**Potential and prospects of grow lights in crop production**

***Golmei Langangmeilu1 and Kamei Gaisinmeilu2***

*1Research Scholar, Department of Agronomy, College of Agriculture, IGKV, Raipur, Chhattisgarh*

*2Research Scholar, Department of Vegetable Science, Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Himachal Pradesh*

***(langangmeilu2@gmail.com)***

**Abstract**

Plants can be manipulated to meet different needs by changing how they respond to different colors of light. Plants primarily use the blue and red regions of the colour spectrum, along with some ultraviolet, for their photosynthetic reaction. The plants will grow taller and their leaves will be lighter in colour if they aren't getting enough regular sunshine. Growing bulbs that provide the precise illumination needed for plants at different growth stages have been made possible by technology. Artificial light can most certainly be used for photosynthesis. However, the rate at which photosynthesis occurs is dependent on the spectral emissions of the light source you plan on using. Utilizing wavelengths to activate specific organic functions is a new area that can be investigated in the world of agricultural applications. One of the most promising directions for future agriculture is the scientific use of light. A fine-tuned management of all vegetation characteristics is now possible thanks to increasingly accurate numerical data on sunshine. Utilizing wavelengths enables cutting-edge crop protection options. In addition to their intensity, spectrum, and energy, LEDs are an innovative artificial lighting source for plants, whether used as supplemental or sole source lighting. This is because they allow for the precise modulation of metabolic reactions to increase plant quality and production. LEDs are increasingly widely used in agriculture, mostly for leafy greens, vegetables, herbs, and potted plants. Recent improvements in LED technology have made it feasible to accurately modify a crop's lighting schedule. As a result, there are now opportunities to use plants' ability to adapt during development to raise agricultural yield and quality.

**Keywords-** grow lights; colour spectrum; LED; photosynthesis; Controlled-environment agriculture

1. **INTRODUCTION**

Light is an important component of plant life. A plant (more precisely, its dry weight) consists of 45% carbon obtained from air for the process of carbon assimilation in photosynthesis. This process occurs only with the participation of light, many external factors affect the intensity of photosynthesis. The synthesis of organic matter, on which agriculture is directly reliant is mainly based on photosynthesis. Plants synthesize organic matter by using light energy, absorbing carbon dioxide from the air and releasing oxygen. In agriculture, there are two sides to sunshine. On the positive side, it contributes to the growth of plants by allowing photosynthesis and by providing them with a healthy environment. Excessive sunshine exposes plants to thermal and water stress that impairs their growth, can endanger their survival, and increases water consumption.

The law of limiting factors, which influences plant quality, is the most crucial idea to comprehend when growing plants. The primary factor affecting plant development is light. No matter how much of any other variable - water, growth medium, or fertilizer - plants receive, they will not develop at their maximum rate or reach their greatest potential if they do not receive enough light. Plants can be manipulated to meet different needs by changing how they respond to different colours of light. Plants primarily use the blue and red regions of the colour spectrum, along with some ultraviolet, for their photosynthetic reaction. The plants will grow taller and their leaves will be lighter in colour if they aren't getting enough regular sunshine. When that occurs, it's time to take action and seek out more light. Growing bulbs that provide the precise illumination needed for plants at different growth stages have been made possible by technology

Light is one of the main factors modulating the biosynthesis of specialized metabolites, determining the cascade response activated by photoreceptors and the consequent modulation of expressed genes and biosynthetic pathways. Recent developments in light emitting diode (LED) technology have enabled improvements in artificial light applications for horticultural crops. In particular, the possibility to select specific spectral light compositions, intensities and photoperiods has been associated with altered metabolite content in a variety of crops. The ability of plants to respond to light is determined by the presence of multiple photoreceptors, proteins capable of sensing different light intensity, quality, direction, and photoperiod, triggering signals that regulate multiple physiological and metabolic responses. Five classes of photoreceptors have been identified, which enable plants to respond to a broad spectrum of light, from ultraviolet B (UV-B) to far-red wavelengths. Phytochromes are the main receptors for red and far-red light spectral development and also promote seed germination and seedling de-etiolation.

1. **LIGHT AND ITS EFFECTS ON PLANT GROWTH**

To produce food, plants collect minerals and nutrients from the earth, as well as water and carbon dioxide through their stomata and roots, respectively. Without light, which is the primary source of energy, the three cannot exist. The sun serves as the primary energy source for the majority of plants because they are grown outside.

1. ***Essential for direct growth***

The fact that plants always grow toward the light is not a coincidence. The plant hormone auxin is released on the stems when they are exposed to light, encouraging them to grow in that direction. A plant's stems will bend in nearly any direction in quest of light if you deny it direct light. For direct growth, plants require light; otherwise, their stems would deteriorate. Food is stored in various ways by different plants. Some plants store their nourishment in the stems, some in the roots, and yet others on the leaves. Light is essential for the storage process to be successful, especially where the storage is in the stems. Sugarcane and cacti are two examples of plants that store food in their stems.

1. ***Seasonal effects***

Some plants have a seasonal nature. They depend on the seasons to blossom, set seeds, or fertilize. Plants bloom in the majority of four-season countries in the spring and summer that is the time when the plants bloom and produce their fruits. The majority of plants are dormant and only exist to store energy in other seasons when there is insufficient sunlight. Some plants occasionally lose their leaves, look dry, and then come back to life in the spring.

1. ***Light Exposure***

Photosynthesis cannot occur when plants are not exposed to light, which means they cannot create enough food and energy to be healthy or grow at all. Checking whether the plants are classified as low-light, medium-light, or high-light is necessary because the needs of plants in terms of light differ. They simply require a minimum of 4 hours of light exposure for low-light plants. High-light plants require between 12 and 16 hours of light exposure, whereas medium-light plants require at least 8 hours. It is also essential to arrange a schedule for light exposure so that plants can adapt to photosynthesis and its opposite, respiration, without difficulty. Below is a list of various lighting elements that have an impact on plant growth:

1. ***Intensity***

More photosynthesis will occur if the light is stronger. Moreover, plants will grow larger as photosynthesis increases. By shortening or lengthening the distance between the plants and the light source, a grow tent's light intensity can be changed. This is a challenge because certain grow lights create heat that may be detrimental to plants. But not all; some brands have efficient cooling systems that guarantee little to no heat is released [1].

1. ***Duration***

While some plant species can only flower when exposed to brief periods of light, others can only do so when exposed to long durations of light. Photoperiodism is the name for this occurrence. Chrysanthemum and strawberries are among the first group of plants, also referred to as short-day plants. Radishes and spinach are examples of the latter, also referred to as long-day plants. Photoperiodism has little impact on day-neutral plants like tomatoes and cucumbers. Short-day plants can avoid flowering and bolting if they are briefly exposed to light at night. Conversely, the same exposure will encourage flowering in long-day plants.

The rate of growth is higher when plants are exposed to light for longer periods of time. The key factor that contributes to indoor gardening's higher yields is that grow lights can be adjusted to enhance sunlight hours, whereas the sun cannot.

1. ***Light spectrum***

Light is more of an energy type that propagates as electromagnetic waves. An entire light spectrum consists of 12 bands with various types of light. All of these light spectrums are necessary for plant growth, but red, blue, and violet light are particularly important. The longest of all the light spectrums, red light lacks energy. It made its way through thick canopies and even slightly warmed the earth. This is the light that encourages plants to grow and flower. Plants with insufficient red light experience delayed flowering. The vegetative phase of growth requires blue spectrum light. Plants that receive insufficiently or no blue light are prone to turn yellow. This is due to the straightforward fact that blue light aids in the production of chlorophyll when magnesium is present.

Plants’ reactions to various colors of the light spectrum can be used to manipulate plants to satisfy different needs, including the following:

* **Ultraviole**t radiation can be used to shorten the internodes.
* **Blue light** can be used to stimulate vegetative growth and prevent shorter-day plants from flowering during their propagation stages.
* **Red light** can be used to induce flowering and lengthen the internodes to produce plants with longer stems and bigger flowers. Roses are an example.
* **Far-red** radiation can be used to control the photoperiodism of plants

According to [NASA researchers](https://www.nasa.gov/centers/goddard/news/topstory/2007/spectrum_plants.html), this spectrum doesn’t really have much effect on the growth of your plants. A lot actually debate on this, but some researchers actually found that plants exhibit less growth if they are only exposed to this color without the blue and red spectrums. **Each one of these colors has a different effect on plants.**

* **Violet –**violet gives better color, taste, and makes them smell better
* **Blue –** plants grow faster.
* **Green –**to create chlorophyll for the production of food to survive.
* **Yellow –** this color is useful, but not as much as blue and red light
* **Red –** to create more leaves. Combination with blue, it will produce larger crops.

The most important variable affecting plant growth is light exposure, and it is therefore important to measure the amount of light plants receive. **Ensuring enough light for plants** through:

1. **Daily light integral (DLI):** The DLI is a measure of the total daily light input that plants receive, which is measured in millimeters per day. The length and intensity of light exposure are other factors that affect DLI (number of sunlight hours). The DLI modification could shorten the time needed for cuttings and seedlings to take root and improve crop quality while using less energy
2. **Photomorphogenesis: It** determines the development of plants from seed to flowering. This depends on different photo pigments to detect and react to light colours, which include all the colours of the rainbow that we experience as reflected light and range from ultraviolet to near-infrared.
3. **Increasing light increases yield**

According to a general rule of thumb, 1% additional light will result in a corresponding proportion increase in plant growth and 1% more yield.

1. **Winter growing**

Because there are fewer sunlight hours in winter than in summer, growers often heat their greenhouses during winter in their efforts to maintain summer yields.

1. **SYMPTOMS OF LACK OF LIGHT IN PLANTS**

* ***Abnormal growth*:** plant seeks to move to an area with more light when it realizes it is too dark. In order to outgrow shade-givers, the orientation is typically then as high up as possible. The term "abnormal growth" describes this phenomenon.
* ***Loss of buds and leaves*:** plant may experience irregular growth in addition to just losing its buds and/or leaves. The leaves initially turn yellow before just dropping off. Some even understand the basics of photosynthesis.
* When plants aren’t exposed to enough light for an extended period of time, they will begin showing signs, such **as color changes in the leaves and a “leggy” stem.**
* ***Yellow Spots***: this is due to lack of chlorophyll since the plant is not getting enough light to produce more of this.
* ***Plant’s Growth*:** plants aren’t getting tall when it should be.
* **Extended Internodes**: this is the spacing between the leaves and the spaces between the leaves of your plants will be bigger.
* ***Small Leaf size*:** since the leaves are not producing energy and food, they won’t grow as they should.
* ***Leaning*:** since the plants are struggling to get enough light, the tendency is it will look for what it needs, so you’ll notice that the plant itself will extend and lean towards the light. However, it will not seem like it’s growing healthily as it will look like it’s having a hard time leaning towards the light

1. **GROW LIGHT**

**A plant grow light is an artificial light source that effectively stimulates a plant’s growth. The grow light must produce an adequate light balance of blue and red wavelengths to encourage the plant’s photosynthesis capabilities.** Grow lights either attempt to provide a [light spectrum](https://en.wikipedia.org/wiki/Light_spectrum)similar to that of the sun, or to provide a spectrum that is more tailored to the needs of the plants being cultivated. Outdoor conditions are mimicked with varying color, temperatures and spectral outputs from the grow light, as well as varying the intensity of the lamps. Depending on the type of plant being cultivated, the stage of cultivation (e.g. the [germination](https://en.wikipedia.org/wiki/Germination)/vegetative phase or the flowering/fruiting phase), and the [photoperiod](https://en.wikipedia.org/wiki/Photoperiod) required by the plants, specific ranges of the [spectrum](https://en.wikipedia.org/wiki/Spectrum), [luminous efficacy](https://en.wikipedia.org/wiki/Luminous_efficacy) and [color temperature](https://en.wikipedia.org/wiki/Color_temperature) are desirable for use with specific plants and time periods.

Grow lights are used for horticulture, indoor gardening, [plant propagation](https://en.wikipedia.org/wiki/Plant_propagation) and [food](https://en.wikipedia.org/wiki/Food) production, including indoor [hydroponics](https://en.wikipedia.org/wiki/Hydroponics) and [aquatic plants](https://en.wikipedia.org/wiki/Aquatic_plants). Although most grow lights are used on an industrial level, they can also be used in households. Say for example, during the winter months, grow lights can be used to supply additional hours of light for plant growth. It helps grow vegetables and fruits grow indoors as well. In large scale, indoor farming operations, grow lights can completely replace direct sunlight. However, grow lights don’t always have to mimic sunlight exactly. In many applications, they can outperform sunlight.

***Types of Grow Lights***

There are three basic types of grow lights available for indoor urban farming: fluorescent grow lights, HPS or HID grow lights, and LED grow lights [2].

* 1. ***Fluorescent Grow Lights.***

**Indoor herb and vegetable growth uses fluorescent grow lights. Fluorescent tubes and compact fluorescent lights are two examples of them (CFLs). There are numerous different intensities of fluorescent tubes. In comparison to incandescent bulbs, the standard bulbs that have been used to light homes for decades, they are more durable and energy efficient. Due to their extreme thinness, fluorescent lights are perfect for confined locations. On the other hand, CFLs are becoming more frequently used in homes rather than solely for indoor urban farming. CFLs last six to eight times longer than conventional incandescent bulbs while using just 20 to 30 percent of the energy. They are unquestionably the least expensive of the three main categories of grow lights. CFL bulbs have the benefit of not producing excessive heat, which enables farmers to keep the lights near the plants. It is also incredibly energy-efficient thanks to this low heat function.**

* 1. ***HPS Grow Lights*:**

The popularity of high-pressure sodium (HPS) lights has increased to the point that they are replacing fluorescent tubes and bulbs. Commercial and seasoned indoor growers use these lights more frequently, and the technology behind them is well-established and has been around for more than 75 years. HPS has a heat production issue since it generates a lot of heat. As a result, you need to keep the lights well away from the plants. It costs a lot of money to set them up and keep them running. HPS is therefore not advised for small growers.

* 1. ***LED Grow Lights*:**

Light Emitting Diodes (LED) are small, yet efficient bulbs used to customize the light spectrum. These are typically used in a panel to emanate more than one wavelength at a time. Hence, LEDs are useful for all growth stages. LEDs are monochromatic sources of lights. Yet, they are the only sources of light that are designed to provide the right spectrum for the growth of your plants. They also save power because they can give off a great deal of light without drawing much power. Hence, you save money in the long run.

Too much heat could be risky because the leaves may get burned. Fortunately, LED lights do not generate much heat. Some models even come with a self-cooling feature. Moreover, LED lights are low heat [**artificial source of light**](https://urbanorganicyield.com/artificial-light-for-plants/)**.** The LED technology is customizable, meaning every bulb is different. This is where you can secure different color wavelengths most utilized by plants. In some cases, LED lights can help plants grow healthier and faster, way better than under natural sunlight.

1. **BEST FITS BASED ON FARMING OR FARMER TYPE:**

Artificial illumination should provide plants the energy and knowledge they need to grow. To accomplish the continuous photosynthetic photon fluence required for high productivity, fluorescent lamps, particularly those with enhanced blue and red spectra (i.e., cool fluorescent white lamps), are extensively utilized in growth chambers. Fluorescent light's spectrum and intensity, however, are not long-term constants. Typically employed in greenhouses and plant growth chambers, high intensity discharge (HID) lamps like metal halide and high-pressure sodium have comparatively high fluence (max. 200 lumens per watt) and high photosynthetically active radiations (PARs) efficiency (max. 40%).

LED lighting systems have the highest PAR efficiency (80–100%) of all artificial lighting systems. Due to their narrow-bandwidth light spectrum, LEDs generating blue, green, yellow, orange, red, and far-red light are readily available and can be paired to produce either high fluence (over full sunlight, if needed), or specific light wavelength characteristics. LEDs can be utilized in pulsed lighting and positioned close to the leaves in inter-lighting and intra-canopy irradiation thanks to their high efficiency, low operating temperature, and small size. They are perfect for year-round use greenhouses due to their extended life expectancy and simplicity of control. It's expected that LED technology would revolutionize controlled growing conditions and replace fluorescent and HID lighting in horticultural systems.

* ***Indoor farming****:* The best fit is CFL. CFL is ideal for usage at all phases of plant development and is widely accessible in a variety of wavelengths. The fact that CFLs produce less heat is also beneficial for small farmers.
* ***Grow foods in large scale***: Given that they are the most energy efficient, LEDs can be a good long-term investment. Utilizing LEDs can result in energy savings of up to 70%. LED grow lights are far superior to natural light for plants in many ways.

**Here are a few types of plants that grow well under lights:**

* **Vegetables:** Lettuce, radishes, peppers, kale, chard, carrots, onions, tomatoes, and bush beans.
* **Herbs**: Chive, catmint, cilantro, basil, parsley, oregano, lavender, and rosemary.
* **Flowers:** Geraniums, petunia, candytuft, roses, alyssum, and daisies.
* **Fruit:** Citrus, strawberries, blueberries, and apples.
* **Houseplants:** African violet, croton, aluminum plant, cast iron plant, asparagus ferns, orchids, and spider plant.
* **Succulents:** Jade, aloe vera, panda plant, zebra plant, flaming Katy, and burros’ tail.

Table 1: Comparison of Regular LED bulb and Specific LED Grow light

|  |  |  |
| --- | --- | --- |
|  | **Advantages** | **Disadvantages** |
| **Specifically Designed Led Grow Lights** | * Contains specific light spectrum wavelengths. * Supports all stages of growth, especially photosynthesis. * Uses low energy, but produces great power. | * More expensive than normal lights. * Can be damaging to the human eye. |
| **Regular Led Light Bulbs** | * Inexpensive, permitting you to buy tons of bulbs. * Long-lasting, like actual LED grow lights. * Energy efficient only when used sparingly. | * Contains narrow spectral wavelengths. * Releases high amounts of heat. |

1. **IMPORTANCE AND BENEFITS OF LED GROW LIGHTS**
2. **Photosynthesis**

Red is the [key component for photosynthesis](https://www.researchgate.net/publication/322266750_THE_EFFECTS_OF_RED_BLUE_AND_WHITE_LIGHT_ON_THE_GROWTH_AND_DEVELOPMENT_OF_CANNABIS_SATIVA_L) and stem elongation inhibition. It also signals that there are no other plants above it or competition in light absorption, giving your plants an uninhibited development. The [blue wavelength](http://ursalighting.com/effect-blue-light-plants/) works on the budding, flowering, and expansion of leaves. Thus, it drives the stomatal opening and stem elongation inhibition. Additionally, it is responsible for leaf curvature towards the light, leaf expansion, and photoperiodic flowering. Blue and red are 2 main lights colors recommended for cultivating in a grow space.

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* Blue Lights + Red Lights = Encourage plant to reach the vegetative stage**.** Furthermore, red and blue LED chips are good for photosynthesis, which helps your plants thrive. LED lights are also the cheapest to obtain

Investigations on the applications of LED in incubators and plant growth chambers as in urban agriculture found that plant growth is limited by the availability of light. Light emitting diodes (LED) could provide specific quality and quantity of light overcoming existing limitations for normal plant growth. The devices fabricated in their study, were lighted with 100 % red, 100 % blue, 70 % red plus 30 % blue, or 100 % white LED. They cultivated *Mentha piperita*, *Mentha spicata* and *Mentha longifolia*, lentil, basil, and four ornamentals to test the effect of various LED lights on plants productivity compared with field and greenhouse conditions. The results show that 70/30 % red-blue LED light increased *Mentha* essential oil yield up to four times along with increases in plant photosynthesis and fresh weight compared with field condition. The red-blue LED incubator also led to a better growth of lentil and basil and to higher flower buds and less days to flowering for pot flowers versus greenhouse conditions. Hence their findings demonstrate that LED could improve economic characteristics of plant species by probably stimulating plant metabolism [3].

In cucumber grown under low radiations, illumination of chloroplasts with blue light resulted in a higher number of grana lamellae and more stacked thylakoid membranes than that with white or red light [4]. Through the effects on leaf area, leaf orientation, and branching, light quality can influence light interception and, thus, indirectly affect photosynthetic capacity at the whole plant level.

1. **Better and faster growth**

LED grow light is better for plant growth. All the factors required for plant growth in a synthetic environment, including light wavelength and time. Thus, enables indoor plants to produce more photosynthesis and, as a result, grow more quickly and effectively. It is preferable than sunlight for the growth of plants. [**Full spectrum LED grow lights**](https://urbanorganicyield.com/best-full-spectrum-led-grow-lights-review/) can make the following colored wavelengths for greatest plant growth.

* **Red Wavelengths:** Fruiting and flowering plants need red wavelengths to complete their life cycles.
* **Blue Wavelengths:** Plants must have blue wavelengths to produce ample foliage. A healthy plant has robust leaves to absorb the energy of the light for maximum growth.

The impact impacts of various LED light qualities, including 100% red, 100% blue, 70% red + 30% blue, and 100% white, on the growth and photosynthesis, phytochemical contents, and mineral element concentrations in lettuce (*Lactuca sativa* L. cv. ‘Grizzly’) in comparison to normal greenhouse conditions found that photon flux of 300 μmol m–2 s–1 which was provided for 14 h by 120 LEDs set on a 60 cm × 60 cm sheet of aluminum platform in the growth chambers, where plants were grown for 60 days showed significantly higher Fresh mass per plant was when grown under 100% blue and 70% red + 30% blue LEDs compared to the other environments including greenhouse conditions[5]

The effect of different LED-based light regimes on growth and performance of passion fruit (*Passiflora edulis*) seedlings was studied by combinations of different light irradiances (50, 100, and 200 µmol m−2 s−1), quality (red, green, and blue light-emitting LEDs), and photoperiods (10 h/14 h, 12 h/12 h and 14 h/10 h light/dark cycles) to investigate the photosynthetic pigment contents, antioxidants and growth traits of passion fruit seedlings in comparison to the same treatment white fluorescent light. Light irradiance of 100 µmol m−2 s−1 of a 30% red/70% blue LED light combination and 12 h/12 h light/dark cycles showed the best results for plant height, stem diameter, number of leaves, internode distance, and fresh/dry shoot/root weights. 14 h/10 h light/dark cycles with the same LED light combination promoted antioxidant enzyme activities and the accumulation of phenols and flavonoids. In contrast, lower light irradiance (50 µmol m−2 s−1) had negative effects on most of the parameters. They conclude that passion fruit seedlings' optimal performance and biomass production requires long and high light irradiances with a high blue light portion [6].



Figure1: Lettuce production using grow light

Hikosaka *et al.*[7] reported increased in photosynthetic rate in tomato plants where one and two leaves were irradiated by supplemental LED lighting with 12 % and 28 % higher than the control (only top lighting)

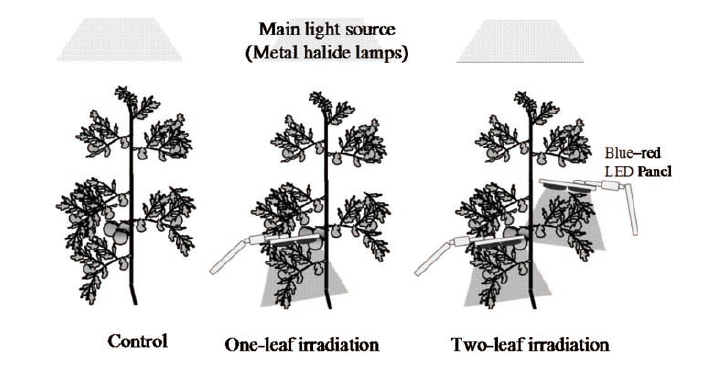


Figure 2: LED lighting in tomato

1. **Faster Harvest Cycles**

Utilizing LED grow lights for indoor farming has a number of benefits, one of which is the acceleration of plant development. The lights can be utilized continuously, enabling the maximum amount of plant development per season. With this lighting, agricultural yields can be increased annually, increasing profitability. The ability of LEDs to control the light spectrum provides the possibility to optimize plant morphology without chemical intervention. Blue light is known to inhibit stem elongation in many species; for instance, stem elongation of Chrysanthemum and *Stevia rebaudiana* decreases as the blue light proportion increases [8, 9].

LED irradiation at 75 μmol m-2 s-1 of blue light and a B/R ratio of <1.0 would suppress spindly growth and promote flowering during tomato seedling growth [10].

1. **Higher yield**

LED systems are able to provide multiple light spectra for horticultural production. In the production of leafy vegetables such as lettuce, radish, and spinach, combined red/blue light was beneficial for accumulating biomass [11]. Lettuce is the most common crop to grow in a vertical farming facility, LED grow lights are used for multilayer applications to produce large heads of bright green lettuce or more compact heads of deep red varieties.

In fruit production, Samuoliene *et al*. [12] reported that additional blue light resulted in bigger fruits with higher sugar content in strawberries, blue light was found to increase the oil content compared with white light treatments in basil leaves [13] whereas the use of red light alone inhibited flowering [14]. Light intensity influences the biosynthesis of secondary metabolites, with increasing light intensity resulting in an increase in the production of polyphenols in herbs [15].

Strawberry plants cultivated in the plastic green house with supplementary LED lights yielded much higher production of strawberry fruits than those cultivated in the growth chamber illuminated with LED lights as the sole light source. When the effects of different LED lights were examined, a remarkably higher production of fruits was achieved in the plastic green house when ambient light was supplemented with either blue LED light or combined blue and red LED light. Furthermore, greater accumulation of organic acids and phytochemicals such as phenolic compounds were observed in the fruits that had been cultivated in the plastic green house when ambient light was supplemented with either red LED light or combined blue and red LED lights [16].

1. **Better taste and nutrition**

Phytochemical concentrations and a nutritive value of lettuce were also significantly affected by the light treatments. Chlorophyll and carotenoid concentrations increased in the plants grown under 70% red + 30% blue LEDs compared to those grown in the greenhouse [5]. Vitamin C content was 2.25-fold higher in the plants grown under 100% blue LEDs compared to those grown in the greenhouse. Higher photosynthesis and maximal quantum yield of PSII photochemistry were also observed in the plants treated with LED lights. The application of LED light led to the elevated concentrations of macro- and micronutrients in lettuce possibly because of the direct effect of LED light and lower stress conditions in the growth chambers compared to the greenhouse

The study of the post-harvest maturing of tomatoes under different light treatments was investigated. Raw tomatoes got the red coloration under all light treatments but the redness (lycopene content) was highest under LEDs which also had far red in the spectrum. The best coloration came with the higher red to far red ratio (R:Fr) in the spectrum (Valoya’s AP673L spectrum). The firmness of the tomatoes, measured with a fruit pressure tester, was enhanced under the previously mentioned spectrum. This same light spectrum had also earlier shown to increase antioxidants in basil. This increase in the antioxidant content in the consumed produce brings a vast variety of health benefits for the consumer but it also protects the plant itself from fungal pathogens like downy mildew. The particular smell enhancement of increased rosmarinic acid content, anti-inflammatory health benefits to the consumer and pathogen resistance can all be considered quality enhancements caused by the right spectra selection. The shelf life is enhanced by the higher dry matter content of the leafy greens. When the plant has higher content of fibers and less water the produce stays fresh looking for longer periods as drying takes longer time. Total phenolic amount is associated with flavor and smell of the vegetable and this is also increased with the finely balanced light spectrum.

1. **Durability and Performance**

With a lifespan of 102,000 hours, LED lights are made to last forever. These contemporary lights endure significantly longer than conventional lights, which generate more heat, in large part due to their low working temperature. The system lasts longer because of the reduced wear and tear caused by the lower temperature. Since LED lighting is based on solid-state technology, it has a longer lifespan because there are no moving parts. All the light required for growing healthy plants is provided by LED lighting. Using LED lighting instead of conventional lighting systems, which emit damaging light wavelengths, would result in far healthier plants. With the ability to alter the light's wavelength provided by LED lights, growers can facilitate a better photosynthesis process. Since they don't emit heat, these lights also do away with the requirement for installing indoor cooling systems

1. **Energy Efficiency and Environmental Safety**

Cost and energy are significant considerations for any company aiming for sustainability. Compared to conventional lights, LEDs are about 60% more energy efficient. Not only do they produce less heat, but they also deliver more useful light at a lesser price since burning is not required to produce light with LED lighting, there is a significant reduction in energy consumption and heat output. A software-based energy usage tracking system can help you improve energy efficiency even more. Since LED lights are recyclable and do not contain any harmful materials, they are also more environmentally friendly than traditional lights.

1. **FUTURE ADVANCES**

Food production relies on photosynthesis. Providing sufficient quantity and quality of food for nine billion people as predicted in 2050 is especially challenging under the constraints of global climate change. **Controlled-environment agriculture (CEA**) technologies, including greenhouse, hydroponics, aquacultures and aeroponic systems, as well as vertical farming possibilities, provide alternative and complementary sources for crop production, particularly in areas with limited daylight (in northern latitudes) or adverse environmental conditions (droughts, floods, storms and saline soils) or in areas with limited space, such as cities and space stations.

The benefits of CEA technologies, such as increased crop yield annually (due to shorter culture period under ideal environmental conditions and year-round cultivation), greater growth area per m2 (large plant density, multi-tier cultivation shelves), efficient nutrient and water use, decreased crop losses, and absence of pesticide application, make them effective for crop production. Additionally, these technologies might result in the production of typical, high-quality horticultural goods. Closed and interior plant cultivations, in contrast to outside agriculture, rely on cutting-edge light sources like LEDs that can stimulate plant growth while significantly lowering energy use.

Figure 3: Controlled-environment agriculture (CEA) technologies

The use of LEDs also holds great promise for processes that produce oxygen and clean water, for the production of food, drugs, fuels, or colours in algal culture, and for the micropropagation of plants such as strawberry or blooming plants in plant tissue cultures. The efficient use of LED lighting technologies in plant cultivation in enclosed environments may be influenced by research on the effects of LEDs on primary and secondary metabolism of plants and on how the direction and mixing of LEDs influences plant responses, along with advancements in the dynamic modification of light quantity and quality in different phases of growth.

The lighting industry needs to offer energy-efficient, ecologically sustainable lamps adapted to the changing requirements of consumers. LEDs equipped with driver chips could provide the additional benefits of operational flexibility, efficiency, reliability, controllability and intelligence for greenhouse lighting systems.

Horticultural output in controlled environments and the horticulture industry are both predicted to expand in the near future. Future developments in technology will make it possible to grow crops both on Earth and in space while consuming light energy in a financially advantageous manner. This could contribute to the preservation of outdoor (mainly forest) ecosystems and the feeding of the planet's growing population of people.

**CONCLUSION**

**Artificial light provides the energy necessary for their growth. It ensures proper photosynthesis from germination to flowering. The most popular artificial light sources are LED Grow lights, HPS and CFL lamps.** A standard light that is labeled as full-spectrum is a good overall choice for most plants. **The most crucial colors needed are red and blue.** Using plant grow lights during the winter can help you to extend the growing season. Plants typically grow better under these lights because it creates the perfect environment with the lighting, humidity, temperature, water, and fertilizer to encourage robust growth.

The advances in LED technology have made it possible to create the perfect environment to grow vegetables at a large scale with shorter growing cycles and higher yields. In fact, LED is becoming the de facto source of lighting to create the most advantageous controlled environment for indoor farming. The advances in LED technologies have made indoor cultivation of vegetables very energy-efficient. But the gradually decreasing prices of LEDs should help those farmers convert to LED as it offers a significant energy cost saving. LED lighting is a strong and reliable choice for long-lasting and low-maintenance lighting goal. Grow lights for agricultural operations need to be as powerful as possible without sacrificing cost efficiency.

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