Illuminating the Impact of Diverse Lighting Environments on Barley Plant Photosynthesis

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ABSTRACT

Hordeum vulgare, known as Barley in English and Jamara in Nepali, is used in the Dashain festival traditionally. For this project, the seeds of Barley were collected from the Kathmandu district of Nepal and observed in three different samples. Seeds sowed in this study were kept under different light conditions. The samples were kept under regular sunlight, LED light source with a color temperature of 6500K and in a dark room with no light source separately for a period of 15 days. If the plants were exposed to various kinds of light it was observed that growth of the plants is influenced by types of light. It was also found that each of the above-mentioned sources of light affected the plant growth differently. Out of the three samples that were taken; the first sample was exposed to direct sunlight while the second sample was exposed to light with a daylight color temperature of 6500 Kelvin and the third sample was placed in a room with no exposure to light. This experiment drew conclusions based on the differences in growth rate, the color of the leaves, the number of branches developed from a seed, the formation of roots, and the strength of anchorage.

Keywords:
Photosynthetic Reaction Centers, Photosynthetically Active Radiation, Bose-Einstein condensate, Electron Transfer, Barley

1. INTRODUCTION

Photosynthesis is one of the most diverse and important phenomena in the sphere of botany: Thus it contributes to stocking people up with basic needs – food fibers, and other useful items, it also contributes in a way to supporting life on earth in one or the other forms. It will be appropriate to make a brief detour before proceeding further, to introduce the oxygenic photosynthetic organisms which are the plant, algae, and cyanobacteria that can use light energy to fix change carbon in the form of carbohydrate probably carbonates, sugars, and starch from the inorganic carbon in the form of carbon dioxide (CO_2) and water (H_2O) and liberate oxygen molecules or O_2 into the environment.

1.1 Role of radiation in photosynthesis

Light energy $+ 6CO_2 + 12H_2O \longrightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O$

The above general equation of photosynthesis exposes the fact that the oxygen molecules released into the atmospheric space are produced through water oxidation and not carbon dioxide. In photosynthesis, the processes where light is active occur in the chloroplast. In the photosynthetic process, the chloroplast produces ATP and NADPH by utilizing light. Here, water decomposes into oxygen, protons, and electrons. Thus, protons and electrons move through the chloroplast and generate energy-storing substances, namely ATP and NADPH. The Calvin Benson cycle, or the dark reactions, then makes use of the ATP and NADPH to convert carbon dioxide into carbohydrates [2] [3]. All of this happens at the chloroplast stroma. This whole process of using sunlight to make food, shuffling energy around, and managing carbon is crucial for the existence of plants [3] [4].

UV-B radiation may modify canopy morphology, lower photosynthetic and auxiliary pigments, reduce PAR penetration, affect stomatal function, and change canopy shape all of which could indirectly delay the assimilation of photosynthetic carbon. UV-B radiation may therefore restrict the yield of numerous plant species. Elevated PAR intensity resulted in reduced leaf length and width, plant height, and fresh weight of aerial parts while increasing the dry weight of the same. Increased UV-B irradiation was linked to decreased plant height, leaf expansion, and fresh and dry aerial part weight. It is noteworthy that elevated PAR intensity significantly mitigated the adverse impact of UV-B radiation on plant shape and growth [5].

2. METHODOLOGY

Three newly planted barley seeds were taken and put under different light conditions to observe the effect of light on photosynthesis. For the sake of clarity and identification, the plants were named Sample A, Sample B, and Sample C. Sample A was put under direct sunlight with no other light source, Sample B was kept under an artificial source of light, and Sample C was kept in a dark room with no other source of light. Sample A and Sample B were exposed to their respective light sources regularly for 8 hours for 15 days. Sample C was not introduced to any light source during this timeframe. Each of these Samples was provided with a total of 40 milliliters of water at intervals of 24 hours.

After the changes were thoroughly observed and the numerical data were noted, methods like graphs and charts were made for interpretation Matplotlib and Pandas libraries in Python programming language were used for the numerical representation in graphs and charts. The graphs plotted through these Python libraries were crucial to draw accurate conclusions from this research.

3. ELECTRON TRANSPORT CHAIN AND CHLOROPHYLL

It is a biochemical procedure that takes place in the chloroplast structure existent within cells of green plants with the help of chlorophyll pigments which assist in the capture of light energy. The process of photosynthesis can be broken down into two stages: the light-dependent phase of the photosynthesis process and the light-independent phase of the photosynthesis process. In the light-dependent reactions of photosynthesis, water molecules are oxidized into O2, ATP, and NADPH whereas in light-independent reactions CO_2 is reduced to sugar-like glucose utilizing ATP and NADPH formed in the light-dependent reaction [1] [4]. Blue and red light pass through the cell and get absorbed by chlorophyll while green light is reflected and makes the plant appear green. All of the light reactions occur in the thylakoid membrane while the dark or the Calvin cycle occurs in the stroma of the Chloroplast. While the raw materials for photosynthesis include water and carbon dioxide the output that is formed is glucose and oxygen gas. Cellular respiration is the process, which is the opposite of photosynthesis through which glucose as well as oxygen are synthesized into carbon dioxide and water, and in the process, energy is released [4] [6].

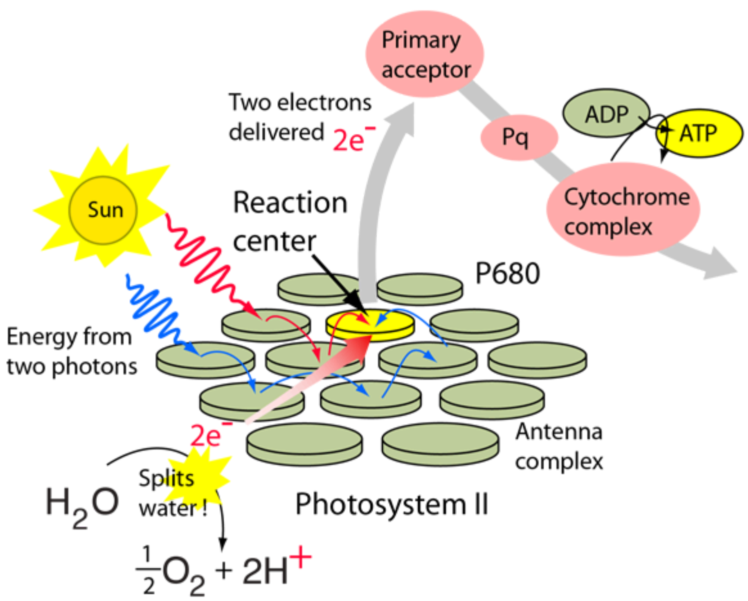


Fig 3.1 Random Movement of Excitons Through Chlorophyll Molecules [7]

Firstly, the light energy is absorbed by the light-harvesting antenna complexes and then transferred to the photosynthesis reaction center, where the primary charge separation and electron transfer occur. Photosynthetic reaction centers from purple bacteria are the best-known membrane protein complexes [4] [6]. Several integral membrane proteins and co-factors are present in the photosynthesis reaction center. The three-dimensional structure of the reaction center has been determined from the photosynthetic bacterium Rhodobacter sphaeroides by x-ray diffraction at the resolution of 2.2 Å [8] [9].

The reaction center from Rhodobacter sphaeroides contains three protein subunits: H (Heavy), M (Medium), and L (Light). The L and M subunits form the core and include two special pair bacteriochlorophylls (D), two monomer bacteriochlorophylls (BchlA and BchlB), two bacteriopheophytins (BPA and BPB), one non-heme iron, and two ubiquinones (Q_A and Q_B) as electron acceptors. These pigments are arranged in nearly symmetrical branches, 'A' and 'B' [9].

After chlorophyll gets excited after absorbing light energy from the photons from the light source, the following chemical reactions occur in sequence [2].

$$2H_2O \rightarrow 4H^+ + 4e^- + O_2$$

Here, the oxygen gas is released and the emitted electrons begin the electron transport chain. In photosystem I, Nicotinamide Adenine Dinucleotide Phosphate ion or $NADP^+$ accepts electrons along with protons (H^+) from the stroma, forming NADPH [10]:

$$NADP^+ + 2e^- + 2H^+ \rightarrow NADPH$$

Protons (H^+) are pumped from the stroma into the thylakoid lumen, creating a proton gradient.

$$H^+ \ + \ (stroma) \rightarrow H^+ + (thylakoid\ lumen)$$

Protons (H^+) flow back into the stroma through ATP synthase complexes, driving the synthesis of ATP from ADP and inorganic phosphate (Pi) [10].

$$ADP \ + \ Pi + H \rightarrow ATP$$

4. LINK BETWEEN PHOTOSYNTHESIS AND THE FIFTH STATE OF MATTER

A recent research carried out at the University of Chicago points towards a seemingly unexpected association between photosynthesis and the occurrence of exciton condensates- a phenomenon in the field of physics that renders movement of energy in certain materials possible. When the energy is supplied an electron can jump across the leaf and instead of the hole it makes on the other side of it an electron begins a petrification process that results in the formation of sugars in the plant. When these electrons and holes are combined, the structure is called an exciton, and when engaged in the movement of these structures, the routs look like the Bose-Einstein condensate, this material state is also called the fifth state of matter [6].

The excitons can cooperate with each other to get into the same quantum state and hence energy can be transported through the material with no form of resistance [8]. Exciton condensates have only been observed when the sample is cooled to temperatures far below that which is considered room temperature [11].

This state was described where a group of atoms is regarded as a single quantum system with homogeneous characteristics, the atoms are no longer distinct entities and coalesce to make up one compound state. This leads to special properties like, non-Newtonian fluids which are resistless to viscous forces and therefore have a viscosity of zero, the substance is a superconducting substance among others.

With the de-excitation generally occurring at temperatures a lot lower than the room temperature, the researchers noted the existence of exciton-like behaviors in leaves as they conducted photosynthesis [6]. By simulating molecular interactions of photosynthesis with the help of a computer nearly it was found that excitons in leaves could exhibit patterns similar to exciton condensate boson which means it is a boson – even of matter at or above room temperature and in a disordered state. Even if these condensates are not wholly effective, these researchers said that it increased energy transport and estimated the efficiency could be doubled. This link creates opportunities to synthesize ambient conditions for future technologies' materials when it was not possible before, and it defies the long-held view that specific conditions are necessary for optimizing exciton condensates [12]. The results share such a conclusion with a decade of investigation highlighting that a local electron correlation plays a crucial role in elucidating complicated natural phenomena [11].

5. Impact of Light Intensity on Photosynthesis

One of the key elements required by plants to produce food and control different developmental processes is light. However, exposure to either high or low light levels is a significant stressor that has a profound impact on plant development. Because plants absorb more light during photosynthesis than is necessary for optimal growth, high light levels can be stressful for plants. Similar to this, low light exposure causes variations in the pigment composition and lowers the plant's stomatal conductance, both of which lower photosynthetic efficiency [6] [13].

5.1 High Light

The former is the aggressive light that tends to overwhelm the photosynthetic apparatus, thus occasioning photoinhibition. This is a condition in which increased light energy causes a decline in quantum efficiency, the number of useful electrons created for each photon absorbed, thereby lowering the photosynthetic rate. Photosystem II (PSII) is an especially sensitive structure manifested by bleaching of the reaction centers and D1 core proteins under excess light-induced oxidative stress [13] [14]. This leads to the photoinactivation of PSII, and the repair processes cannot deal with the extent of damage. Moreover, when the water molecules absorb more energy than is necessary for Photosystem II (PS II), energy is created in other forms such as fluorescence and heat, which also impacts PSI. It therefore becomes important to understand these processes so as to facilitate the development of strategies that would enhance plant growth and increase photosynthesis efficiency [15] [16].

5.2 Low Light

Abiotic factors such as light have a close relationship with plant growth especially as it influence the photosynthetic process leading to changes in photosynthetic pigments. Some of the plant responses that are likely to take place in order to adapt to this condition include amplification of the size of the leaves as well as enhancement of chlorophyll production with an aim of improving light capture. This adaptation which is based on the absorptance of light and quantum mechanics is to increase the size of the leaf area and also the quantity of chlorophylls in order to capture more light energy [16]. Research on plant types such as nine-bark species (P. amurensis and P. opulifolius) reveals that when light conditions are low, chlorophyll concentrations increase for the purpose of enhanced light capturing. Despite this photochemical activity of photosystem II (PSII) and the rate of carbon assimilation are reduced and thus, how rate of efficiency of photosynthesis comes about as a delicate balance between several factors [14] [15].

5.3 Enhancing light capture

Light intensity and spectral properties strongly influence the efficiency of photosynthesis in plants. Several strategies for optimizing light harvesting and utilization in plants have been investigated to increase photosynthetic efficiency.

The reduced antenna size in their photosystem allows plants to penetrate dense canopies more accurately, reducing shade and increasing overall photosynthetic efficiency. Light-harvesting complexes from cyanobacteria-like organisms, plants can extend their light-absorbing range chlorophyll d and the cyanobacterial genes encoding can absorb light in the far-red region (up to 750 nm), increasing the number of available photons by 19% [17]. Solar light with a photon flux spectrum ranging from 300 has been developed to 4000 nm is plotted below to generalize the available radiation at different wavelengths. This highlights how the solar energy can be reused to enhance the photovoltaic effect.

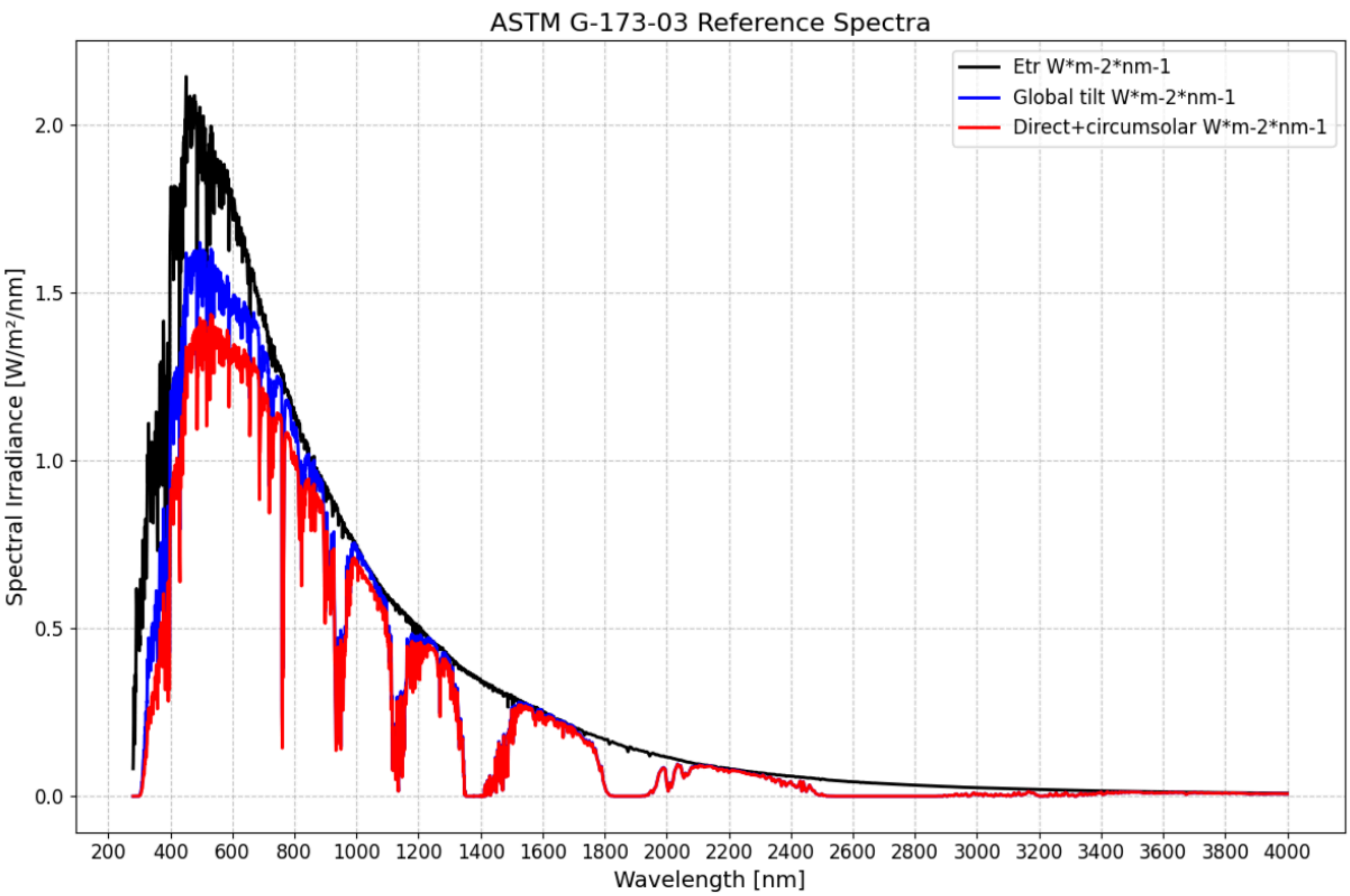


Fig 5.3.1 Plot of reference Spectra ASTM G-173-03 highlighting the photon flux spectrum between (300-4000) nm

The graph above, based on the ASTM G-173-03 reference spectra, presents an outline of the sun spectrum from 300 to 4000 nm. It highlights the irradiance to be had across specific wavelengths, emphasizing the capability for harnessing extra of the sun spectrum for photosynthesis. This consists of the UV, visible, and close-to-IR regions.

The scene (300 - 4000 nm) is wherein conventional photosynthesis occurs, making use of chlorophylls and carotenoids to capture light electricity. The Black Line represents the entire extraterrestrial solar irradiance (Etr Wm-2nm-1), indicating the whole-to-be-had sun electricity. The Blue Line represents the worldwide tilted irradiance, showing the quantity of sun electricity incident on a tilted floor. The Red Line represents the direct circumsolar irradiance, indicating the direct beam and circumsolar contribution. This shows how classical photosynthesis uses only a small portion of the spectrum. This gives an idea of how the graph's additional near-IR irradiance can be used to engineer plants to use light longer than 700 nm [18] [19].

6. RESULT AND DISCUSSION

The cool temperature of the soil surrounding, wet soil moisture, and ideal light energy are prime factors that help in the growth of the plant [20]. The availability of each of these conditions plays a vital role in the development phase of a growing plant. In this experiment, we observed that the specimen placed under the artificial light grew into the best state compared to its other counterparts.

According to the factors mentioned above, the most ideal conditions were met by the specimen placed under the artificial light. It had an ideal source of light with a cool temperature, which is favorable for the growth of the barley plant [13] [14] [15]. The cool temperature helped to keep the soil moist for most of the duration of the experiment by minimizing the degree of evaporation. Due to these factors, the growth of the plant under artificial light was best among the others.

6.1 Comparison based on Growth Rate

Days of Emergence	Dark (Growth in cm)	Sunlight (Growth cm)	Bulb (Growth cm)
0	0	0	0
1	0	0	0
2	0	0	0
3	0	0	1
4	1.2	0	4.9
5	4.1	1.7	9
6	8	5.6	12
7	13.7	7.7	16.2
8	17.7	9.2	19.2
9	20.7	10.7	22
10	23.2	11.9	23.8
11	26.7	12.8	25
12.5	28.7	13.6	26.4
13	30.2	14	27.6
14	30.2	14.7	29.3
15	30.4	16.5	30.5
16	30.4	18.1	31.2
17	30.4	18.8	31.8
18	30.4	19.2	32.3
19	30.4	19.7	32.7

Table 6.1.1 Comparison of Plant Growth Under Different Lighting Conditions

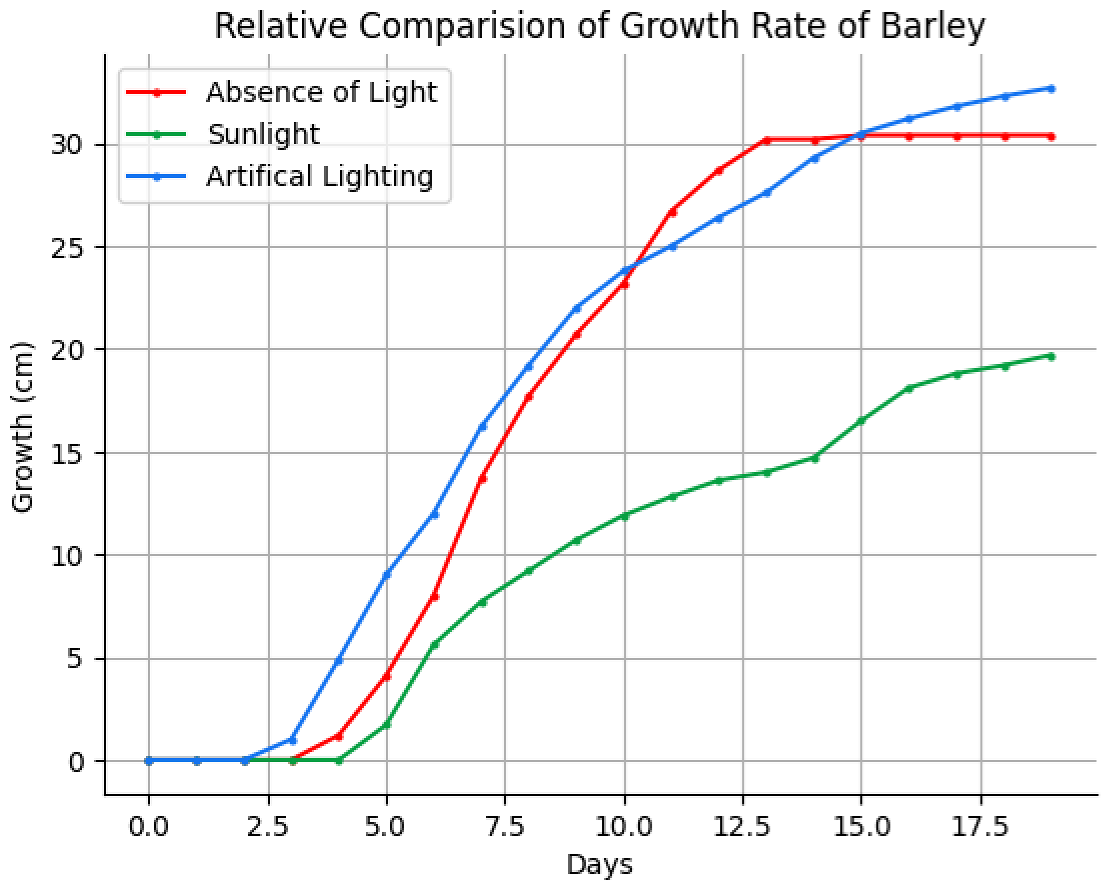


Fig 6.1.1 Graphical Plot of Rate of Growth of the Specimens

The sample under the 6500K light bulb sprouted earliest on the third day. It had the highest average growth rate of all other samples and grew dramatically up to the 10th day at an astounding height of 23.8 cm. This sample of seeds continued growing further but at comparatively slower rates for the remaining days of the experiment.

In the absence of light, the seeds grew from the surface of the soil on the fourth day. Though this sample of seeds had a slower rate of growth at the first 5-7 days of the experiment, their growth rate dramatically increased and eventually surpassed the growth rate of the development of the seeds put under artificial light conditions on the 10th day of the experiment. On the 10th day, the height of the samples in the absence of light was almost the same as the height of the plants in the presence of a light bulb at 23.2 cm. For the next 5 days, the seeds surpassed the growth rate of the sample under the artificial light, but after the 15th day, the 30.4 cm tall plant stopped growing completely.

On the sixth day after the experiment's start, the sample under the presence of sunlight finally sprouted. This sample was also observed to be growing at a slower rate as compared to the other two samples. Compared to the average growth rate of the other two samples, the growth rate of the seeds under the presence of sunlight was far slower. The seeds of these samples grew to only a height of 11.9 cm, which is vastly lower than the other two seed samples. At the end of the experiment, the growth of the specimen had nearly settled down at a height of 19.7 cm.

(a) (b) (c)

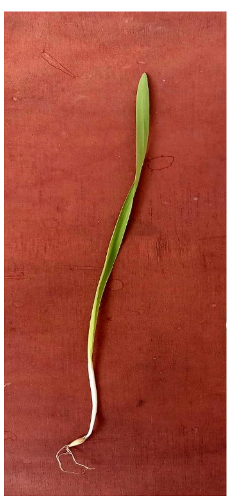
Fig 6.1.2 Growth of specimen under (a) sunlight (b) artificial lighting condition (c) dark condition

6.2 Comparison based on the quality of the plant

At the end of this experiment, out of all three samples, the specimen with the light bulb as the main light source had left with the best conditions. This sample also had the best average growth rate compared to the other two samples. On the last day of the experiment, the sample under the 6500K light bulb had grown up to a height of 32.7 cm, the sample under sunlight had grown up to 19.7 cm and the sample that was kept with no light source had grown up to 30.4 cm. The leaves of the seeds that were grown under the artificial light were deep green while the leaves in the dark condition were white. The seeds under the sunlight were green in color, however, some of the leaves had withered and died. This shows that the seeds that grew under the artificial light produced the best results and showed promise for future growth.

Through this experiment, we were able to confirm that the light energy falling on the canopy had a significant effect on the growth of the plants. The light energy of higher intensities helped the plants to grow into a healthier state. The specimen placed under the artificial light grew the best among all other specimens and it was also the best in quality. The specimen that was placed in the absence of any kind of light source didn't grow to be a healthy plant, though it could grow in terms of height. The radiation within the 400–700 nm waveband of photosynthetically active radiation (PAR) controls the photochemical reactions, converting light energy into chemical energy, through the synthesis of ATP and NADPH used to assemble carbon atoms in organic molecules in the Calvin cycle, in the reduction of NO_3 and the synthesis of amino acids and lipids (Malkin and Niyogi 2000) [3] [4] [10]. LED white light promotes growth in the upper part of the barley plant while inhibiting proper root growth in the lower portion of the plant. Led blue light can promote barley root growth and biomass accumulation even though plant height elongation is limited. The combination of red and blue LEDs produces optimal light quality for growing barley fodder by enhancing barley biomass [15] [16].

It could also be analyzed that the samples in the bright cool environments had better growth compared to the sample that was placed in a warmer environment(under sunlight) [20]. Though the sample placed under sunlight had higher exposure to light energy as compared to the other two samples placed under different light sources, it had the slowest growth rate. It is because the specimen placed in sunlight was in a much warmer state than the other samples, which severely affected the growth rate of the barley plant [21]. During the growth season, the ideal temperature ranges for barley cultivation are between 15 and 20 °C (59 and 68 °F). Frost may be tolerated by barley to some extent, but excessive cold or heat could damage the plant's development [22].



(a) (b)

Fig 6.2.1 Plant Samples Grown in Sunlight (a), Artificial Light (b)

7. CONCLUSION

Through experimental-based observation, this paper established that out of the three specimens that were put through the test the barley plant thrives best under the artificial radiation of 6500 K color temperature. This shows us that *Hordeum vulgare* grows the best in a low-radiation environment, while it doesn't survive for long under extreme conditions of radiation. Thus, the results obtained serve as evidence that light stress causes impacts on the development of plants and it is pointed out that the lighting conditions need to be effectively controlled to achieve better yield in the agricultural field. The present research outcomes present promising opportunities for more suitable control of farming in the future that might expand the current understanding of how to cultivate plants more efficiently and sustainably to feed the world's growing population. Thus, further research could be carried out on aspects like the effect of temperature, humidity and other environmental stresses on barley growth under different light conditions.

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