging from being a staple ingredient in various food products to offering pharmacological benefits (Li et al., 2010). Currently, it has sustained an upward trend in global pepper consumption and among the nations at the forefront of pepper exports are Vietnam, Brazil, Indonesia, Cambodia, Sri Lanka and India. In 2021, Sri Lanka ranked as the 5th most significant pepper exporter globally (IPC, 2021). Sri Lankan pepper stands out for its remarkable pungency, attributed to its elevated levels of piperine, the main active compound in black pepper. Consequently, Sri Lankan pepper commands a premium price in the international spice market. The spice crop sector holds significant importance in Sri Lanka's economy and among the various spice crops, pepper stands as the second most important contributor to foreign exchange earnings in Sri Lanka (EAC, 2022).

Currently, the cultivation of black pepper covers an expanse of 41,744 ha (IPC, 2021). Pepper cultivation in Sri Lanka is primarily confined to the wet and intermediate zones of the low and mid-country agro-ecological regions, with notable districts being Matale, Kandy, Kegalle, Badulla, Ratnapura, Monaragala, and Kurunegala.

The pepper vines exhibit two distinct types of branches during its development: orthotropic branches, which grow straight upward and possess short, thick internodes with adventitious roots for climbing support (Priyadarshani et al., 2012), and plagiotrophic branches, which grow horizontally and lack aerial roots but produce spikes as they extend from the terminal bud (Krishnamurthy et al., 2010). The inflorescence of black pepper appears as a spike-like catkin at the nodes opposing the leaves. Compared to the natural species, peppers that are grown for commercial purposes frequently contain a higher percentage of bisexual blooms. The prevailing weather during the growth season has a significant impact on the success of berry setting (Shango et al., 2021). Black pepper exhibits bimodal flowering patterns, occurring twice a year in conjunction with the south-west monsoon rains in May-June and the north-east monsoon rains in November-December in Sri Lanka. A dry period followed by rainfall is necessary for flowering and subsequent berry development, with the first flowering season coinciding with a dry spell in February and March, and the second flowering season during a dry period in August and September (Ariyatilaka et al., 2018).

The recommended spacing by the Department of Export Agriculture for monocrop pepper cultivations is 2.4m×2.4m. Even though the potential yield of pepper is over 2500 kg/ha, the current national average yield is around 550 kg/ha due to various factors including inadequate shade regulation practices, insufficient attention to soil moisture conservation, and negligence in fertilizer application. Among these, negligence of shade management practices and mutual shade in pepper canopy play a major role in decreasing the crop yield. Poor light penetration to lower canopy levels of the pepper plant because of the tightly packed cylindrical canopy shape and no annual pruning practices for pepper vines also contribute for the low productivity of pepper cultivations in Sri Lanka. *Gliricidia sepium* Jacq. Walp is the commonly used support tree for pepper cultivation in Sri Lanka, with pepper predominantly grown on live support systems.

Productivity of agricultural systems heavily depend on the interception of solar radiation. Moreover, improving the photosynthetic environment in the field through carbon dioxide (CO_2) and light enrichment can increase crop yields. The use of radiation for the generation of dry matter is primarily dependent on two variables: the percentage of incident Photosynthetically Active Radiation (PAR) that is intercepted and the effectiveness with which it is converted into dry matter (Mavi & Tupper, 2004). In C3 crops, mature and healthy crop leaves typically consist of multiple layers with the uppermost layer intercepting the majority of the midday light, while only about 10% reaches the next layer and 1% penetrates to the layer below (Long et al., 2006). To optimize light distribution within the canopy, it is advantageous to have more vertical uppermost leaves and horizontal lowermost leaves, enabling increased light transmission to lower layers (Long et al., 2006). However, it is worth noting that in certain pepper cultivars, the photosynthetic rate begins to decline when the illumination exceeds 900 μmol m^{-2} s^{-1} (Mathai, 1983).

Most of the perennial crop canopies are different in shape with varying light harvesting efficiency. Among them cone-shaped canopies are quite efficient in PAR interception. Marini (2001), reported that apple trees are trained and pruned to grow and maintain small, conical shaped (Christmas tree-shaped) trees that can produce abundant, high-quality fruit early on and is the most effective tree shape that allows sunlight penetration. However, pepper being a climbing vine has a cylindrical canopy shape, which is less efficient in harvesting radiation compared to other tree crops. Higher light exposure, accumulation of high dry matter in the fruiting branches before spike initiation, higher carbon fixation capacity, and higher photosynthate translocation from leaves to developing berries are important for higher productivity in black pepper (Krishnamurthy et al., 2010).

According to Subasinghe and Dharmaparakrama (2012), the interception of PAR in the pepper canopy varied from 95% to less than 5% in the first six weeks after pruning of *Gliricidia* live supports, whereas the opposite trend was observed in the *Gliricidia* support itself. Consequently, almost all yield attributes in the pepper canopy showed a decreasing trend as light penetration decreased from upper to lower canopy layers. The uppermost layer had a significantly higher number of spikes, but other yield attributes did not show significant differences. These findings indicate that most pepper yield attributes are directly influenced by the amount of PAR absorbed by the canopy (Subasinghe and Dharmaparakrama, 2012). In a study by Subasinghe and Welage (2015) on three different pepper varieties (Panniyur-1, GK-49, and MB-12) under varying shade levels, it was observed that reducing shade levels resulted in an increase in almost all yield attributes. The highest yields were recorded at 0% shade level, indicating that decreased shade positively affects pepper yield (Subasinghe and Welage, 2015).

Vine pruning is a common practice in pepper cultivation to promote leader shoot production, induce lateral shoot development, increase yield (Azmail and Yau, 1993), and remove unwanted terminal growth that encourages lateral shoot formation and spike production (Kurien and Nair, 1988). Three rounds of pruning in pepper vines are typically conducted to ensure an adequate number of climbing shoots and appropriate bushiness. Subasinghe and Dissanayake (2014) reported that pruning of *Gliricidia* live supports directly affects the allocation of dry matter into pepper spikes and fine roots. After pruning shade plants, the exposure of the pepper canopy activates various physiological activities, such as photosynthesis, transpiration, phloem translocation, and root absorption, thereby requiring an increased presence of fine roots for water and nutrient uptake. Kurien (1982) has observed significant differences in shoot production, the number of bearing shoots, and spike production as a result of removing hanging shoots.

Pepper vines have the potential to grow up to 10 meters or more in height, but under ideal conditions with restricted height, the mature vine typically exhibits a bushy columnar appearance, reaching approximately 4.0 meters in height and 1.5 meters in diameter (Krishnamurthy et al., 2010; Purseglove et al., 1981). This columnar canopy appearance is commonly observed in most pepper cultivations in Sri Lanka, with a ball-shaped bush on the upper part of the vine and fewer lateral shoots in the lower parts, resulting in lower yields. This is primarily caused by the lack of initial vine training and pruning practices, use of relatively short *Gliricidia* poles and a lack of proper pruning practices to maintain an ideal height for the support tree. In Sri Lanka, while *Gliricidia* supporting plant is pruned 3 to 4 times per year, only a few prunings are performed on pepper vines. When the pepper vine reaches 8-10 nodes, pruning is conducted at the 3rd node to encourage the growth of 3-4 vertical (orthotropic) shoots over the support and an adequate number of lateral (plagiotropic) branches. This pruning practice aims to shape the vine into a cylindrical canopy with a greater number of plagiotropic branches when fully mature. Ground runners are produced from the base of the main stem as well as from a fully-grown vine, and some of the top plagiotropic branches give rise to hanging shoots. Both ground runners and hanging branches are pruned at the second step in pepper cultivations. Currently, these two stages of pruning are commonly practiced in pepper cultivation. Removing these parasitic branches, which do not contribute to net dry matter production, allows for better partitioning of dry matter into fruiting branches.

Spike initiation in pepper plants is closely linked to the interception of solar radiation, particularly the amount of PAR intercepted (Bai et al., 2016). However, the efficiency of light-harvesting in a pepper canopy with a cylindrical shape is relatively low. Some research suggested that maintaining a cone-shaped canopy (Duursma et al., 2012) or a looser canopy structure (Skillman et al., 2011) with fewer lateral branches could enhance light interception and penetration compared to a compact cylindrical canopy. Despite the importance of canopy structure on light interception, the effects of pruning lateral (plagiotropic) branches on canopy light interception, as well as the growth attributes of pepper vines are not adequately explored. Therefore, this study aims to investigate the impact of different canopy pruning practices on the PAR interception efficiency of the pepper plant canopy and its impact on variation of crop yield.

METHODOLOGY

Location

Uniformly grown healthy black pepper vines (MB12 variety, eight years old) with a cylindrical canopy, cultivated at the Central Research Station, Department of Export Agriculture, in Matale district, were used in the experiment. The location belongs to the mid-country intermediate zone (IM3) of Sri Lanka with an annual rainfall of 1600 mm - 2000 mm and daily mean temperature of 25 °C–30 °C. The selected plots were marked, and canopies of the shade trees were removed before applying the treatments and were continued at six weeks intervals. The canopy height of 3.6 m was maintained throughout the study period.

Experimental design of treatment application

Four pruning methods were applied to the pepper plants in early- April, 2022 with the onset of *Yala* season rains: T1 Control (no pruning), T2 Maintaining cone shape canopy by pruning only the plagiotropic branches, T3 Partial pruning of lateral branches of only the upper half of the canopy (layer 1 and 2), and T4 - Removal of 25% of lateral branches allowing uniform distribution of lateral branches on the whole canopy. Experimental design was a Randomized Complete Block Design (RCBD) with four replicates, with the slope of the land as the blocking factor. Each plot contained four pepper vines.

Measurements

Photosynthetically Active Radiation (PAR)

The PAR (μmol m^{-2} S^{-1}) measurements were taken between 10.00 a.m. to 2.00 p.m. on sunny days using a Line Quantum Sensor (Model LI-COR, LAQ-2469). Data collection was started soon after the application of different pruning methods. Thereafter, data were collected at one-month intervals from April 2022 to October 2022. When taking PAR measurements, the pepper vine was roughly divided horizontally into four equal sections where L1 is the uppermost layer and accordingly, L4 is the bottom layer (Figure 1). One section was approximately 0.9 m in height. The incident PAR and Transmitted PAR were measured at each level using Line Quantum Sensor (Model LI-COR, LAQ-2469). Reflected PAR from each level was also measured by inverted Line Quantum sensor above the level of canopy. Three light measurements (Incident PAR, Transmitted PAR, Reflected PAR) were taken for each layer of the canopy to calculate the absorbed PAR percentage at each canopy level. Measurements were taken at four canopy levels on selected two pepper vines in each plot (there were four pepper vines in each plot). There were four replicates for each treatment. Altogether 32 pepper vines were considered for data collection, which contained 8 pepper vines from one treatment. These selected plants were used to take all other data continuously throughout the research.

Yield data

Number of days taken to spike initiation

After the application of treatments, time taken for new spike initiation was measured in each layer in all the treatments.

The number of days taken to spike initiation after the treatment was observed by calculating the number of days taken to just exceed a constant number of spikes in each treatment. Here, half the number of total spikes initiated in the control treatment (T1) was considered as the constant spikes count, which was 214 number of spikes.

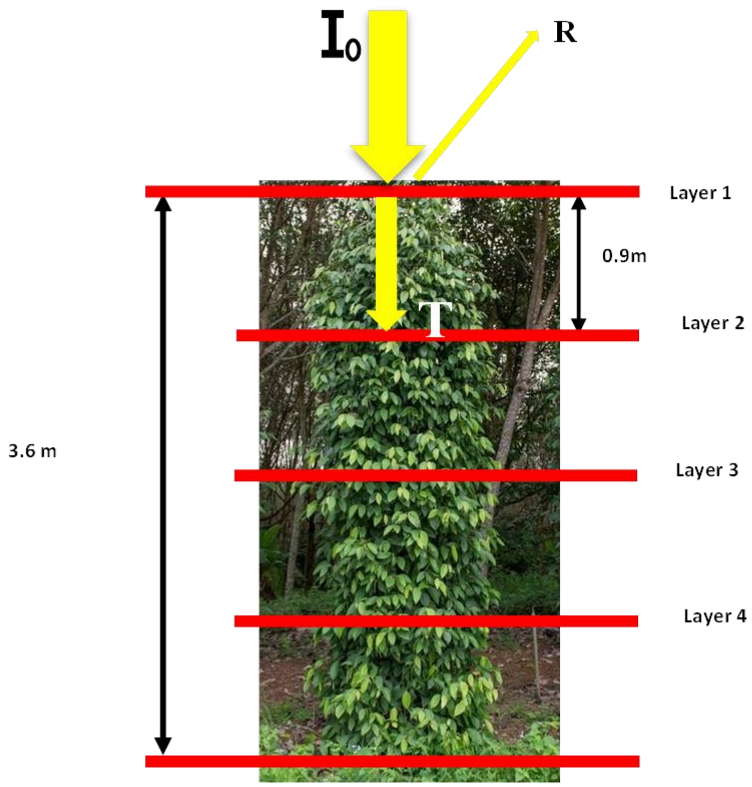

Figure 1. Illustration of separation of pepper canopy layers for data recording.

Percentage of Absorbed PAR by each canopy level was calculated using Equation 1 (Subasinghe and Dharmaparakrama, 2012).

$$Absorbed\ PAR\ \% = \frac{Incident\ PAR(Io) - \{Transmitted\ PAR(T) + Reflected\ PAR(R)\}}{Incident\ PAR(Io)} \text{x}100 \quad \text{.... Equation 1}$$

Number of spike initiation

After the initiation of shoots, number of new spikes in each layer of the selected peppervines under different pruning methods was counted. Thereafter, data were collected at two-week interval until the termination of spike initiation for the season. At the end of the study the number of spike initiations was recorded as the first yield parameter in each layer of the selected plants under different pruning methods. Two plants (selected for light data gathering) from each plot were considered for data gathering i.e., 8 plants from each treatment (4 replicates). Altogether 32 plants were considered for data collection.

Statistical analysis

Statistical analysis was conducted using Analysis of Variance (one-way and two-way ANOVA as per the contextual requirements) ($P < 0.05$) with Spearman's rank correlation using the Statistical Analysis System (SAS) 9.0 statistical software.

RESULTS AND DISCUSSION

PAR distribution within the pepper canopy

The PAR distribution between the four canopy layers in each treatment was statistically compared (Table 1). There was a significant difference in PAR distribution in the cone-shaped canopy in L2, L3 and L4 layers. The control treatment significantly absorbed the highest percentage of PAR in the L1 uppermost layer.

There was a significant difference between the treatments in PAR absorption in L1 ($P<0.05$). In L1, the no-pruning control (T1) significantly absorbed the highest PAR% compared to the other treatments while the lowest PAR absorption was observed in T2 (pruned to a cone shape). However, PAR absorption percentage between T3 (pruned two uppermost layers only) and T4 (25% lateral branches removed all over the canopy) was not significantly different (Table 1).

The PAR absorption percentage within L2 also showed a significant difference between the treatments ($P<0.05$). The treatment T2 (cone-shaped canopy) significantly absorbed the highest percentage of PAR compared to other treatments at L2. This might be due to more light penetration to the L2 because of the low absorption at L1 for T2. At L2, T1 significantly absorbed the lowest PAR% compared to other treatments. No significant difference was observed between T2 and T3. Further, PAR absorption between T3 and T4 was also not significantly different at L2 (Table 1).

At both L3 and L4 there was a significant difference between the treatments ($P<0.05$) and T2 (cone-shaped canopy) absorbed the highest PAR% compared to other treatments. There were no significant differences of PAR% absorption among the remaining three treatments at L3 and L4 (Table 1). When considering the results given above for PAR absorption in different layers, it is clear that PAR distribution within the whole canopy performed well in the cone-shaped canopy (T2). According to the results on PAR, it is evident that the uppermost layer (L1) absorbed the highest percentage of PAR (Figure 2). Then it decreased drastically to L2 and then gradually up to the lowest layer (L4). But PAR penetration behaviour from the upper layer to the lower layers in T2 is remarkably different compared to the other treatments.

Treatment 1 (control) significantly absorbed the highest PAR in layer 1 while the T2 treatment (cone-shaped canopy) absorbed the lowest, which is the uppermost part of the canopy. Considering the next three layers (L2, L3, L4), the cone-shaped canopy significantly absorbed the highest amount of PAR than the other three treatments. However, PAR absorption by the T4 treatment (25 % lateral branches pruned all over the canopy) and T3 treatment (two uppermost layers pruned) were between T1 and T2. Results indicate that once a greater part of PAR is absorbed by the uppermost canopy, the PAR passed to the lower canopy decreases resulting in lower PAR absorption percentage in lower canopy layers. Accordingly, cone-shaped canopy (T2)

Table 1. Variation of PAR absorption percentage in four layers (L1 to L4) as affected by different canopy pruning methods (T1 to T4).

Treatment	% PAR Absorption			
	L1	L2	L3	L4
T1	92.4[a]	1.4[c]	0.3[b]	0.2[b]
T2	72.4[c]	9.1[a]	5.0[a]	2.2[a]
T3	84.6[b]	5.9[ab]	0.9[b]	0.5[b]
T4	85.0[b]	5.4[b]	2.1[b]	0.9[b]

Within a given column, the means followed by the same letter are not significantly different at P=0.05.

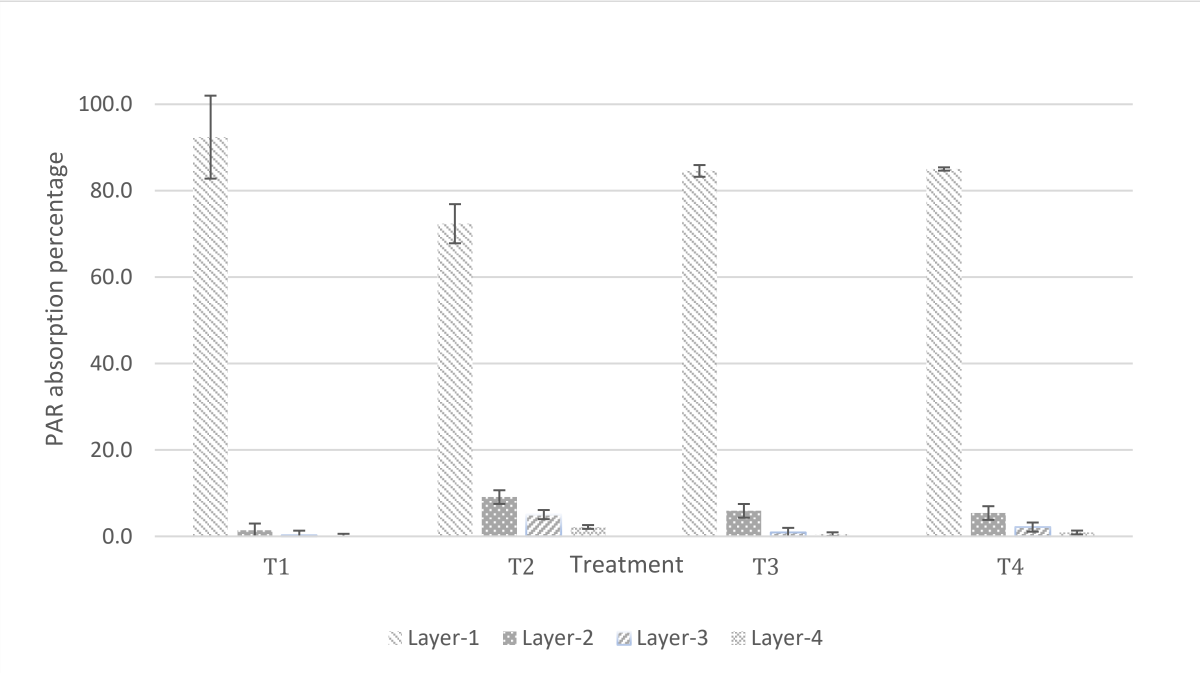

Figure 2. Variation of % PAR absorption within four canopy layers in different treatments.

resulted in higher incidence of PAR at lower canopy.

According to Long et al. (2006), to optimize light distribution within the canopy, it is advantageous to have more vertical uppermost leaves and horizontal lowermost leaves, enabling increased light transmission to lower layers. Pruning and training techniques are specialised horticultural practices that were developed not only to control plant growth in some situations, but also to modify the plant canopy to increase light absorption. Hence, pruning and training practices need to be carefully chosen based on the type of buds (vegetative or reproductive), abundance, and method of distribution within the tree crown, to ensure maximum light penetration through the canopy and provide plants with the highest growth and productivity (Matloobi, 2012).

Variation in spike initiation between the different canopy layers

In all four layers (L1-L4), spike initiation was significantly different (P<0.05) between the treatments (Table 2). At all four layers, the treatments T2 and T4 produced the significantly highest spike initiations while treatments T1 produced the lowest average number of spikes. Except at L2, in all other layers, T1 and T3 resulted in statistically similar number of spike initiations (P>0.05) (Table 2).

In overall considering the entire canopy, there was a significant difference in spike

Table 2. Variation of spikes initiation in four layers (L1 to L4) as affected by different canopy pruning methods (T1 to T4).

Treatment	Mean No. of spike initiations			
	L1	L2	L3	L4
T1	31[b]	19[c]	08[b]	04[b]
T2	64[a]	55[a]	51[a]	32[a]
T3	34[b]	32[b]	19[b]	13[b]
T4	55[a]	56[a]	45[a]	25[a]

Within a column, the means followed by the same letter are not significantly different at P=0.05

initiation ($P<0.05$). The highest number of spikes were initiated in T2, followed by T4 (Table 3). There was no significant difference between number of spikes under T2 and T4, and these two treatments performed significantly better than the remaining two treatments (T1 and T3). Compared to other treatments the control (T1) produced the significantly least number of spikes (Table 3).

According to the above results it is clear that T2 (cone-shape canopy) and T4 treatments significantly initiated the highest number of spikes in all four layers (L1, L2, L3, and L4), while the T1 (control) treatment initiated the least number of spikes in all four layers. Thus, according to the total number of spikes initiated in the whole canopy, the cone-shaped canopy produced the highest mean number of spikes and the control the least. The loose canopy (25% lateral branches removed all over the canopy) produced the second-highest mean number of spikes. Therefore, the trend in mean number of spike initiations is similar to the observation on trend in PAR absorption. These results agree with Sarlikioti et al. (2011), who showed that leaf angle and vertical leaf distribution are highly relevant for the daily amount of photosynthesis and an increase in light penetration to lower canopy layers resulting in an increase in photosynthesis.

Further, it is evident that spike initiation in T1 (cylindrical shaped-no pruning) was significantly lower than the other three treatments, which is similar to the conclusion given by Bai et al., (2016) that a closed and serried canopy would contribute to intercepting more solar radiation, but not necessarily beneficial for the improvement of RUE (Radiation Use Efficiency). Therefore, our results show that canopy pruning in pepper has a positive impact on efficient PAR absorption and spike initiation. Louarn et al., (2008) stated that the amount of PAR intercepted by the canopy and the effectiveness of converting the captured radiation into biomass, (i.e., RUE), is responsible for the production of crop biomass. Related research studies have indicated that the first attribute of PAR interception is primarily controlled by the green leaf area, its exposure time, and the canopy structure; RUE is primarily controlled by the plant's net photosynthetic capacity, as well as to some extent by canopy structure (Vargas et al.,2002).

Table 3. Variation of spikes initiations in each treatment when considering the whole canopy.

Treatment	Mean No. of spikes
T1	61[c]
T2	201[a]
T3	98[b]
T4	181[a]

Within a column, the means followed by the same letter are not significantly different at P=0.05

Number of days taken for spike initiation after canopy pruning

The cone-shaped canopy (T2) treatment took the least number of days for initiation of spikes while the highest number of days was taken by the control (T1) (Figure 3). Even though, there was no significant difference (P>0.05) between T2 and T4, these treatments were significantly different (P<0.05) to the other two treatments. These results show that canopy pruning has a significant effect on spike initiation. This is in agreement with Marini (2001), where for apple trees to come in to production, it is necessary to encourage a transition from vegetative to reproductive growth since continued excessive vegetative growth may delay fruiting and pruning increases earlyfruiting. Kaveriamma et al., (2018) also showed comparable results in *Phalaenopsis* orchid where the number of days taken for emergence of new flower spikes were significantly minimum in pruned plants compared to non-pruned (control) plants. Kaveriamma et al., (2018) explained that physiological stress caused by the pruning process might induced the blooms by directing energy toward the desired region.

Relationship between the PAR absorption % and spike initiation of different canopy layers of pepper

The correlation was statistically significant (P<0.05) and negative (r=-0.633) between the number of spikes initiated in layer 1 and the percentage of PAR absorbed in layer 1(uppermost layer) (Figure 4.a).

Among the four treatments, the PAR absorption by layer 1 of treatment T1 (control) was the highest (no pruning, cylindrical shape, compact canopy), and the T2 treatment (cone-shaped) absorbed the least (Table 1). But in relation to spike initiation, the opposite was observed in layer 1, which produced the highest number of spikes in T2 and the least in T1. The L-1, the uppermost layer of T1 treatment, was tightly compact with a higher number of lateral branches, intercepting the maximum incident radiation and allowed less PAR to penetrate in to the lower canopy levels. Even though more PAR was intercepted by L-1 layer, the distribution of light among leaves and branches was limited due to the compact canopy structure. Leaves and branches were shaded by each other arresting the light distribution throughout the canopy reducing the efficiency of absorption. According to Long et al., (2006), with the sun overhead, the photosynthetic photon flux densities (PPFD) intercepted per unit leaf area by an almost horizontal leaf at the top of a plant canopy would be 1400 μmol m^{-2} s^{-1} or more, about three times the amount required to saturate photosynthesis; as a result, at least two-thirds of the energy intercepted by the upper leaves is not assimilated. In this study, the T1 control plants produced a more cylindrical compact canopy architecture with horizontal leaves. Even though, L-1, the uppermost layer of T1 intercepted more PAR, it was insufficient to initiate the growth of spikes. Nonetheless, the L-1 layer of treatment T2 absorbed less PAR and its distribution throughout the canopy was much efficient and may have facilitated photosynthesis better due to its cone shape and loose canopy structure. This could be the reason for more spikes production in L1 in T2. Therefore, Figure 4.a shows the negative correlation between the number of spikes initiated and PAR absorption in L-1 layer.

The correlation was statistically significant (P<0.05) and positive between the mean number of spikes initiated and the percentage of PAR absorbed for L2, L3, and L4 layers (Figure 4.b, 4.c, 4.d).

In L2, L3, and L4 layers, the percentage of PAR absorbed varied from 0 to 9%, which is insufficient to saturate leaf photosynthesis. Therefore, with increasing PAR absorbed, the number of spikes initiated also increased in all the lower layers. The strongest correlation (r=0.7766) was observed in the lowest layer of the canopy(L4).

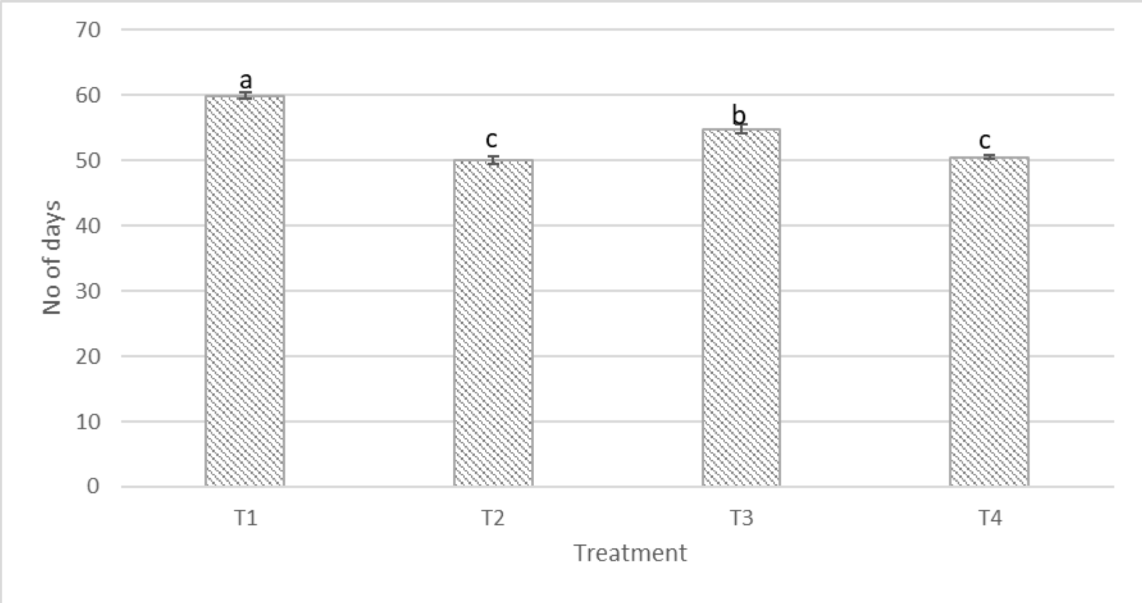

Figure 3. Mean number of days taken for spike initiation after vine pruning (error bars indicate the standard errors).

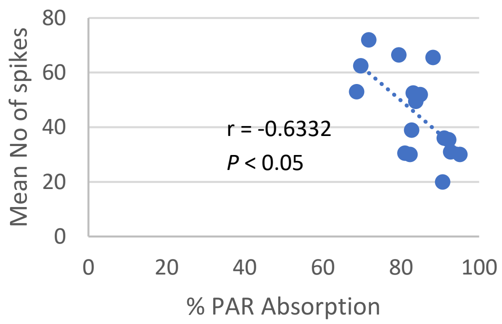

Figure 4.a. Relationship between Mean number of initiated spikes in Layer 1 and absorbed PAR% in layer 1.

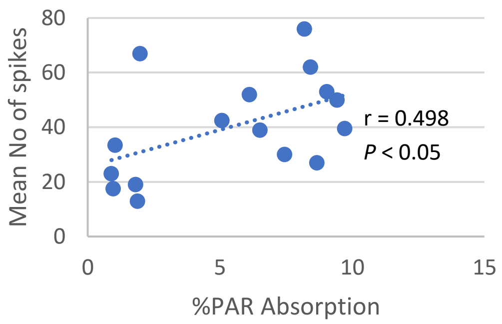

Figure 4.b. Relationship between Mean number of initiated spikes in Layer 2 and absorbed PAR% in layer 2.

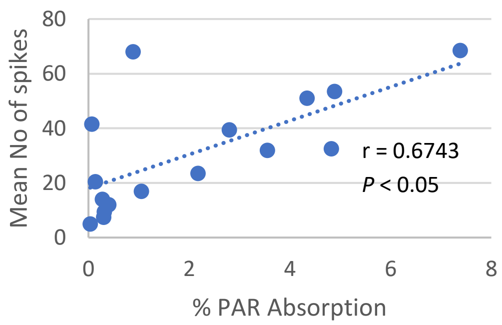

Figure 4.c. Relationship between Mean number of initiated spikes in Layer 3 and absorbed PAR% in layer 3.

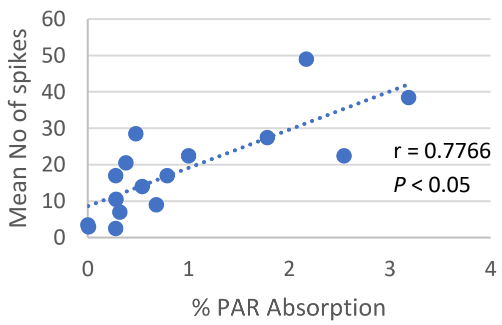

Figure 4.d. Relationship between Mean number of initiated spikes in Layer 4 and absorbed PAR% in layer 4.

CONCLUSION

Modification of the canopy architecture through different pruning methods significantly affected the percentage of PAR absorption and spike initiation in the black pepper canopy. The cone-shaped canopy allowed more PAR absorption and more light penetration into the lower canopy layers followed by 25% removal of lateral branches. Lowest PAR penetration within the canopy was observed in the control treatment. Efficient PAR absorption and penetration induces more spike initiation. Thus, the cone-shaped canopy and loose canopy facilitates more PAR absorption and penetration, which leads to more spike initiation. Further, pruning affects the days taken to spike initiation after pruning with comparatively fewer number of days for the cone-shaped canopy followed by removal of 25% lateral branch canopies. Therefore, pruning of lateral branches into a cone shape and removing 25% of them uniformly all over the canopy can be recommended for pepper growers to maximize their crop yield as most appropriate canopy pruning methods.

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