Morpho-anatomical adaptation of lesser yam (*Dioscorea esculenta*) on different planting pattern and relative light intensity in Java community forest

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Abstract. Lesser yam (*Dioscorea esculenta*) is traditionally cultivated as a valuable crop species in a various planting pattern of teak-based agroforestry (AF) system in Watubonang village, Sukoharjo District, Central Java. Different planting pattern contributes to various light intensity which is associated with plant morphological and anatomical changes and directly affect to yam tuber production. Research site was selected by mean of purposive sampling method with three yam planting patterns, i.e. yam monoculture (Y), yam in trees along border (TAB) and yam in full teak trees (T-Y), in three replicates of 20 m x 20 m plots. In each plot, four subplots were established to investigate relative light intensity and take leaf samples. Changes in morphological and anatomical characteristics of yam to different planting pattern and relative light intensity (RLI) were studied, including leaf size, leaf color, tendril and internode length, chlorophyll content and stomatal density. The result showed that RLI were significantly different among planting pattern (Y: 78.66%, TAB: 66.94%, T-Y: 34.05%). Planting pattern and interaction between planting pattern and RLI significantly affected yam morphological and anatomical characteristics (of leaf size, tendril & internode length, and stomatal density) at P < 0.05. Leaf size, tendril and internode length increased with decreasing of RLI in TAB, but opposite adaptation was found in T-Y planting pattern. Higher RLI resulted in reductions of chlorophyll and chlorophyll b content, and therefore increased of chlorophyll a:b ratio. Leaf color of yam grown under high RLI (Y) were light green, while those grown under shaded condition with relatively low light intensity (TAB, T-Y) were dark green that may related to the foliar chlorophyll content. Hence, a trend of decreasing stomatal density was found associated with lower RLI (Y: 35 stomatal/mm², TAB: 25 stomatal/mm², T-Y: 19 stomatal/mm²). Approximately 50-60% of RLI is suggested to be an optimum intensity for yam cultivation to support yam tuber production. Agroforestry practice by applying pruning and managing planting density are needed to reach the optimum light.

1. Introduction

Integration of trees and agricultural crops in agroforestry is the most appropriate land use system and practice developed by smallholder farmers in the rural areas. Agroforestry provide not only a number of environmental services (e.g. enhance soil fertility, improve water and air quality, increase carbon storage) but also responsible for other fundamental needs for human supporting food security (e.g. leafy vegetable, cereals, fruits, staple crops) [1-3]. Agroforestry in Java has long been practiced in the simple
Agroforestry systems represent associations of small number of components which often concern to the “agro/crops” commodity, while tree has received much less paid attention. However, recently agroforestry system was transformed into diverse models (e.g. home gardens, fruit tree system, timber tree system, mixed fruit-timber system and understory system) [4] affected by socio-economic and biophysical factors. Many agroforestry systems are then addressed by the tree species, for example teak, mahogany and acacia-based system in Central Java [5] due to its highly valued, less labor & technical management and seen as being less susceptible to the yield failure than crops. As a consequence, agroforestry system dominated by tree species decrease the staple food production. To overcome this problem, agroforestry farmers should therefore introduced crop commodities which can adapt well to the less light intensity. This idea is implemented in catching agroforestry’s goal in economical aspect to ensure and repair not only timber product but also the food needs (improving the availability of food, diversification of food needs, and the sustainability of food [6].

Yam (*Dioscorea esculenta*) can adapt to a wide range of light intensities both in unshaded and under shaded conditions [7,8]. It has been traditionally cultivated in a various planting pattern under teak-based AF system in Watubonang village, Sukoharjo, Central Java to fulfill farmer’s basic needs of foods and also improved their income through its promising economic value than other crops. Lesser yam has been known and utilized as source of carbohydrate as substitute or an alternative food of rice, especially at dry season [9,10]. Yams are generally consumed by local farmers in very simple way, mostly from fresh tuber, then steaming, boiling, roasting, baking, or frying and just mixing with coconut flesh and adding brown sugar to get much tasty [10,11]. In addition, yam can be ground into flour. High inulin content in yam tubers is a good prebiotic component which is beneficial for the digestion process and mostly used as ingredient of dietary fiber and low-fat products. Thus, inulin content providing an added value for lesser yam [12-14].

Different planting pattern in the AF systems resulted tree’s height, crown projection and an overlapping trees canopy. It contributes to the various light intensity received by crops commodity which is associated with plant morphological and anatomical changes directly affect to the yam growth and tuber production [15,16]. Therefore, it is an urgent need to determine the optimum light intensity to ensure sustainable yam growth and tuber production. This research focuses on the effects of planting pattern and relative light intensity (RLI) in the different AF system, on various morphological (leaf size and color, tendrils and internode length) and anatomical (chlorophyll content and stomatal density) characteristics of *D. esculenta*.

2. Materials and methods

2.1. Study site

This research was carried out in a community forest located at Watubonang Village, Tawangsari Sub District, Sukoharjo District of Central Java Province. The study was conducted during two months (March-April, 2014). Sukoharjo farmers cultivated yam at three different planting pattern (i.e. yam monoculture (Y), yam in teak trees along border (TAB) and yam in full teak trees (T-Y)) as shown in figure 1. Research site was selected by mean of purposive sampling method, in three replicates of 20 m x 20 m plots. Therefore, totally there were 9 plots. In each plot, we developed 4 subplots to measure light intensity and collect the morpho-anatomical data.
2.2. **Data collection**

Light intensity was measured in each plot using digital lux meter. This measurement was also conducted in the area exposed to full sunlight (unshaded area) as well as for the comparison to calculate the relative light intensity (RLI). All measurements were taken at midday sun (11.30 am-00.30 pm).

Morphological characteristics (of leaf size, tendril length, internode length) and anatomical characteristics (of chlorophyll a, chlorophyll b, chlorophyll a:b ratio, stomatal density) were measured in order to determine their adaptation under the different light condition. Leaf samples were taken from the three youngest fully expanded and healthy leaves in the upper, middle and bottom part of the independent yam plants at each subplot. During the sample collection, leaves were kept in the cool box to keep the sample fresh. In this study, leaf was scanned into a digital format, then measured the leaf size using Irfanview software. Leaf color was observed using Munsell color chart for plant tissues. Tendril and internode length were measured simply using a ruler. Chlorophyll content was observed using spectrophotometric method. Chlorophyll a and b in each sample were extracted from 0.1 g ground fresh leaf mixed with 10 ml of 80% acetone and was measure at 663 and 645 nm [17]. For the stomatal density measurement, replica impressions were made by coating clear nail polish and adhesive cellophane tape on the middle of epidermis surface of the leaves. The impressions were then detached from leaves and placed on a glass slide to observe the stomatal density microscopically [18].

2.3. **Statistical analysis**

Significant differences among means were determined by analysis of covariance (ANCOVA) with Tukey’s post hoc test at P < 0.05 using SPSS 16.0. In this statistical analysis, planting patterns were independent variable, RLI were covariate and morphological and anatomical characteristics were dependent variables. In addition, Microsoft Excel program was used for the graphical presentation of data using mean ± SE (Standard Error).

3. **Results**

3.1. **Relative light intensity under different yam’s planting pattern**

Relative light intensity at the three different planting patterns were significantly different (figure 2). The highest relative light intensity was achieved by yam monoculture (78.66%). Relative light intensity in the trees along border planting pattern was 66.94%, while teak-yam planting pattern exposed the lowest relative light (34.05%). Generally, relative light intensity in the planting pattern with less teak trees (yam monoculture) was greater than that on more teak trees planted by farmers (Trees Along Border, Teak-Yam).
Figure 2. Relative light intensity in the different yam planting pattern in Sukoharjo community forest. Data are means ± SE of three replication. Different letters in each planting pattern indicate significant difference determined by Tukey post hoc test at P < 0.05.

3.2. Effects of planting pattern and relative light intensity on yam’s morpho-anatomical adaptation

Planting pattern and relative light intensity influenced yam’s morpho-anatomical characteristics (figure 3). According to the covariance analysis, it showed that relative light intensity did not affects any morpho-anatomical characteristics independently. However, planting pattern and interaction of planting pattern and relative light intensity showed significant effect on leaf size, tendril length, internode length and stomatal density (table 1).

Table 1. The result of covariance analysis on effect of planting pattern and relative light intensity on the D.esculenta morphological and anatomical characteristics (leaf size, tendril length, internode length, chlorophyll a, chlorophyll b, chlorophyll a:b ratio and stomatal density)

| Source of Variance     | Significant value |      |      |      |      |      |      |
|------------------------|-------------------|------|------|------|------|------|------|
|                        | Leaf size         | Tendril length | Internode length | Chlorophyll a | Chlorophyll b | Chlorophyll a/b ratio | Stomatal density |
| Planting pattern (P)   | 0.000*            | 0.000*         | 0.006*           | 0.681ns       | 0.657ns       | 0.612ns                  | 0.238ns          |
| Relative light intensity (RLI) | 0.863ns         | 0.575ns        | 0.874ns          | 0.462ns       | 0.498ns       | 0.702ns                  | 0.435ns          |
| P x RLI                | 0.000*            | 0.000*         | 0.008*           | 0.665ns       | 0.490ns       | 0.405ns                  | 0.020*           |

* Significance at P < 0.05
ns Not significance
**Figure 3.** Effects of planting pattern and relative light intensity on the yam’s morphological and anatomical characteristics (leaf size, tendril length, internode length, chlorophyll a, chlorophyll b, chlorophyll a/b ratio and stomatal density). Data were presented as mean, while vertical bars represent SE.

**Figure 4.** Leaf size and chlorophyll content adaptation of *D. esculenta* under different planting pattern and relative light intensity. Optimum RLI to support the optimal growth of *D. esculenta* is showed in range 50-60%.

**Figure 5.** Leaf color of *D. esculenta* under different planting pattern and relative light intensity. A. Yam monoculture (Y), B. yam in Trees along Border (TAB), C. yam in Teak-Yam (T-Y)
The smallest leaf size was showed by yam planted in monoculture planting pattern with the highest RLI. Leaf size was increased sharply at lower RLI with medium RLI, then it was decline in the most shaded conditions with the lowest RLI (figure 3 and figure 4). Yam tendrils and internode length were different between planting pattern and relative light intensity. In the yam monoculture planting pattern, yam’s tendril and internode showed the shortest length. Tendril and internode length increased significantly in the TAB planting pattern, then decreased in T-Y planting pattern which exposed the lowest RLI (Figure 3). Chlorophyll content was affected by different planting pattern and relative light intensity, although they did not showed significantly difference. The highest RLI resulted in reductions of chlorophyll a and chlorophyll b and in contrast, an increase of chlorophyll a:b ratio (figure 3 and figure 4). The highest stomatal density was found in the yam monoculture planting pattern (35 stomatal/mm$^2$) that were exposed by the highest RLI. This study showed a trend that the number of stomatal decreased at lower RLI (TAB 25 stomatal/mm$^2$, T-Y 19 stomatal/mm$^2$) (figure 3). Leaf color of yams grown under shaded condition (TAB and T-Y) were dark green, while those grown under unshaded conditions (Y) were light green (Figure 5).

4. Discussion

Light availability varies depends on the complexity of community structure in the AF systems. Tree age, size, density and canopy structure would changes in the efficiency of light interception through shading mechanism. This study showed clearly that relative light intensity captured by yam in TAB and T-Y planting pattern were lower than that in yam monoculture. It is caused by the number of tree (teak) planted by Sukoharjo’s agroforestry farmers in T-Y planting pattern were greater than in TAB, while in the yam monoculture, yams were cultivated without any association with tree (figure 1). The presence of teak tree canopy in T-Y and TAB created a shading condition affects light that reached the canopy is rapidly absorbed by the teak tree crowns. Thus, only some of the light intensity penetrates to the yam as understory crops.

Light intensity is one of the important environmental factor influencing plant growth, development and regulating plant metabolism [19-21]. Plants grown under shaded conditions has a specific adaptation. Low light intensity in the shade condition was associated with a strong photo-acclimation response, as could be inferred from the increasing of leaf size [22,23]. Yam planted in TAB and T-Y planting pattern with the lower RLI has bigger leaves than that planted in yam monoculture planting pattern, respectively. This result was supported by the previous study in *Vigna radiata* and *Olea europaea* species which showed leaf area was increased under shaded conditions [19, 23, 24]. According to Björkman and Powles [25] the shaded plant generally had bigger leaf size because the leaves were characterized by having larger layer of palisade cells. This larger leaves adaptation bring a benefit for plant to maintain the light capture and distribution [26].

Our study showed decreases in chlorophyll a and b content in higher RLI (yam monoculture) (figure 3 and figure 4). This result was supported by the previous results in *Tetrastigma hemsleyanum* showed that chlorophyll were decreased significantly in 0% and 50% shaded conditions [24]. Recently, a study in vanilla also found that chlorophyll a and b content were significantly higher in plant established in the most shaded treatment (23.6 µg/cm$^2$), intermediate (17.0 µg/cm$^2$) and high relative intensity (8.5 µg/cm$^2$) [27]. High chlorophyll a and b under shaded conditions per unit leaf area could optimize their effectiveness of light harvesting complex (Light Harvesting Complex II) and enlargement of antenna in photosystem II during photosynthesis process. Photosynthesis is the most essential process in plant for growth and biomass production. Lower chlorophyll contents observed in yam monoculture planting pattern with high RLI may represent a greater chlorophyll degradation which leads to the chlorophyll bleaching/whitening [26-30]. Consequently, it will reduce the photosynthetic rates and affect the yam biomass production at the end of harvesting time. Furthermore, yam adapted to low light intensity decreased its chlorophyll a:b ratio and that adapted to high light intensity enhanced chlorophyll a:b ratio (Figure 4). Low values of chlorophyll a:b ratio are correlated with high degree of stacking of thylakoid membranes in the chloroplast, which increases the area of the cross section of the grana and produces increased risk of photo inhibition [27, 31].
Leaf also responds to light intensity through its color. Figure 5 showed differences in leaf color grown under T-Y and TAB (low RLI) and Y (high RLI). Leaf color of yam grown under high RLI (Y) was light green, while those grown under shaded condition (TAB, T-Y) were dark green. This finding is supported by Stanton [16] where 40% shade treatments have darker green leaves, whereas full-sun plants resulted in lighter green. The darker green leaves color was related to the increased of foliar chlorophyll content under shaded condition [32, 33]. Other morphological characteristics affect by light intensity are tendrils and internode. Tendrils are specific organs of vine in yams which allow vines to climb host plants and other objects. Yam is fixed on the host plants (teak) in TAB and T-Y planting pattern, while in monoculture they were cultivated using horizontally bamboo stick (figure 4). In this study we found longer tendrils (12,530 m) and internodes (10,898 cm) in yam under low light intensity (Figure 3) than those grown under high RLI (tendril: 10,690 m, internode: 4,588 cm). Some researchers explained that in a shaded environment, since low light intensity was exist, plant adapted to an elongated morphology to increase light uptake [27, 31].

Stomata are particularly important as it allows for the gaseous exchange and regulate the loss of water vapor in unfavorable environmental conditions during the photosynthesis and transpiration process. Stomatal density can vary within leaves, among plant species and individuals of a single species. It also vary due to some environmental factors such as light, canopy level, water availability and atmospheric CO\(_2\) concentration [34, 35]. Our study on effects of light to stomatal density showed that the number of stomatal increased at higher RLI (T-Y: 19 stomatal/mm\(^2\), TAB: 25 stomatal/mm\(^2\), Y: 35 stomatal/mm\(^2\)). The enhancement of stomatal density also could be observed in tobacco and Arabidopsis linear with increasing of stomatal index and pore length as their adaptation to high light [34, 36, 37]. Principally, an increase in stomatal density could allow plants under well-watered conditions to increase conductance for gas exchange at the leaf surface and, thus, avoid photosynthetic limitation by sub-optimal CO\(_2\) supply [37]. There is a strong indication that stomata have major roles to play in the control of plant growth and yield.

Of the three planting pattern (Y, TAB, T-Y) with various relative light intensities found in this study, yams growth were sufficiently reduced under an extreme light intensity conditions (extreme high or low). Banerjee & Roychoudhury [38] explained that an extreme low light intensity causes stress by insufficient supply of energy-rich photons which fuel the photosystems and regulate photosynthesis. Insufficient photosynthesis results in insufficient food production for the autotrophic plants leading to unusual retarded growth patterns and lowered productivity. Otherwise, extremely high light intensity will reduced growth and productivity by photo-inactivation and photo-damage of photosynthetic apparatus and degradation of photosynthetic proteins mechanism.

More detail, our study revealed that some morpho-anatomical characteristics of yams such as leaf size, tendril and internode length tend to be small under planting pattern which has very high RLI. Those morpho-anatomical characteristics increase in size and number with lower RLI until a certain level is reached, then they are decline with further decreases in RLI or in the very low RLI (Figure 4). The results presented here indicated that although yam has a wide-range of light intensity to survive and it can tolerate some degree of shade or high light intensity, there was an optimum relative light intensity value were reached and required by yams in order to grow optimally and resulting high tuber yield. We suggest that approximately 50-60% of RLI is to be an optimum intensity for yam growth and support tuber production (Figure 4). In this case tree canopy management is required. Shading effects in T-Y and TAB planting pattern can be managed through pruning of the teak tree crown. Crown pruning has been reported to have a positive effect on understory crops production through increased light transmission mechanism [39, 40]. Agroforestry farmers was also suggested to apply thinning in order to widening spaces between trees to reduce shading effects. These two silvicultural practices are effective and desirable to have less shade and increase the light intensity levels on yam, thereby boost the growth and production of tuber at the end of harvesting time. On the other hand, it is also important to highlight the need of modify yam monoculture planting pattern to a mixed-species plantation systems [2] by introducing tree species in properly tree spacing that provide shade effects in order to reduce extremely high light intensity in yam monoculture planting pattern.
5. Conclusion
Planting pattern and relative light intensity were significantly affects the morpho-anatomical adaptation in yam agroforestry system. Leaf size, tendril and internode length tend to be small under planting pattern which has very high RLI. Those morpo-anatomical characteristics increase in size and number with lower RLI until a certain level is reached, then declined with further decreases in RLI. Although chlorophyll content and stomatal density did not showed a significantly difference among planting pattern and RLI but this study found that chlorophyll content were increased with the decreases in relative light intensity, otherwise stomatal density increased with the higher light intensity. This study indicate that optimum RLI (50-60%) were required for better growth of yam. Some silvicultural practices (pruning, thinning and tree planting) were required to manage tree canopy and light intensity condition in an agroforestry systems.

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