Full Length Research Paper

The effect of Light Color (wavelength) and Intensity on Vegetable Roselle (Hibiscus Sabdariffa) growth

J. B. Yerima¹; M. A. Esther¹, J. S. Madugu², N. S. Muwa³ and S. A. Timothy⁴

¹: Department of Physics, Modibbo Adama University of Technology Yola, Nigeria
²: Technical Training Services, TSAC Mubi, Nigeria
³: Federal Polytechnic Bali, Nigeria
⁴: Department of Physics, Adamawa State University Mubi, Nigeria

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The effect of the colors (wavelengths) of white light on the phototropic growth of vegetable roselle (hibiscus sabdariffa) has been studied. The results show that green light has the maximum observed transmitted intensity indicating that chlorophyll and accessory pigments in roselle leaf are good reflectors of green light (i.e. insignificant amount of the energy of green color is absorbed). Blue and red colors have low observed transmitted intensities showing that chlorophyll and the pigments are good attenuators of these colors (i.e. significant amount of the energies of blue and red colors are absorbed). This means that blue and red components of white light transfer their energies to the electrons of chlorophyll and the accessory pigments during photoelectron absorption process and the energy transferred is used in photosynthesis and then finally growth. Similarly the percentage transmittance (%T) of the colors has been used successfully to explain growth in vegetable roselle.

Keywords: Light, Wavelength, Intensity, Effect, Roselle, Growth

INTRODUCTION

Light is a visible form of electromagnetic wave. It makes it possible for plants to grow and produce the food we eat. Plants derive this energy from sunlight by means of photosynthesis. The characteristics of light such as intensity, quality (color) and duration determine to some extent the level of its interaction with matter. Intensity of incoming radiation from the sun is altered by both atmospheric and terrestrial obstructions. A host of researchers (Holmes and Smith, 1977a; Ballare et al., 1991; Baraldi et al., 1994; Gratani, 1997) have shown that change in spectral energy distribution affect plant growth and development. Photoreceptors in plants are divided into two: phytochrome principally sensitive to light in the red and far-red regions of the visible spectrum (Batschaver et al., 1998; Ballare, 1999; Smith, 2000) and crytochrome and phototropin sensitive to blue light (Briggs and Huala, 1999). Most plants use the photoreceptors to regulate the time of flowering, germination of seeds, elongation of seedlings, size and shape of leaves, number of leaves, the synthesis of chlorophyll, straightening of the epicotyls hook of dicot seedlings and stomata opening (Gay and Hurd, 1980; Wild and Wolf, 1980; Furukawa, 1997; James and Bell, 2000; Hennig, 2001; Answer, 2006). Photosynthesis is the process by which green plants and certain other organisms (seaweeds, algae and certain bacteria) use the energy of light to convert carbon dioxide and water into simple sugar (Leal, 2007). Light energy causes the electrons in chlorophyll and light-trapping pigments to boost up the electrons out of their orbits; the electrons instantly fall back into place, releasing vibration energy as they go, all in millionths of a second. Chlorophyll and the other pigments absorb the energy released by the electrons which is used during photosynthesis. Plants from different environments have different responses to colors of light. For example, species that have adapted to shade do not usually show a marked shade avoidance response. Branching, internodes length, and flowering initiation can all be affected, to varying degrees, by the ratio of red light to far-red. Greenhouse films (Batschaver et al., 1998) have been developed to modify the red/far-red of incoming light by using (i) additives that absorb green or UV and fluoresce to the red waveband and (ii) films that absorb preferentially in the far red. Therefore, it

Corresponding Author E. mail:bejakwa@yahoo.com
can be clearly seen from existing literatures that light affects almost all processes associated with growth, photosynthesis, and flowering in plants. This study investigated the effects of light color and intensity on the growth of vegetable Roselle (hibiscus sabdariffa). We have attempted to explain the phototropism of rosette under different colors of light in terms of percentage transmittance (%T) according to Beer-Lambert (exponential) law of light passing through at least a pair of media. Using the knowledge of photoelectron absorption and Compton scattering processes, we have shown how %T and half-value layer can be used to explain photosynthesis and phototropism in plants.

**Vegetable Roselle (Hibiscus Sabdariffa)**

Roselle (hibiscus sabdariffa) is plant species of malvaceae family growing up to 2m. The vegetable is widely grown in the tropics and is one of the most important leafy vegetables in the lowlands of Africa and Asia. For example, it is commonly grown in the northeastern and middle belt regions of Nigeria (Akanya et al., 1997; Palada and Changl, 2003). Vegetable rosette is an annual, fast growing plant, and is easily cultivated in gardens and fields. It grows well in both hot humid and hot dry climates with temperatures between 25°C and 30°C. Roselle is photoperiod-sensitive and most species will flower when day lengths are shorter than 12 hours. Many botanical varieties have been recognized and consumed over a long period of time. For example, the red calyx is used to cook soup, stew, and sauces. The fresh red (green) calyx is very rich in carbohydrates with relatively high fiber content and contains enough moisture to permit action by their enzyme and microorganisms. Babalola (2002) reported that the calyx is very high in vitamins A and C, and riboflavin with some major minerals (calcium, iron, etc.) present. It finds many uses in traditional medicine as a digestive and purgative agent and a folk remedy for abscesses, billows, cancer, hypertension, etc. (Dake, 1985). Presently in western Nigeria roselle calyx used in cooking soups is usually prepared by steeping it with wood ash or parboiled with wood ash to neutralize the acid in it (Ojokoh et al., 2002). The knowledge of the phototropism response to colors can be used to study the effect of colors on yield, medicinal and nutritional values of the plant.

**Theory**

The various phenomena arising from interactions of electromagnetic radiation with substances include reflection, refraction, dispersion, diffraction, and absorption. Frequency is a fundamental property of electromagnetic radiation which remains constant as the medium of propagation is changed unlike wavelength. This explains why photons with energy, \( E = \frac{hc}{\lambda} \) of the different colors of visible light have different photon energies. The ability of a material to absorb and transmit monochromatic radiation has formed the basis of many instrumental techniques in modern physics and analytical chemistry. The purity of the interaction radiation in terms of monochromacity has a lot to do with the sensitivity, precision and accuracy of photometric analysis (Ogugbuaja, 2000).

Beer-Lambert spectroscopic law states that the portion of light absorbed by a medium is proportional to the length the light transverses (path length, \( x \)) at constant amount of the absorbance. Thus,

\[
A = kx \tag{1}
\]

where \( k \) is the proportionality constant called the absorption/spectroscopic coefficient and \( A \) is the absorbance. The transmittance \( T \) is the ratio of the transmitted light intensity \( I_t \) to the incident light intensity \( I_i \), i.e.,

\[
T = \frac{I_t}{I_i} \tag{2}
\]

The percentage transmittance is

\[
\%T = 100 \frac{I_t}{I_i} \tag{3a}
\]

Also, absorbance is defined as the negative of the logarithm of transmittance \( T \) i.e.,

\[
A = -\log \frac{I_t}{I_i} = -\log T \tag{3b}
\]

Hence from equations (3a) and (3b), we have

\[
A = 2 - \log \%T \tag{4}
\]

On the other hand, the Beer-Lambert optical law can be expressed in exponential form as

\[
I_t = I_i e^{-\mu x} \tag{5}
\]

where \( \mu \) is the attenuation/optical coefficient and \( x \) the thickness of the medium traversed by the light. Thus, it can be shown that

\[
-\log T = 2.303 \mu x \tag{6a}
\]

or

\[
A = 2.303 \mu x \tag{6b}
\]
Comparing equations (1) and (6b) we have

\[ k = 2.303\mu \]  \hspace{2cm} (7)

Equation (7) gives a relationship between the spectroscopic coefficient \(k\) and optical coefficient \(\mu\). For a homogeneous radiation, the total linear attenuation coefficient \(\mu\) can be calculated from the half-value layer (or thickness) using the equation

\[ \mu = \frac{0.693}{x_1} \]  \hspace{2cm} (8)

where \(x_1\) is the distance traveled by the light when

\[ I_r = \frac{I_i}{2}. \]

**MATERIALS AND METHODS**

**Materials**

The materials used in carrying out the experiments include: dark room, optical glass filters (436-700nm), rectangular box (30cm×180cm), electric bulbs (40W, 200W), power source, connecting wires, multi-meter, photocell, lamp holders, retort stand and clamps, rubber pipes (5cm, 10cm diameter), plant pots, roselle seeds, loamy soil, thermometer, sole tape and traveling microscope.

**Experiments**

The experimental techniques employed in this research work include measurements of intensities of incident coherent colors of light at various distances in air. Also, the intensities of incident and transmitted colors through roselle leaf were measured. Others include measurements of growth of roselle and its phototropic response to color stimuli. In all the experiments, all factors other than light were kept constant for all plants. We kept the duration of light the same so that differences observed were due to wavelength and not how long the plants received light. The experimental procedures are presented as follows:

**Germination of roselle (hibiscus sabdariffa)**

Loamy soil was made up of sand, silt and clay in the ratio 2:2:1 respectively. The prepared loamy soil was mixed with cow dung and equal amounts were put in similar seedling pots. Equal number of viable roselle seeds identical in size and weight were planted in the soils in the pots. Equal quantity of water was also added at equal intervals of time to the soil mixture in each pot throughout the period of the experiment. The germination of the seeds in each pot under different colors was monitored and recorded.

**Measurement of height of vegetable roselle**

The experimental set up is illustrated on Figure 1. The optical glass filter was fitted to one end of short tube and the other end joined to a bigger tube. The tubes were painted black to prevent reflection or transmission of white light from the bulb to the surroundings.

The day the seeds were planted in the pots, each pot was placed under a particular color at suitable distances from the source of the color. The period of germination of seeds for each color was reported. The height and thickness of plants in each pot were measured using traveling microscope and vernier calipers respectively as in Table 1. The temperature was monitored by means of a temperature probe placed alongside the plants in the pots since heating due to the light can cause change in temperature and hence photosynthesis and growth. This
was done by adjusting the intensity of the light incident on the plant by moving the bulb toward or away from the plants.

**Measurements of phototropic response to different colors**

A rectangular box of width 30cm and height 180cm with open ends for free air circulation between the top and bottom was constructed (Figure. 2). On each face of the box a hole of diameter 2cm was made equidistant from the brim of the pot. Filters (436, 470, 540, 578, and 700nm) each fixed at one end of joined tubes were used to close the 2 cm diameter holes in such a way that the axis of the tubes supported by retort stand and clamp were perpendicular to the faces of the box. The filters were illuminated by a 40 w bulb suspended equidistant from the plant inside the box. The 2cm diameter holes determined the amount of each color that entered the box per unit area at a time. The roselle seed was planted in the center of the pot so that the growing plant was equidistant from the filters and the source of light. After 2 days the pot and the plant were transferred into the box.
placed in a dark room. The color towards which the plant bent first was noted. The optical filter towards which the plant bent first was removed and the corresponding 2 cm diameter hole was completely closed by a black polyethylene. This procedure was repeated for the remaining filters until the color with least phototropism was identified. The whole procedure was repeated five more times. The trend or order in which the colors of white light favor phototropism was established.

Measurements of intensities of colors of white light at different distances in air

A 200W bulb was suspended in the rectangular box equidistant from the optical filters covering the 2 cm diameter holes. The coherent beam from each optical filter was used to illuminate a photocell connected in series with a galvanometer. The current due to the coherent beam was measured at various distances from the filter (Table 2).

### RESULTS AND DISCUSSIONS

#### Germination of roselle seeds

Viable roselle seeds of the same average size and weight were selected, planted under the same conditions and allowed to germinate under different colors of visible light. The procedure was repeated five times. In all cases, the seeds germinated after two (2) days of planting. There was no remarkable difference in time to ascertain under which particular color the seeds germinated first.

#### II.2 Height and thickness of vegetable roselle

The heights of plants grown under different colors were measured and recorded in Table 1. The results show that blue colors (436 and 470nm) and red (700nm) light favor growth most and least for yellow color (578nm). This implies that plants grown under low intensity lights (blue and red) toward the ends of visible spectrum were taller.

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**Table 2.** Intensities of colors at fixed (column) and varying (row) distances, x in air

<table>
<thead>
<tr>
<th>Color (nm)</th>
<th>x=0</th>
<th>x=2</th>
<th>x=4</th>
<th>x=6</th>
<th>x=8</th>
<th>x=10</th>
<th>x=12</th>
</tr>
</thead>
<tbody>
<tr>
<td>436</td>
<td>2.4</td>
<td>2.0</td>
<td>1.8</td>
<td>1.6</td>
<td>1.4</td>
<td>1.2</td>
<td>1.0</td>
</tr>
<tr>
<td>470</td>
<td>17.7</td>
<td>14.0</td>
<td>12.0</td>
<td>10.5</td>
<td>8.5</td>
<td>7.0</td>
<td>6.0</td>
</tr>
<tr>
<td>490</td>
<td>21.4</td>
<td>16.0</td>
<td>12.0</td>
<td>11.0</td>
<td>10.0</td>
<td>6.0</td>
<td>4.0</td>
</tr>
<tr>
<td>520</td>
<td>56.4</td>
<td>36.0</td>
<td>32.0</td>
<td>28.0</td>
<td>20.0</td>
<td>15.6</td>
<td>8.0</td>
</tr>
<tr>
<td>540</td>
<td>20.5</td>
<td>13.0</td>
<td>9.0</td>
<td>8.0</td>
<td>5.0</td>
<td>3.0</td>
<td>2.0</td>
</tr>
<tr>
<td>546</td>
<td>11.2</td>
<td>8.0</td>
<td>7.0</td>
<td>6.0</td>
<td>5.0</td>
<td>4.0</td>
<td>2.0</td>
</tr>
<tr>
<td>578</td>
<td>2.8</td>
<td>2.5</td>
<td>2.2</td>
<td>2.0</td>
<td>1.8</td>
<td>1.6</td>
<td>1.4</td>
</tr>
<tr>
<td>700</td>
<td>2.19</td>
<td>2.0</td>
<td>1.8</td>
<td>1.65</td>
<td>1.6</td>
<td>1.35</td>
<td>1.2</td>
</tr>
</tbody>
</table>
than those under high intensity lights (green-yellow) in the middle of the visible spectrum. This indicates that growth in plants does not depend on the magnitude of the energy of photons but the ability of the plant to absorb certain colors. The thickness in most cases slightly decreases with increasing number of days. This is in line with previous experimental reports that plants grown in total darkness gradually shrink and eventually die (Ann, 1999). The control experiment was carried out on an open window. It was observed that the height of plants in the control experiment was shorter and more vegetative than those of the test experiments in the dark room.

**Phototropic response**

It has been observed that phototropism in vegetable roselle is a function of wavelength of the colors of white light. However, the dependence is not linear. The phototropism is favored in this order: red (700nm), blue (436nm), green (549nm) and yellow (578nm) indicating that the plant has higher affinity or response to wavelengths (red and blue) at the extremes of the visible spectrum favor phototropism in vegetable roselle than the colors of high intensity at the middle. This implies that phototropism in vegetable roselle does not depend on the magnitude of the photon energies of the colors of white light but the ability of the plant to absorb certain colors of light.

**Intensity of various colors**

From measurements at fixed points (Table 2 or Figure 4(a)), the intensity of light changes along the colors. For fixed distances, the intensity is highest in the middle
Table 3. %T of colors at fixed (column) and varying (row) distances, x from source

<table>
<thead>
<tr>
<th>Color (nm)</th>
<th>X=0</th>
<th>x=2</th>
<th>x=4</th>
<th>X=6</th>
<th>x=8</th>
<th>x=10</th>
<th>x=12</th>
</tr>
</thead>
<tbody>
<tr>
<td>436</td>
<td>100</td>
<td>84.7</td>
<td>76.2</td>
<td>67.8</td>
<td>59.3</td>
<td>50.8</td>
<td>42.4</td>
</tr>
<tr>
<td>470</td>
<td>100</td>
<td>79.1</td>
<td>67.8</td>
<td>59.3</td>
<td>48.0</td>
<td>39.5</td>
<td>33.9</td>
</tr>
<tr>
<td>490</td>
<td>100</td>
<td>74.9</td>
<td>56.1</td>
<td>51.5</td>
<td>46.8</td>
<td>37.3</td>
<td>18.7</td>
</tr>
<tr>
<td>520</td>
<td>100</td>
<td>63.9</td>
<td>56.8</td>
<td>49.7</td>
<td>35.5</td>
<td>30.0</td>
<td>14.2</td>
</tr>
<tr>
<td>540</td>
<td>100</td>
<td>63.4</td>
<td>43.9</td>
<td>39.0</td>
<td>24.4</td>
<td>14.6</td>
<td>9.8</td>
</tr>
<tr>
<td>546</td>
<td>100</td>
<td>71.3</td>
<td>62.4</td>
<td>53.4</td>
<td>44.6</td>
<td>9.9</td>
<td>6.6</td>
</tr>
<tr>
<td>578</td>
<td>100</td>
<td>89.1</td>
<td>76.8</td>
<td>71.6</td>
<td>64.4</td>
<td>35.8</td>
<td>17.8</td>
</tr>
<tr>
<td>700</td>
<td>100</td>
<td>91.3</td>
<td>82.2</td>
<td>73.1</td>
<td>61.6</td>
<td>54.8</td>
<td>61.6</td>
</tr>
</tbody>
</table>

Figure 5. Variation of %T with (a) distance and (b) wavelength of colors in air

(green region, 520nm) and drops in both directions towards red and blue (Figure 4(b)). Also, the results show that the intensity of light decreases with increasing distance from the source. The decrease in intensity is faster toward the red and blue regions of the electromagnetic spectrum.

Percentage transmittance %T of colors

Figure 5(a) shows that the percentage transmittance (%T) of the seven colors of white light in air decreases with increasing distance from the source (filter) and at fixed points Figure 5(b) the %T increases towards the ends of the visible electromagnetic spectrum. That is, green light has the minimum %T in air.

Percentage transmittance of colors in roselle leaf

Figure 6 shows that the %T of colors in roselle leaf is opposite that in air, that is, in leaf green color has maximum %T as opposed to minimum %T in air. The molecules or atoms in air do not contain colored
Table 4. Intensities of colours in roselle leaf

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>$I_0$ (µA)</th>
<th>$I$ (µA)</th>
<th>%T</th>
</tr>
</thead>
<tbody>
<tr>
<td>436</td>
<td>27</td>
<td>2</td>
<td>7.4</td>
</tr>
<tr>
<td>470</td>
<td>40</td>
<td>4</td>
<td>10.0</td>
</tr>
<tr>
<td>490</td>
<td>44</td>
<td>4</td>
<td>9.1</td>
</tr>
<tr>
<td>520</td>
<td>60</td>
<td>26</td>
<td>43.3</td>
</tr>
<tr>
<td>540</td>
<td>34</td>
<td>4</td>
<td>11.8</td>
</tr>
<tr>
<td>546</td>
<td>28</td>
<td>2</td>
<td>7.1</td>
</tr>
<tr>
<td>578</td>
<td>84</td>
<td>14</td>
<td>13.0</td>
</tr>
<tr>
<td>700</td>
<td>89</td>
<td>14</td>
<td>16.0</td>
</tr>
</tbody>
</table>

Figure 6 Variation of %T with wavelength of colors in roselle leaf

Pigments like chlorophyll in plant leaves. Previous studies have revealed that these pigments (chlorophyll, accessory pigments, and enzymes) absorb colors of white light. For example, it has been reported that chlorophyll reflects green light and absorbs all the other colors of white light and that is why plant leaves appear green to the eye (Ann, 1999). The high %T of green light in roselle leaf confirms that a large proportion of the green light is not absorbed but it is partly transmitted and partly reflected. Similarly, in the case of the other colors, especially red and blue, large proportions of them are partly transmitted and partly absorbed by the leaf. The part of red or blue light absorbed by plant is used in photosynthesis for plant growth. The study of %T of colors of light in air and roselle leaf has shown that attenuation of light in a medium largely depends on the atoms or molecules of the pigments present in the medium. The low %T of red and blue colors in roselle leaf may be attributed to Compton scattering and photoelectric absorption processes. However, photoelectric process is expected to prevail in plant growth since absorption of energy is involved. For example when an incident photon of red or blue light has energy greater than the binding energy of an electron in an atom of roselle leaf, the photon can ionize the atom by ejecting electrons from a shell. The incident photon gives up all its energy to the atom and the photoelectron is ejected with kinetic energy. The vacant site in the shell is then filled by an electron jumping inwards from another shell further away from the nucleus. Photoelectric process does not involve scattering because the incident photon gives up all its energy to the leaf and cease to exist. Thus, the energy absorbed is used to ionize or excite atoms or electrons of the photosystem I pigments in the leaf. Photosynthesis begins when light strikes pigments and excites their electrons. The energy passes rapidly from molecules to molecules until it reaches a special chlorophyll molecule called p700, so named because it absorbs light in the red region of the spectrum at 700 nm (Leal, 2007). When this happens, electrons themselves transfer energy between molecules. The p700 uses the energy of the excited electrons to boost its own energy to a level that enables an adjoining electron acceptor molecule to capture them. The electrons are then passed down a chain of carrier molecules, called an electron transport chain. The electrons are passed from one carrier molecule to another in downhill direction, like individuals in bucket brigade passing water from the top of a hill to the bottom. Each electron carrier is at a lower energy level than the one before it, and the result is that electrons release energy as they move down the chain. At the end of the electron transport chain lie the molecules nicotine adenine dinucleotides (NADP). Using the energy released by the flow of electrons from the electron transport chain combine with a hydrogen ion and NADP⁺ form NADPH.

When p700 transfers its electrons to the electron acceptor, it becomes deficient in electrons. Before it can
Table 5 Absorption coefficients and half-value thickness of colors of light in air

<table>
<thead>
<tr>
<th>Colour (nm)</th>
<th>Energy (eV)</th>
<th>µ (cm⁻¹)</th>
<th>K (cm⁻¹)</th>
<th>x₁/₂ (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>436</td>
<td>2.845</td>
<td>0.0714</td>
<td>0.1644</td>
<td>9.71</td>
</tr>
<tr>
<td>470</td>
<td>2.640</td>
<td>0.0914</td>
<td>0.1829</td>
<td>7.58</td>
</tr>
<tr>
<td>490</td>
<td>2.532</td>
<td>0.1271</td>
<td>0.2927</td>
<td>5.45</td>
</tr>
<tr>
<td>520</td>
<td>2.385</td>
<td>0.1386</td>
<td>0.3192</td>
<td>5.00</td>
</tr>
<tr>
<td>540</td>
<td>2.298</td>
<td>0.1829</td>
<td>0.4212</td>
<td>3.79</td>
</tr>
<tr>
<td>546</td>
<td>2.273</td>
<td>0.1257</td>
<td>0.4895</td>
<td>5.51</td>
</tr>
<tr>
<td>578</td>
<td>2.147</td>
<td>0.0571</td>
<td>0.1315</td>
<td>12.14</td>
</tr>
<tr>
<td>700</td>
<td>1.773</td>
<td>0.0457</td>
<td>0.1062</td>
<td>15.16</td>
</tr>
</tbody>
</table>

Figure 7 variation of (a) absorption coefficient and (b) half value-thickness with energy

function again, it must be replenished with new electrons. Photosystem II accomplishes this task. As in photosystem I, light energy activates electrons of the photosystem II pigments. These pigments transfer the energy of their excited electrons to a special photosystem II chlorophyll molecule, p680 that absorbs light best in the red region at 680nm. Just as in photosystem I, energy is transferred among pigment molecules and is then directed to the p680 chlorophyll, where the energy is used to transfer electrons from p680 to its adjoining electron acceptor molecule.

From the photosystem II electron acceptor, the electrons are passed through a different electron transport chain. As they pass along the cascade of
electron carrier molecules, the electrons give up some of their energy to fuel the production of ATP, formed by the addition of one phosphorus atom to adenosine diphosphate (ADP). Eventually, the electron transport carrier molecules deliver the photosystem II electrons to photosystem I, which uses them to maintain the flow of electrons to p700, thus restoring its function.

P680 in photosystem II is now electron deficient because it has donated electrons to p700 in photosystem I. P680 electrons are replenished by the water that has been observed by the plant roots and transported to the chloroplasts in the leaves. The movement of electrons in photosystem I and II and the action of an enzyme split the oxygen, hydrogen ions and electrons. The electrons from water flow to photosystem II, replacing the electrons lost by p680. Some of the hydrogen ions may be used to produce NADPH as the end of the electron transport chain, and the oxygen from the water diffuses out of the chloroplast and is released into the atmosphere through pores in the leaf. Figure 7(a) shows that green color has the highest absorption coefficient in air and decreases towards the red and blue colors at the ends of the visible spectrum. Figure 7(b) indicates that green color has minimum half value-layer in air which increases towards the red and blue colors i.e. Figure 7(b) is the mirror image of Figure 7(a).

SUMMARY AND CONCLUSIONS

In this work, we have reported that the intensities of colors in air decrease with increasing distance. At fixed distances in air, green light has maximum intensity and generally the intensity of colors decreases towards red and blue lights at the ends of the visible spectrum. The observed high intensity of green light in air is a signature that air molecules do not absorb green light but reflect and scatter it. Similarly, green color has the highest transmitted intensity in vegetable roselle leaf. In the case of observed low transmitted intensity of blue and red lights in leaf indicates that these colors are poorly transmitted i.e. chlorophyll in roselle leaf is a good attenuator of red and blue lights. This means that red and blue lights transfer their energies to chlorophyll electrons during photoelectron absorption process and the energy transferred is used in photosynthesis.

The calculated percentage transmittance (%T) of colors in roselle leaf (at x = 0) is maximum for green light and it decreases towards the end of the visible spectrum. In air at various distances (x>0), %T of green light is minimum and increases towards the ends of the visible spectrum. The maximum %T of green light in leaf signifies that chlorophyll is a good reflector of green light and the minimum %T of green light in air portrays those air molecules which are void of chlorophyll and accessory pigments are good absorbers of green light. This means that the process that will dominate depends on the wavelength of radiation and the number of pigment/enzyme molecules present in the medium.

In another vein, it has been observed that the absorption coefficient of green light in air has the same pattern similar to that of intensity while that of half-value layer in air takes the pattern of %T. Thus, the explanation given for intensity holds good for absorption coefficient and that of %T satisfies half-value layer.

RECOMMENDATIONS

We have studied plant growth under various colors of white light and identified colors that favor phototropism/growth. We have also explained the growth mechanism in terms of radiation processes. However, there is still room to improve on the results. We make the following suggestions for readers who want to extend our work:

(a) Different types of plants should be used instead of one plant
(b) A turntable of suitable period of rotation can be designed and constructed to study phototropism in plants using coherent light or direct sunlight
(c) The effect of colors on nutritional and medicinal values of plants can be investigated
(d) Economic values of plants grown under different colors and different chemical regulators can be compared

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