[NC-Rase 18]
DOI: 10.5281/zenodo.1488741

ISSN 2348 – 8034
Impact Factor- 5.070

GLOBAL JOURNAL OF ENGINEERING SCIENCE AND RESEARCHES

VERTICAL FARMING AND THE EFFECT OF RED, BLUE AND WHITE LED'S ON GROWTH AND DEVELOPMENT OF HYDROPONICALLY GROWN LETTUCE

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ABSTRACT

Vertical Farming Systems have been proposed as an engineering solution to increase the productivity per unit area of cultivated land by extending the crop production into the vertical dimension as it reduces the requirement of water to up to 70% and also saves considerable space and soil. This method of farming is ecosystem friendly and will possibly make farming possible in really difficult environments. The vertical farming can be done through hydroponics or aeroponics. In an artificial environment, the combination of LED light such as R (Red) and B (Blue) was used as it is an effective light source for plant growth and development. The parameters of light like light spectra, intensities, and durations can easily be controlled by growers in artificial growing environments. The aim of the study is to find the influences of Red, Blue and fluorescent light on plant biomass and accumulation of chlorophylls (chl), carotenoids (car), soluble proteins and sugars, and nitrates in the leaves of lettuce. Plants were hydroponically cultured in an artificial environment with a 16-h photoperiod at 24/2 ◦C (day/night), 75% relative humidity, with precise value of CO_2, and photon flux density under all three source inside growth chambers for 20. The shoot & root fresh, dry weights along with the crispness, sweetness, and shape of the plants treated with RBW and FL were higher than those of plants treated with RB. The soluble sugar and nitrate contents in plants grown under RBW treatment were significantly higher and lower, respectively, compared to those under RB treatment. These results demonstrate that supplemental light quality can be strategically used to enhance the nutritional value and growth of lettuce plants grown under RBW LED lights. This technique with precise irradiance and wavelength may hold promise in maximizing the economic efficiency of plant production, quality, and nutrition potential of vegetables grown in controlled environments.

Keywords: *hydroponics, soluble sugar, nitrate, Red, Blue and white LED's*

I. INTRODUCTION

The world population will be almost 9 billion by 2050, a significant portion of which will be the urban dwellers, requiring an increase in production of agricultural yield.

Agriculture uses 70 percent of the world's available fresh water for irrigation and rendering it unusable for drinking as it is contaminated with the fertilizers, pesticides, herbicides etc.;. Farming involves huge quantities of fossil fuels like diesel for various equipment's used. Few agronomists believe that the solution lies even more intensive industrial farming but it will result in using more agrochemicals.

This short-term solution will harm the soil and environment. If we continually generate new farmland by deforestation it will result in global warming[2]. There can be a possible solution to this problem, just grow crops indoors, under rigorously controlled conditions, in vertical farms. The vertical farming has been proposed as an engineering solution to increase the productivity per area by extending plant cultivation into vertical dimension thus enhancing the land use efficiency for crop production.

The implementation of vertical farming on a large scale involves stacking growth rooms, such as glasshousesand controlled environment rooms, on top of each other to construct food-producing high-rise buildings. The same concept can be applied at a smaller scale through vertical farming systems (VFS).These growth systems expand crop production into the vertical dimension to produce a higher yield using less floor area. For example, yield increases of 129–200% in VFS and increased profits of 3.6–5.5 US dollar·m−2 compared to conventional soil cultivation have been reported. [1]

II. THE VISION

As the population is increasing by leaps and bounds we need to focus on different techniques for agriculture. Three techniques like hydroponics, aeroponics and drip irrigation are used around the world.

*Hydroponics:*It involves the growth of plants in solutions of nutrients that are essentially free of soil.The roots of the plants are submerged in a solution of nutrients. This is frequently circulated and monitored in order to ensure that there is the maintenance of the correct chemical composition in the nutrient solution.

Aeroponics:It involvesgrowing plants in an air/mist environment with no soil and very little water.It is undoubtedly the most efficient way in vertical farming as it uses a staggering 90% less amount of water than the most efficient hydroponics systems too. It has also been observed that the plants that are grown with the aeroponics system uptake more vitamins and minerals, thus making the plants potentially healthier and more nutritious.

*Drip Irrigation:*It is a type of micro-irrigation system that allows water to drip slowly to the roots of plants, either from above the soil surface or buried below the surface. The goal is to place water directly into the root zone.

Fig. 1: Hydroponics

Fig. 2: Aeroponics

Materials and Methods:
The study was conducted in a 3.4 m × 4.15 m walk-in Controlled Environment room (CE room). Illumination was provided by 12,400 W metal halide lamps for a 16 hour photoperiod. Highly reflective plastic film was placed on the walls of the room in order to increase the diffusion of light. Room temperature ranged between 16-18 °C and

relative humidity ranged from 60% to 80%. EktronIIC sensor was used Room temperature and humidity, whichwas hanging from the ceiling in the middle of the CEroom, at 1.83 m above the ground. The CE room accommodated 2 VFS and 2 HHS, with one of each arranged on each side of the room. Preliminary measurements of photosynthetic photon flux density (PPFD) were taken.

III. LITERATURE SURVEY

Vertical Farming increases lettuce yield per unit area compared to conventional horizontal hydroponics, in this paper comparison between the conventional method and vertical farming is presented. It shows that the Vertical farming system(VFS) optimizes growing space, increases efficiency, thereby producing more crop per unit area.Here it is observed that the increase in yield can be obtained by using artificial light within VFS.

The rise of vertical farms, in this paper various techniques for the vertical farming are explained, and comparison of how the yield is increased compared to conventional farming methods, a one square block farm 30 stories high could yield as much food as 2400 outdoor acres. Also, it emphasizesconverting and using the municipal waste for irrigation.

The effects of red, blue, and white light-emitting diodes on the growth,development, and edible quality of hydroponically grown lettuce, in this paper the author suggested the use of various artificial lights for effective growth and development of plants. He has experimented and explained the comparative analysis of using the RB (Red Blue) LED, RBW (Red Blue and White) LED and FL (Fluorescent Lamp) on the development and growth of the lettuce focusing on features like the shoot, root fresh and dry weights as well as the crispness, sweetness, and shape of the plant. Along with these the protein, soluble sugar and nitrate contents in the crop were studied to get that the RBW LED leads to good quality and highly nutrition plants.

IV. PROPOSED METHODOLOGY

Various light sources such as metal-halide, high-pressure sodium, fluorescent and incandescent lamps are generally used for plant cultivation. These sources are used to increase photosyntheticphoton flux levels but it also contains unnecessary wavelengthsthat are located outside the photosynthetically active radiation spectrum and are of low quality for promoting growth.[3]

Light-emitting diode (LED) systems of Gallium–aluminum–arsenidehave several unique advantages, including the ability to control the spectral composition, a small mass and volume,durability, long operating lifetimes, wavelength specificity and narrow bandwidth, relatively cool emitting surfaces, minimum heating, and photon output that is linear with the electrical input current.
These solid-state light sources are therefore ideal for
use in plant lighting designs influences plant morphology and metabolism. LEDs emit radiation within a narrow band of the spectrum. In particular, their low operating temperature (approximately 25–35◦C), low operating voltage and physical robustness make LEDs uniquely suitable for use in inter lighting applications.[4]

The development of the plant is strongly influenced by the light quality, which refers to the color or wavelength reaching a plant's surface. Red (R) and blue (B) lights have the greatest impact on plant growth because they are the major energy sources for photosynthetic CO_2 assimilation in plants. It is well known that action spectra have action maxima in the B and Rranges. Combined RB LED lights were proven to be an effective lighting source for producing many plant species, including lettuce, in controlled environments(Shin et al., 2008).

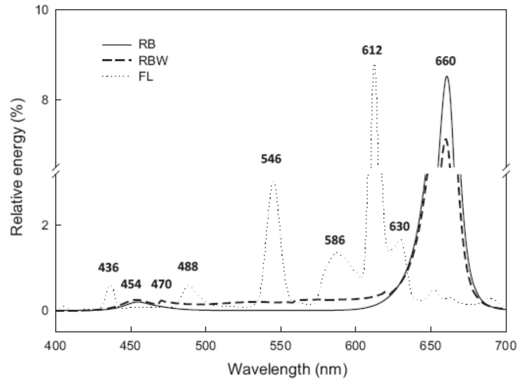

Fig. 3: Spectral distributions in the relative energy of the LED's and fluorescent Lamp.

Materials and methods

Plant material and growth conditions:

Seeds of Boston lettuce weregerminated in cubes (2.5 cm × 2.5 cm × 3.0 cm) andhydroponically grown for 15 days in anenvironmentally controlledgrowth room. The temperature was at a constant 24 ◦Cunder a light intensity of approximately 100 mol m−2 s−1 photonflux density (PFD) for 14 h with cool white fluorescent lamps.Uniform-sized seedlings of lettuce were individuallyraised in a polystyrene foam cube, then mounted into a Styrofoam plate with eight holes, and placed in a container(59 cm × 48 cm × 9.7 cm) filled with continuously aerated completenutrient in a commercial growth chamber. The nutrient solutionwas renewed every week and adjusted to pH 6 and an electricalconductivity of 1.1 mS cm−1. The photoperiod was maintainat 16 h. The air temperature, relative humidity, and CO2 levels for all treatments were respectively maintained throughout theexperiment at 24/20 ◦C (day and night), 75%, and 900 mol−1 in the growth chamber.

Light treatments:

Treatments consists of three commercially available light sources: (1) RBLEDs, (2) RBWLEDs, and (3) fluorescent lamps (FL, as the control). The peak emissions of the B (454 nm) and R (660 nm) LEDs closely coincide with the absorption peaks of chlorophylls a and b, and the reported wavelengths are at their respective maximum photosynthetic efficiency. The spectral energy distribution scans were recorded at 400–700 nm with 2-nm steps of the LEDs and FL (Fig. 3)with a calibrated spectroradiometer placed horizontally in the cabinets used for the experiments, withthe sensor covered by the glass lid of the vessel. Each treatmentwas run in a growth chamber, and the spectrum was recorded at the top of the plant canopy. The RBWLEDs had peak outputsin B and R regions with a broad spectral energy of500–600 nm. All treatments maintained a 16/8-h light/dark photoperiod and the same light intensity expressed as photosynthetic PFD of 210 mol m−2 s−1 which was measured daily above theplant canopy and maintained by adjusting the distance of the LEDsto the plant canopy. Plants were harvested at 35 days after sowing(DAS).

Plant growth measurements:

Measurements included shoot fresh weight (FW), root FW, shootdry weight (DW), root DW, shoot/root (S/R) DW, leaf area (LA), andspecific LA (SLA). Plant tissue samples were dried in a drying ovenfor 48 h at 70 ◦C before weighing. The LA (cm2) of every plant wasmeasured by an LA meter (LI-3100, LI-COR). A standard growthanalysis was used to calculate the LA index (LA/shoot DW).

Chlorophyll (chl) and carotenoid (car) contentsChl and car were eluted from the shoot DW samples (0.05 g) with1 mL 80% acetone at 4 ◦C overnight and determined by the methodsofPorra et al. (1989) and Holm (1954), respectively. The sample was then centrifuged at 13,000 × g for 5 min. The supernatant wasapplied to determinate the absorbances of chl a, chl b, and car inacetone, as measured with a spectrophotometer (U-2000, Hitachi,Tokyo, Japan), at respective wavelengths of 663, 645, and 470 nm. Concentrations (g g−1 DW) of chl a, chl b, and car were determined

Soluble sugar determination:

The content of soluble sugars was measured by the method ofFairbairn. Samples were put into a testtube, to which 5 ml of distilled water was added and mixed. After30 min in a water bath at 85 ◦C, the supernatant was collected. Thisstep was repeated twice, and then distilled water was added to avolume of 10 ml. The soluble sugar content was determined withthe sulfuric acid athrone method at a wavelength of 620 nm.

Soluble protein content:

Soluble proteins were measured by the Bradford method.Samples) were ground up in a mortar with liquidnitrogen, to which 3 ml of a phosphate-buffered solution (pH 7.0)was added. The extract was centrifuged at 13,000 × g for 15 min at4 ◦C, and 0.1 ml of the supernatant was combined with 4.9 ml of aCoomassie brilliant blue G-250 solution.After 2 min, thesoluble protein content was determined at a wavelength of 595 nm.

Nitrate determination:

The nitrate content was measured by the method of Cataldo. Briefly, samples were ground up, andthen 10 ml of hot distilled, deionized water was added. After 30 minin a water bath at 80 ◦C, the extract was centrifuged at 13,000 × gfor 10 min, and 0.2 ml of the supernatant was mixed with 0.8 mlof 5% (w/v) salicylic acid (in pure H_2SO_4) and 19 ml of 4 M NaOH.After 30 min, the nitrate content was measured at a wavelength of410 nm.

Sensory analysis:

A comprehensive survey of the sensory characteristics of shape,color, crispness, and sweetness of the fresh lettuce was conductedfor marketable acceptability using a scale of 0–6, with 6 being thehighest score, that is, 6 = like extremely, 3 = neither like nor dislike,0 = dislike extremely. Random samples from different treatmentswere separately evaluated by 50 untrained consumer panelists. Each panelistwas served 3 samples, and tested one sample at a time for everytreatment of lettuce presented in three-digit coded plates. The panelistswere also provided with water to cleanse the palate betweensamples. The sensory intensitieswere obtained by averaging theindividual intensities for the 50 subsamples.

Statistical analysis:

All measurements were evaluated for significance by an analysisof variance (ANOVA) followed by the least significant difference(LSD) test at the $p < 0.05$ level.

Table 1: Influence of light quality on shoot fresh weight (shoot FW), root FW, shoot dry weight(shoot DW), root DW, shoot/root DW, leaf area (LA), specific LA (SLA), chlorophyll (chl), chl a, chl b, and carotenoid (car) contents at 35 days after sowing.

Parameter	Light quality		
	RB	RBW	FL
Shoot FW (g)	136.3 b*	164.1 a	149.0 b
Root FW (g)	9.1 b	13.5 a	11.8 ab
Shoot DW (g)	7.02 a	7.97 a	7.17 a
Root DW (g)	0.43 b	0.62 a	0.58 a
Shoot/root DW	16.3 a	12.8 b	12.3 b
LA (cm^2)	6425 b	7435 a	7480 a
SLA ($m^2\ kg^{-1}$)	91.5 c	93.3 b	104.3 a
Chl a ($\mu g\ g^{-1}$ DW)	2954 a	2932 a	3053 a
Chl b ($\mu g\ g^{-1}$ DW)	971 a	925 a	988 a
Chl a+b ($\mu g\ g^{-1}$ DW)	3925 a	3857 a	4041 a
Car ($\mu g\ g^{-1}$ DW)	1789 a	1715 a	1825 a

V. RESULTS

Plant growth and morphology, and pigment contents. Results of the biomass measurements of lettuce influenced bythe light spectra treatments are shown in Table 1, and plantsshowed distinct growth responses to different light-quality treatments.Shoot FW and DW, and root FW and DW of the plants werethe greatest when grown under RBW light while lowest under RBlight. The shoot FW significantly increased by 10% with the RBWtreatment compared to the FL control. Plants under RB treatment had a significantly higher S/R DW compared with those under RBW and FL treatments. The LA and SLA decreasedin the order of plants grown under FL, RBW, and RB, and bothparameters under FL were significantly higher than under RB light.In addition, a normal appearance and compact morphology withvigorous roots of the lettuce plants treated with RBW lights wereobserved. However, plants grown under RB light looked small oreven severely dwarfed (Fig. 4).Chl a contents of lettuce leaves in all treatments were higherthan the respective chl b contents. However, no significant differenceswere observed in pigment contents (chl a, b, a + b, and car)regardless of the light spectra (Table 1).

Nutritional quality of lettuce plants:

Fig. 5shows the effects of light quality on the contents of soluble proteins, sugars, and nitrate in the lettuce leaves. There were no significant differences in the soluble protein content among the light treatments, but soluble sugar and nitrate contents were greatlyaffected by the light quality. The soluble sugar content in plantswas highest under RBW treatment, followed byFL treatment, and then RB treatment. On the contrary, in the RBW treatment, thenitrate content of lettuce plants was significant lower than thoseof plants under RB and FL treatments.

Sensory evaluation:

Shape, color, crispness, and sweetness are the four major marketableproperties of lettuce. To show trends in the evaluationof attributes by the panelists, results for mouthfeel and visualcharacteristics were depicted for each treatment as spider-webgraphics. Plants under RBW treatment hadhigh grades of 5–5.5 for all parameters. FL-treated plants (4.5) had a lower level for crispness than RBW-treated plants (5.5). The rangesof shape, crispness, and sweetness observed in RB plants were 2– (Fig. 5). The larger the rhombus was, the higher edible quality itrepresented. All of the sensory characteristics from RBW- and FLtreatedplants had above-average scores. Nevertheless, the shape,crispness, and sweetness of RB-treated plants were not acceptablefor the market.

Fig. 4. Growth of lettuce plants under different light qualities for 35 days after sowing. Bar indicates 7.3 cm.

ISSN 2348 – 8034
Impact Factor- 5.070

The evaluation scale was 1–6, with 6 being the highest grade

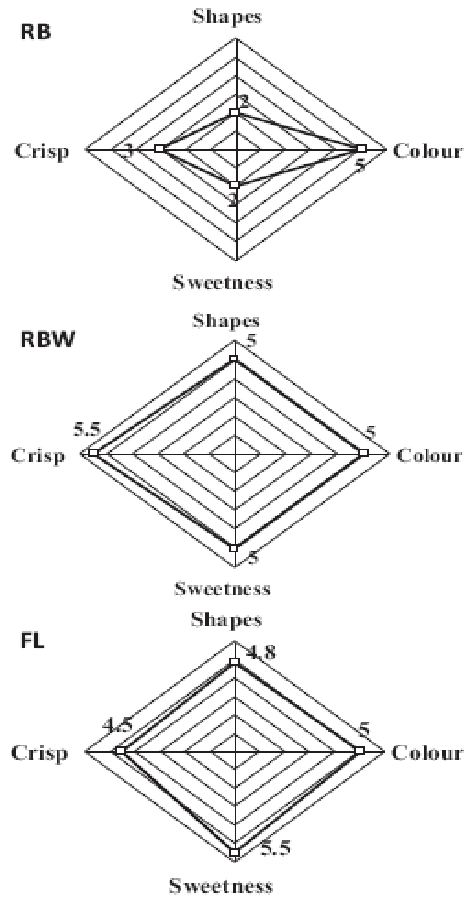

Fig. 5. Sensory analysis of the shape, color, crispness, and sweetness of fresh lettuceunder red and blue (RB) LEDs, RB and white (RBW) LEDs, and fluorescent lamps (FL). The evaluation scale was 1–6, with 6 being the highest grade.

VI. DISCUSSION

Lettuce is also a major crop grown in greenhouses worldwide and seems to be a model crop due to its fast growth and sensitivity to differentlight qualities. The spectral quality oflights is the relative intensity and quantity of different wavelengthsemitted by a light source and perceived by photoreceptors withina plant.

From the table 1 we can say that SLA: FL-treated plantshad a greater SLA than RBW- and RB-treated plants, it shows that plants treated with FL were puffy with loose shoot structure. However from the Fig. 4 the lettuce leaves androots was comparatively greater in plants grown under RBW and FL treatments than under RB treatment.

Shoot structure: The shoot structure of RBW- and RB-treatedplants had a tight appearance, butthatof RB treatments were deleterious or adversely affected plant performance.

The biomass of lettuce shoots significantly increased with RBW treatment compared to RW treatment probably due to the enlargedLA (Table 1). The larger leaf allowed greater light interception,which may have led to the significant increase in biomass. The higher SLA under RBW light is a good indicator of higher photosyntheticsurface area per unit investment in leaf tissue (Kim et al.,2004b). Vigorous roots support shoot growth by fully supplyingthe plant with water and mineral nutrition. In contrast, sprouting eedlings in which stems rapidly elongate under low irradiation orexcess water have small roots that do not take up sufficient water ormineral nutrients, which decreases plant growth. Poor roots cannotsupply sufficient water for large shoots, so plants with highS/R ratios are unsuitable for active growth (Johkan et al.,2010).

S/R DW ratio: It was suboptimal under RB light (16.3)compared to RBW light (12.8) and FL (12.3). This shows the poor growth of roots under RB light and also indicates that root induction is probably also dependent on the spectralquality of light.

Chl and car have high light absorption at 400–500 and at 630–680 nm, respectively, and low light absorption at 530–610 nm. Although different quality lights for all treatments were applied at the same PFD level, plants showed similar absorption spectra of photosynthetic pigments, chl a, b, a + b, and car(Table 1). Perhaps, the applied PFD level (210 mol m−2 s−1) hadreached a certain minimal PFD, which is essential for sufficient synthesis and activity of photosynthetic pigments and electron carriers. Saeboreported that plants with smaller chlcontents seemed to use the chl more efficiently than plants withexcessive chl. In our study, although the chl a, chl b, chl (a + b),and car contents in the leaves did not statistically differ among treatments, the chl and car contents under RBW lights were thelowest. This indicates that the lettuce plants might be using thechl more efficiently under RBW LED lights than under RB LEDlights. Although the mechanisms of changes in photochemicalsunder different supplemental light qualities are not well known, the lower values of chl and car in the RBW treatment mighthave contributed to “dilution” due to the enhancement of shoot DW under RBW treatment (Li and Kubota, 2009). Plants grownunder all treatments appeared to synthesize more chl a as it hasa wider spectrum compared to that of chl b (Table 1), and chla isthe molecule that makes photosynthesis possible.A specific light quality can be used to improve the nutritional quality of vegetables and yields in commercial production. The selected LED lights differentially affected the metabolic system ofthe investigated vegetables.

The most sensitive response was insugars, the main photosynthesis product, and their accumulation in leaves (Lefsrud et al., 2008). Therefore, changes in lights not only affect sugars, as an index of nutritional quality and content, but they also participate as signaling molecules in regulating importantvital processes. A high content of soluble sugars may be adesirable parameter in terms of food quality. The results showed that lettuce plants had the highest soluble sugar content under RBWLEDs, and this light source might be beneficial for the accumulation of soluble sugars in lettuce plants (Fig. 5).

Soluble Proteins: The amounts of soluble proteins in the plant leaves showed no significant differences among all treatments. It suggests that thelight spectrum might not be advantageous for protein synthesis, and the soluble protein content might not be a suitable parameter to assess the nutritional quality of lettuce plants.

Nitrate: Are duction in the nitrate content is definitely important for improving the nutritional quality of vegetables for human consumption. Results from Fig. 5also show that the accumulation of nitrate in lettuce plants significantly differed among the light quality treatments. The RB LED possibly stimulated vital activities of plant sand nitrate uptake, such that its concentration increased in leaves.

Sugar: The higher sugar level might also result in a sweeter taste(Fig. 5), and the lower nitrate level can be beneficial to human health. In addition to yields, the shape, crispness, color, and sweetness of the lettuce are also important for market acceptance. In a comprehensive sensory evaluation, plants grown under RBW and FL treatments had significant higher overall acceptability than those under RB treatment based on the sensory analysis(Fig. 5). Among plants treated with three light qualities, consumer panelists selected the RBW-treated plants as the most preferable item; in particular, the crispness was the most popular parameter.

ISSN 2348 – 8034
Impact Factor- 5.070

VII. CONCLUSIONS

In agricultural production, yields and costs are the two most important criteria by which optimization of environmental factorsis conducted. The final goal of our project is to develop a new light apparatus with LEDs optimized for vegetable production in plant factories. In the present study, we investigated the effective light quality with sufficient intensity for growing healthier lettuce plants more rapidly. Based on this study, it appears that the combined RBWLEDs resulted in many positive effects on growth, development, nutrition, appearance, and the edible quality of lettuce plants. The bioregenerative and hydroponic culture systems may comply with commercial requirements for rapid, large-scale, and precise management of plant production.

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