Identification and Classification of Indoor Plants According to Light Intensity Requirements for Botanical IoT Application

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ABSTRACT

This study aimed to provide information to urban plant growers on the best light requirement for indoor plants. Chlorophyll fluorescence analysis was used to determine the photosynthetic activity of indoor plants as affected by light intensity. Determination of the light intensity requirement for each plant was done by applying the Bayesian Michaelis-Menten equation which was obtained using the Lineweaver-Burk plot. The V_{max} and K_m values were determined, where the photosynthetic activity measured as electron transport rate (ETR) was denoted as V_{max} and light intensity (photosynthetically active radiation, PAR) of $\frac{1}{2}$ maximum ETR was designated as K_m . The ETR of 93 indoor plant species were determined and $V_{max}/2$ and K_m values of each plant were calculated which resulted in seven levels of light intensity. The levels are as follows: Level 1 - more than the K_m value; Levels 2 to 7 were determined using the formula: maximum K_m value of the level = $K_m(\frac{1}{2})^{n-1}$ where n refers to the level (i.e. $n_2 = \text{level } 2, \dots, 7$). The best is level 1 while the most sub-optimal is level 7. The different plants have a wide range of light intensity requirements. Majority of the plants (70) had $\frac{1}{2}$ maximum ETR at 20 up to less than $100 \mu\text{mol m}^{-2} \text{s}^{-1}$ PAR, while 13 plants at 100 to $149 \mu\text{mol m}^{-2} \text{s}^{-1}$ and only 10 plants at 150 up to $290 \mu\text{mol m}^{-2} \text{s}^{-1}$. The indoor plants can be classified according to light intensity requirement: low light intensity, e.g. *Dracaena sanderiana* 'Gold' (20.9); moderate light intensity, e.g. *Cyclamen persicum* (99.1); and high light intensity, *Polyscias fruticosa* ($290.2 \mu\text{mol m}^{-2} \text{s}^{-1}$). The data generated from this study can be utilized in IoT to make the information on plant cultivation and environmental conditions accessible to urban growers who use smartphones.

Keywords: indoor environment, indoor greenery, Internet-of-Things, light intensity, smart home

Introduction

In the advent of smart technologies, services for smart homes become inevitable. A smart home enables the interaction between home owners or users and appliances in the home. The need for Internet of Things (IoT) services for eHomes or smart homes is expected to increase in the coming years. IoT is a technology that tends to connect all the objects in the world to the internet (Channe et al., 2015) including home devices and appliances. The introduction of smart homes has been proposed to improve the quality of life of residents when they are at home. At present, smart homes are focused on energy efficiency and

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convenient living at home (Chen et al., 2017). These may be referred to as the traditional or first-generation smart home or Smart Home 1.0 (Chen et al., 2017).

Recently, smart technology applications have also incorporated green technologies for example making smart green buildings. Few works have introduced greenhouses into smart homes, thus Chen et al. (2017) proposed an upgrade to the Smart Home 1.0 to include botanicals into the home environment in consideration of the users' emotions (Smart Home 2.0). The cultivation of ornamental plants indoors does not only include aesthetic value but also other purposes such as air purification (Kim et al., 2018; Irga et al., 2018), stress amelioration (Lee et al., 2015), or promotion of creativity (Shibata and Suzuki, 2002, 2004). For smart homes that contain indoor plants, platforms or apps that will assist them in successful indoor plant cultivation will be necessary.

Whether in a traditional house or smart house, indoor plants need optimum environment to grow properly. One major environmental factor that greatly influences plant growth is light (Pennisi, 2017). Different plants require a wide range of light intensity for proper growth and development. Indoor ornamental plants are known to favor low to medium light intensities. Knowledge of the light requirements of plants would aid growers to maximize the benefits from indoor plant cultivation. Plants are usually classified according to their light intensity requirements as follows: low-light plants, medium-light plants, high-light plants, and very high-light plants (Pennisi, 2017). Suboptimal light conditions indoors not only limit growth of the plants but air purifying capacity of the plants as well if stomatal absorption of pollutants is to be depended upon (Brilli et al., 2018). One way to investigate the effect of light intensity on plant growth is through chlorophyll fluorescence analysis. Chlorophyll fluorescence analysis has become an important tool in plant biology. It is a non-invasive way to study photochemical and nonphotochemical processes within the thylakoid membranes, chloroplasts, plant tissues, and the whole plant (Rohacek et al., 2008).

To accomplish the intended purpose of aesthetic value, improved air quality, and improved psychological and mental health brought about by indoor plants in smart homes, data is the essential material for intelligence. Therefore, it is important to have a database of plant responses to crucial environmental factors affecting plant growth and development. This study aimed to identify the light intensity requirements of different interior plants and classify these light intensities into categories that may aid in IoT services for smart homes.

Materials and Methods

Plants and Growth Condition

Ninety-three species of ornamental indoor plants in 10 cm-diameter plastic pots containing growth media mix (Sungro®, Canada). Three individual potted plants per species were maintained as replicates and these were grown in a plant growth room with the following conditions: $23 \pm 1^\circ\text{C}$; 12h light cycle; $28 \mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ light intensity (fluorescent lamps); 40-60% relative humidity.

Chlorophyll Fluorescence Analysis

Healthy, intact, 3rd to 4th leaves from the shoot of 2 to 3 month-old potted plants were taken as samples from each plant species per replicate. Sample leaves of each plant species were dark adapted for 20 min before chlorophyll fluorescence analysis using Heinz Walz IMAGING-PAM fluorometer K-5 (Figure 1). The electron transport rate (ETR) was determined by recording a light curve for each plant sample in 0, 5, 16, 26, 41, 61, 86, 116, 151, 191, 236, and $286 \mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ photosynthetically active radiation (PAR).

Figure 1. Chlorophyll fluorescence analysis of three leaves using pulse amplified modulation imaging. Circles on leaves are areas of interest chosen during analysis.

Figure 2. Lineweaver-Burk plot.

The ETR is a relative measure of the apparent electron transport rate. The ETR was computed as follows:

$$\text{ETR} = \text{Yield} \times \text{PAR} \times 0.5 \times \text{Absorptivity}$$

Where: absorptivity amounts to $0.84 \mu\text{equivalents m}^{-2} \text{s}^{-1}$

Determination of V_{max} and K_m

The Michaelis-Menten equation was used to determine the relationship of ETR and different PAR (Equation 1). V_{max} and K_m values were determined by using the Lineweaver-Burk plot (Figure 2, Equation 2). In this study, ETR was designated as V_{max} , and PAR as K_m . K_m for each plant species was determined where $V_{\text{max}}/2$.

$$V_0 = \frac{V_{\text{max}}[S]}{K_m + [S]} \quad (1)$$

$$\frac{1}{V} = \frac{K_m + [S]}{V_{\text{max}}[S]} = \frac{K_m}{V_{\text{max}}} \frac{1}{[S]} + \frac{1}{V_{\text{max}}} \quad (2)$$

Using regression equation in Microsoft Excel, the y-intercepts and slopes were determined and V_{max} and K_m were calculated.

Results and Discussion

Light intensity influences various processes in the plant. Photosynthetic activity of 93 indoor plants at different PAR measured as electron transport rate (ETR) was determined by chlorophyll fluorescence analysis. ETR and PAR values were fitted in a regression equation to derive V_{max} and K_m values. A graph of determined slopes and y-intercepts of three representative plant species is shown in Figure 3.

The measured ETR and PAR where the maximum ETR is halved (K_m) of the 93 indoor plants is shown in Table 1. Among the plants measured, *Dracaena sanderiana* ‘Gold’ had the lowest ETR at the highest PAR used in the study while the highest was in *Polyscias fruticosa*. Several species of *Dracaena* registered the lowest ETR (6.5 – 7.0). However, *D. sanderiana* ‘Virens’ require almost double ($55.6 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) of the K_m value of *D. sanderiana* ‘Gold’ ($20.9 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$). *Hedera helix* varieties ‘Variegata’, ‘Harley Quinn’, and ‘Dream’ registered similar ETR (21.0-26.0) and K_m values ($82.4 - 85.6 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$). These species are known to require medium to high light intensities (Peninisi, 2017; Shaughnessy and Pertuit, 1999).

Plotting the ETR against a particular PAR for each plant resulted in a curve similar to the Michealis-Menten reaction curve (Figure 4). For each plant, seven levels of PAR were formed using the formula, $K_m(1/2)^{n-1}$. Level 1 is designated as the best level, where PAR is highest; while Level 7 is the most sub-optimal PAR level for the plant.

Table 2 shows the upper limit of the PAR levels for each level of each plant studied. According to Pinyuh et al. (2012), perhaps the most limiting environmental factor in indoor plant growth is lack of adequate light since as the natural light enters a home, this decrease very quickly. Categorizing the light intensity into levels may aide in data interpretation when used in IoT applications.

Figure 3. Lineweaver-Burk plot of three representative indoor plant species. Graph, slopes and y-intercepts were generated in Microsoft Excel.

Table 1. Vmax and Km values of 93 indoor plant species

Botanical name	Common name	Vmax (ETR)	Km ($\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$)
<i>Dracaena sanderiana</i> 'Gold'	Belgian evergreen	6.5±0.4	20.9± 1.3
<i>Guzmania</i> 'Ice Cream'	Tufted airplant	6.9±0.5	21.8± 1.6
<i>Dracaena sanderiana</i> 'Victoria'	Belgian evergreen 'Victoria'	7.9±0.8	25.2± 2.7
<i>Dracaena fragrans</i> 'Massangeana Compacta'	Mass cane	7.0±0.6	26.4± 5.1
<i>Asparagus setaceus</i> 'Nanus'	Asparagus fern	8.8±0.6	28.3± 2.0
<i>Begonia rex</i>	Painted-leaf begonia	8.8±2.0	28.4± 6.7
<i>Chamaedorea elegans</i>	Neanthe bella palm	9.1±1.6	34.6± 8.2
<i>Philodendron</i> 'Congo'	Green congo philodendron	9.7±0.6	31.1± 1.9
<i>Peperomia argyreia</i>	Watermelon peperomia	9.8±0.6	31.5± 2.0
<i>Saintpaulia ionantha</i>	African violet	9.8±1.5	31.6± 4.8
<i>Syngonium podophyllum</i> 'Pixie'	Red aglaonema	9.9±1.9	32.1± 6.3
<i>Aglaonema</i> 'Siam Aurora'	Butterfly plant	6.7±2.1	32.1±10.3
<i>Dryopteris crassirhizoma</i>	Thick-stemmed wood fern	10.0±0.7	32.2± 2.4
<i>Peperomia clusiifolia</i> 'Isabella'	Isabella peperomia	10.1±2.0	32.5± 6.5
<i>Codiaeum variegatum</i>	Variegated croton	10.6±1.0	34.2± 0.4
<i>Gaultheria procumbens</i> L.	Eastern teaberry	11.0±0.7	35.4± 2.5
<i>Fittonia verschaffelti</i> 'Redstar'	Red star nerve plant	11.2±2.9	36.4± 9.6
<i>Heteropanax fragrans</i>	Happy tree	11.3±0.2	36.6± 0.6
<i>Calathea insignis</i>	Prayer plant	11.8±0.3	38.4± 1.1
<i>Cordyline terminalis</i>	Good luck tree	12.0±0.7	38.9± 2.5
<i>Selaginella martensii</i>	Variegated spikemoss	12.1±0.9	39.5± 2.9
<i>Nertera granadensis</i>	Coral bead plant	12.2±2.3	39.8± 7.7
<i>Rhapis excelsa</i>	Broadleaf lady palm	13.2±2.5	43.0± 8.3
<i>Ficus elastica</i>	Rubber plant	11.6±1.0	43.8± 6.7
<i>Begonia semperflorens</i>	Wax begonia	13.6±1.0	44.3± 3.2
<i>Codiaeum variegatum</i> 'Mammy'	Mammy croton	13.6±1.0	44.4± 3.4
<i>Asplenium nidus</i> 'Avis'	Bird's-nest fern	14.1±2.7	45.9± 8.9
<i>Trachelospermum asiaticum</i> Nakai	Asiatic jasmine	14.1±1.0	46.0± 3.4
<i>Ficus pumila</i> L. 'Variegata'	Variegated creeping fig	14.4±0.5	47.0± 1.8
<i>Ficus lyrata</i>	Fiddle-leaf fig	14.6±2.4	47.6± 7.8
<i>Ardisia pusilla</i> A.DC.	Small coralberry	14.7±3.1	48.1±10.2
<i>Fittonia albivenis</i> Brummitt 'Whitestar'	White star nerve plant	12.9±0.8	49.0± 8.0
<i>Aglaonema</i> 'Redgold'	Red gold Chinese evergreen	16.1±2.1	52.8± 7.1
<i>Ardisia crenata</i> Sims	Christmas berry	16.2±3.3	52.9±11.0
<i>Schefflera arboricola</i> 'HongKong'	Parasol plant	16.9±1.6	55.3± 5.4
<i>Dracaena sanderiana</i> 'Virens'	Lucky bamboo	11.4±2.1	55.6±10.7
<i>Coffea arabica</i>	Coffee tree	17.5±0.7	57.3± 2.4
<i>Peperomia puteolata</i>	Parallel peperomia	13.0±0.9	57.4±10.5
<i>Pilea glauca</i> 'Greizy'	Silver sprinkles	17.7±2.7	57.9± 8.9
<i>Platynerium bifurcatum</i>	Elkhorn fern	17.8±3.4	58.2±11.3
<i>Ardisia pusilla</i> 'Variegata'	Variegated small coralberry	11.9±3.9	58.4±19.2
<i>Aphelandra squarrosa</i>	Zebra plant	17.9±2.4	58.6± 8.1
<i>Rhododendron simsii</i>	Azalea	18.4±0.9	60.3± 2.9
<i>Sansevieria trifasciata</i> 'Superba'	Snake plant	18.5±1.4	60.4±10.3
<i>Peperomia quadrangularis</i> 'Beetle'	Beetle peperomia	19.0±4.8	62.1±16.0
<i>Aglaonema</i> 'Silver King'	Chinese evergreen 'Silver King'	12.8±2.8	62.7±14.1

(Continued)

Table 1. Continued.

Botanical name	Common name	Vmax (ETR)	Km ($\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$)
<i>Pentas lanceolata</i>	Egyptian star cluster	20.2±4.1	66.3±13.5
<i>Cupressus macrocarpa</i> ‘Goldcrest’	Lemon cypress	20.4±4.0	67.2±13.3
<i>Schefflera actinophylla</i> (Endl.) Harms	Umbrella tree	21.8±1.6	71.8± 5.4
<i>Dischidia nummularia</i> R. Br	String of nickels	22.3±2.4	73.8± 7.9
<i>Epipremnum aureum</i>	Pothos	22.5±4.9	73.9±16.4
<i>Ardisia japonica</i> ‘Variegata’	Variegated small coralberry	22.6±2.0	74.2± 6.6
<i>Fatsia japonica</i>	Paperplant	22.8±4.8	74.9±15.8
<i>Ardisia japonica</i> (Thunb.) Blume	Japanese ardisia	23.1±2.2	76.2± 7.1
<i>Ficus benjamina</i> ‘Variegata’	Variegated benjamin fig	20.1±2.1	77.4±14.4
<i>Podocarpus nagi</i>	Nagi podocarpus	24.7±4.3	81.2±14.3
<i>Tillandsia cyanea</i>	Pink quill	24.9±3.7	82.0±12.2
<i>Hedera helix</i> ‘Variegata’	Variegated English ivy	25.0±4.5	82.4±14.9
<i>Hedera helix</i> ‘Harley Quinn’	Harley Quinn English ivy	21.0±4.8	85.3±32.1
<i>Hedera helix</i> ‘Dream’	Dream English ivy	26.0±4.4	85.6±14.7
<i>Pittosporum tobira</i>	Japanese pittosporum	25.9±0.8	85.7± 2.6
<i>Rhapis humilis</i> Blume	Slender lady palm	26.1±4.2	86.2±13.9
<i>Euonymus japonicus</i> ‘Ovatus Aureus’	Japanese spindle	26.4±1.1	87.3± 3.7
<i>Euphorbia pulcherrima</i>	Poinsettia	26.6±0.2	87.6± 0.8
<i>Ficus retusa</i> ‘Panda’	Ficus panda	27.6±4.5	90.9±15.1
<i>Nematanthus gregarius</i>	Goldfish plant	27.9±9.6	91.6±31.8
<i>Heteropanax fragrans</i>	Happy tree	18.7±3.5	92.2±17.6
<i>Nandina domestica</i> Thunb.	Heavenly bamboo	28.7±6.8	94.6±22.5
<i>Serissa japonica</i> (Thunb.) Thunb.	Snow rose	29.3±5.1	96.6±17.0
<i>Cyclamen persicum</i>	Persian cyclamen	29.9±3.6	99.1±12.1
<i>Kalanchoe</i> sp.	Kalanchoe	30.6±4.7	101.1±15.6
<i>Caladium</i> sp.	Elephant ear	31.0±3.3	102.4±11.0
<i>Acalypha chamaedrifolia</i>	Red cat's tail	31.3±5.0	103.3±16.6
<i>Ficus banghalensis</i>	Bengal fig	31.8±5.1	105.2±17.1
<i>Trachelospermum asiaticum</i> Nakai	Asiatic jasmine	32.0±5.9	105.8±19.7
<i>Pteris multifida</i> Poir.	Spider brake fern	22.0±4.8	108.5±23.8
<i>Clusia rosea</i> Jacq.	Balsam apple	34.8±4.8	115.0±15.9
<i>Eucalyptus globulus</i>	Eucalyptus	35.9±7.0	118.8±23.4
<i>Hedera helix</i>	Ivy	24.0±0.7	119.0± 3.6
<i>Plectranthus tomentosa</i>	Vick's plant	37.3±6.5	123.3±21.6
<i>Crossandra infundibuliformis</i> (L.) Nees	Firecracker flower	37.9±4.7	125.2±15.6
<i>Polyscias scutellaria</i>	Shield aralia	38.7±6.4	128.0±21.4
<i>Podocarpus macrophyllus</i> (Thunb.) D. Don	Buddhist pine	41.6±6.2	137.9±20.9
<i>Pelargonium</i> ‘Vancouver Centennial’	Stellar geranium	47.0±1.9	155.6± 6.4
<i>Fittonia verschaffeltii</i> var. <i>argyroneura</i> ‘Compacta’	Mosaic plant	47.3±3.2	156.8±10.5
<i>Murraya paniculata</i>	Orange jasmine	50.3±2.9	166.6± 9.7
<i>Stephanotis floribunda</i>	Madagascar jasmine	50.3±2.9	167.0± 9.7
<i>Mandevilla sanderi</i> (Hemsl.) Woodson	Brazilian jasmine	50.5±6.8	167.2±22.5
<i>Adenium obesum</i>	Desert rose	53.0±3.2	175.6±10.8
<i>Ceropegia woodii</i>	Rosary vine	60.2±8.9	199.5±29.7
<i>Muehlenbeckia complexa</i> Meisn.	Maidenhair vine	68.7±4.3	227.8±14.3
<i>Zamia pumila</i>	Coontie palm	53.0±3.2	262.6±15.9
<i>Polyscias fruticosa</i>	Ming aralia	87.4±8.4	290.2±28.1

Figure 4. Formation of seven levels of light intensity according to the formula: $Km(\frac{1}{2})^{n-1}$. Inset is $V_{max}/2$ and Km in relation to the V_{max} .

Table 2. Upper limit of light intensity per level of the 93 indoor plant species

Common Name	Upper limit of light intensity ($\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) per level						
	1	2	3	4	5	6	7
Belgian evergreen	> 20.9	20.9	10.5	5.2	2.6	1.3	0.7
Tufted airplant	> 21.8	21.8	10.9	5.4	2.7	1.4	0.7
Belgian evergreen 'Victoria'	> 25.2	25.2	12.6	6.3	3.1	1.6	0.8
Mass cane	> 26.4	26.4	13.2	6.6	3.3	1.7	0.8
Asparagus fern	> 28.3	28.3	14.2	7.1	3.5	1.8	0.9
Painted-leaf begonia	> 28.4	28.4	14.2	7.1	3.5	1.8	0.9
Neanthe bella palm	> 31.1	31.1	15.5	7.8	3.9	1.9	1.0
Green congo philodendron	> 31.5	31.5	15.7	7.9	3.9	2.0	1.0
Watermelon peperomia	> 31.6	31.6	15.8	7.9	3.9	2.0	1.0
African violet	> 32.1	32.1	16.0	8.0	4.0	2.0	1.0
Red aglaonema	> 32.1	32.1	16.1	8.0	4.0	2.0	1.0
Butterfly plant	> 32.2	32.2	16.1	8.0	4.0	2.0	1.0
Thick-stemmed wood fern	> 32.5	32.5	16.2	8.1	4.1	2.0	1.0
Isabella peperomia	> 34.2	34.2	17.1	8.6	4.3	2.1	1.1
Variegated croton	> 34.6	34.6	17.3	8.7	4.3	2.2	1.1
Eastern teaberry	> 35.4	35.4	17.7	8.9	4.4	2.2	1.1
Red star nerve plant	> 36.4	36.4	18.2	9.1	4.6	2.3	1.1
Happy tree	> 36.6	36.6	18.3	9.2	4.6	2.3	1.1
Prayer plant	> 38.4	38.4	19.2	9.6	4.8	2.4	1.2
Good luck tree	> 38.9	38.9	19.4	9.7	4.9	2.4	1.2
Variegated spikemoss	> 39.5	39.5	19.8	9.9	4.9	2.5	1.2

(Continued)

Table 2. Continued.

Common Name	Upper limit of light intensity ($\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) per level						
	1	2	3	4	5	6	7
Coral bead plant	> 39.8	39.8	19.9	10.0	5.0	2.5	1.2
Broadleaf lady palm	> 43.0	43.0	32.3	21.5	16.1	10.8	5.4
Rubber plant	> 43.8	43.8	21.9	11.0	5.5	2.7	1.4
Wax begonia	> 44.3	44.3	22.1	11.1	5.5	2.8	1.4
Mammy croton	> 44.4	44.4	22.2	11.1	5.6	2.8	1.4
Bird's-nest fern	> 45.9	45.9	22.9	11.5	5.7	2.9	1.4
Asiatic jasmine	> 46.0	46.0	23.0	11.5	5.7	2.9	1.4
Variegated creeping fig	> 47.0	47.0	23.5	11.7	5.9	2.9	1.5
Fiddle-leaf fig	> 47.6	47.6	23.8	11.9	6.0	3.0	1.5
Small coralberry	> 48.1	48.1	24.0	12.0	6.0	3.0	1.5
White star nerve plant	> 49.0	49.0	24.5	12.3	6.1	3.1	1.5
Red gold Chinese evergreen	> 52.8	52.8	26.4	13.2	6.6	3.3	1.6
Christmas berry	> 52.9	52.9	26.5	13.2	6.6	3.3	1.7
Parasol plant	> 55.3	55.3	27.7	13.8	6.9	3.5	1.7
Lucky bamboo	> 55.6	55.6	27.8	13.9	6.9	3.5	1.7
Coffee tree	> 57.3	57.3	28.7	14.3	7.2	3.6	1.8
Parallel peperomia	> 57.4	57.4	28.7	14.3	7.2	3.6	1.8
Silver sprinkles	> 57.9	57.9	29.0	14.5	7.2	3.6	1.8
Elkhorn fern	> 58.2	58.2	29.1	14.5	7.3	3.6	1.8
Variegated small coralberry	> 58.4	58.4	29.2	14.6	7.3	3.6	1.8
Zebra plant	> 58.6	58.6	29.3	14.6	7.3	3.7	1.8
Azalea	> 60.3	60.3	30.1	15.1	7.5	3.8	1.9
Snake plant	> 60.4	60.4	30.2	15.1	7.5	3.8	1.9
Beetle peperomia	> 62.1	62.1	31.1	15.5	7.8	3.9	1.9
Chinese evergreen 'Silver King'	> 62.7	62.7	31.3	15.7	7.8	3.9	2.0
Egyptian star cluster	> 66.3	66.3	33.2	16.6	8.3	4.1	2.1
Lemon cypress	> 67.2	67.2	33.6	16.8	8.4	4.2	2.1
Umbrella tree	> 71.8	71.8	35.9	17.9	9.0	4.5	2.2
String of nickels	> 73.8	73.8	36.9	18.4	9.2	4.6	2.3
Pothos	> 73.9	73.9	37.0	18.5	9.2	4.6	2.3
Variegated small coralberry	> 74.2	74.2	37.1	18.6	9.3	4.6	2.3
Paperplant	> 74.9	74.9	37.4	18.7	9.4	4.7	2.3
Japanese ardisia	> 76.2	76.2	38.1	19.1	9.5	4.8	2.4
Variegated benjamin fig	> 77.4	77.4	38.7	19.3	9.7	4.8	2.4
Nagi podocarpus	> 81.2	81.2	40.6	20.3	10.2	5.1	2.5
Pink quill	> 82.0	82.0	41.0	20.5	10.2	5.1	2.6
Variegated English ivy	> 82.4	82.4	41.2	20.6	10.3	5.1	2.6
Harley Quinn English ivy	> 85.3	85.3	42.7	21.3	10.7	5.3	2.7
Dream English ivy	> 85.6	85.6	42.8	21.4	10.7	5.4	2.7
Japanese pittosporum	> 85.7	85.7	42.8	21.4	10.7	5.4	2.7
Slender lady palm	> 86.2	86.2	43.1	21.5	10.8	5.4	2.7
Japanese spindle	> 87.3	87.3	43.7	21.8	10.9	5.5	2.7
Poinsettia	> 87.6	87.6	43.8	21.9	10.9	5.5	2.7
Ficus panda	> 90.9	90.9	45.4	22.7	11.4	5.7	2.8
Goldfish plant	> 91.6	91.6	45.8	22.9	11.5	5.7	2.9

(Continued)

Table 2. Continued.

Common Name	Upper limit of light intensity ($\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) per level						
	1	2	3	4	5	6	7
Happy tree	> 92.2	92.2	46.1	23.0	11.5	5.8	2.9
Heavenly bamboo	> 94.6	94.6	47.3	23.7	11.8	5.9	3.0
Snow rose	> 96.6	96.6	48.3	24.2	12.1	6.0	3.0
Persian cyclamen	> 99.1	99.1	49.5	24.8	12.4	6.2	3.1
Kalanchoe	>101.1	101.1	50.6	25.3	12.6	6.3	3.2
Elephant ear	>102.4	102.4	51.2	25.6	12.8	6.4	3.2
Red cat's tail	>103.3	103.3	51.7	25.8	12.9	6.5	3.2
Bengal fig	>105.2	105.2	52.6	26.3	13.1	6.6	3.3
Asiatic jasmine	>105.8	105.8	52.9	26.4	13.2	6.6	3.3
Spider brake fern	>108.5	108.5	54.3	27.1	13.6	6.8	3.4
Balsam apple	>115.0	115.0	57.5	28.8	14.4	7.2	3.6
Eucalyptus	>118.8	118.8	59.4	29.7	14.8	7.4	3.7
Ivy	>119.0	119.0	59.5	29.8	14.9	7.4	3.7
Vick's plant	>123.3	123.3	61.6	30.8	15.4	7.7	3.9
Firecracker flower	>125.2	125.2	62.6	31.3	15.6	7.8	3.9
Shield aralia	>128.0	128.0	64.0	32.0	16.0	8.0	4.0
Buddhist pine	>137.9	137.9	69.0	34.5	17.2	8.6	4.3
Stellar geranium	>155.6	155.6	77.8	38.9	19.5	9.7	4.9
Mosaic plant	>156.8	156.8	78.4	39.2	19.6	9.8	4.9
Orange jasmine	>166.6	166.6	83.3	41.6	20.8	10.4	5.2
Madagascar jasmine	>167.0	167.0	83.5	41.7	20.9	10.4	5.2
Brazilian jasmine	>167.2	167.2	83.6	41.8	20.9	10.4	5.2
Desert rose	>175.6	175.6	87.8	43.9	21.9	11.0	5.5
Rosary vine	>199.5	199.5	99.8	49.9	24.9	12.5	6.2
Maidenhair vine	>227.8	227.8	113.9	56.9	28.5	14.2	7.1
Coontie palm	>262.6	262.6	131.3	65.7	32.8	16.4	8.2
Ming aralia	>290.2	290.2	145.1	72.5	36.3	18.1	9.1

Note. The values in each column are the upper limit of the range of light intensity in the specific level; e.g. for Belgian evergreens: Level 1: >20.9, Level 2: >10.5-20.9, Level 3: >5.2-10.5, Level 4: >2.6-5.2, Level 5: >1.3-2.6, Level 6: >0.7-1.3, and Level 7: 0-0.7 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$

Figure 5. Histogram of Km values of different indoor plants.

Majority of the studied indoor plants have Km values between 30 to 146 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ PAR as shown in the histogram (Figure 5). In terms of light intensity requirement, this means that most of the plants require medium to high light intensity at about 1,554 to 6,660 lx. Fewer plant species require very low light and very high light intensities. The histogram was created using the different levels of light requirement of indoor plants (Pennisi, 2017)

Perhaps one of the difficulties in light intensity management of indoor plants is that different plants require different light intensities. Even within the same families, plant species may require varying illuminance as seen in Figure 6. This is distinctly observed in families *Acanthaceae*, *Apocynaceae*, *Araliaceae*, and others.

There is a wide diversity of plants in a given light intensity. This is noticeable in light intensity ranges of 21-50 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, 56-90 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, and 91-125 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$; with 19, 19, and 15 families represented, respectively (Figure 7). This shows that a homeowner can diversify his/her indoor plants with convenience if he/she knows the optimum light requirements of specific plants.

Despite the benefits gained from cultivation of indoor plants, homeowners may find it difficult or inconvenient to manage these especially for the working class. In terms of light quantity management, the inconvenience can be aggravated by changes in seasons, time of the days where natural light can enter the house, and others. Conventionally, the easiest way to adjust lighting is to move plants closer or farther away from the source of light. However, in smart homes, this becomes more convenient since adjustment of light intensity can be automated. This can be addressed by intelligent

Figure 6. Number of plant species per family according to PAR range.

Figure 7. Distribution of indoor plant species grouped according to family per PAR range.

Figure 8. Concept of IoT application for indoor plant cultivation in smart homes.

monitoring by light or illuminance sensors which perceive the current environment and collect environmental data; controlled equipment such as smart switch for LED activate itself, adjusting the intensity of indoor light (Chen et al., 2017). The homeowners can monitor the status of their plants and their environment through smart gadgets such as smart phones (Figure 8). Yang et al. (2017) describes how botanical IoT technologies are being applied to agriculture and this can be applied to indoor environments like homes. Ray (2017) reviews several technologies involved in connecting plants to humans like sensing and controlling devices (e.g. Botanicalls, Parrot, etc.).

Conclusion

This study measured the photosynthetic response in terms of ETR of 93 indoor plants at different light intensity levels using chlorophyll fluorescence analysis. With the generated data we were able to create some ways to categorize the different indoor plants according to their optimum light intensity requirement, according to different light intensity range, distribution of plant species according to families, and diversity of plant families within a given PAR range. Specifically, seven levels of light intensity were formed from the generated data which may aide in the intelligence material needed in the IoT technology for smart homes that include greeneries or plant gardening in interior spaces. Although there are other factors influencing indoor plants like temperature and water requirements and effects of stress on these plants, our research is an initial step that can be valuable in the further advancement of indoor plant cultivation in smart homes.

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