Review on Light and Photoreception for crop development under *in vitro* culture

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Abstract

Crop development and proliferation are both dependent on light. Numerous studies have been conducted to determine the impacts of light quality on various elements of plant morphology, physiology, gene expression and chemistry. With the introduction of light-emitting diode (LED) technology, significant advances have been made in environmental controls and morphogenetic responses controlled by the light utilized under *in vitro* cultures. Light is critical in large-scale propagation and a diverse range of LED lights with varying spectra are now available. LED technology is continually evolving and has opened new possibilities. In this review, we summarized the impact of light quality in the field of productional yield, productional quality for horticultural plants *in vitro***.**

Keywords: *In vitro,* Phytochromes, Cryptochromes, Light Emitting Diodes, Photo synthetically active radiation.

1.Introduction

Plant-tissue culture is the *in vitro* cultivation of plant cells, tissues, organs, seeds, protoplasts, or embryos on a nutrient medium under aseptic circumstances. In this process, temperature, photoperiod, humidity, light, and the medium's components works together to provide the ideal and controlled growing environment to the crops. The genetic fidelity of the chosen parents is preserved while producing identical offspring. The most important internal and external factor that controls the growth and development of in vitro plants is light. Light is the utmost vital signals received by the plants that fuels the physiological activities like generation of secondary metabolites and photosynthesis (Kozai, 2016). The most crucial element in *in vitro* plant tissue development is artificial light source. The impact of numerous

in vitro growth metrics, including shoot regeneration, plant height and size, fresh weight, and the chlorophyll and carotenoid content of leaflets, depends on the type and intensity of light. This suggests that altering the light quality, quantity, and duration in the growth environment can enhance the growth and functionality of *in vitro* plantlets. Photosynthetically active radiation (PAR) with wavelengths between 400 and 700 nm is utilized by all the plants for proliferation. It is either reflected, transmitted, or absorbed once it reaches the plant. Some photons from photosynthesis are converted to chemical energy. Specialized photoreceptors that are found in plant tissues, can collect photons, and transform them into chemical energy following the process of photosynthesis. Beyond this highly energy-dependent process of photosynthesis, ambient light levels also have a big impact on photomorphogenesis, photoperiodism, and phototropism. The following sections in the review explain the effect of light on photoreceptor activity and their functional role in in vitro culture.

2. Photoreception- The driving force

Almost every aspect of plant growth and development is influenced by light, including germination, vegetative morphology, reproductive activity, floral initiation and circadian rhythm entrainment (Galvao and Fankhauser, 2015). Plants use a variety of photoreceptors that are sensitive to a particular wavelength to monitor the light signal and control plant behavior in response to the complicated light environment (Mawphlang and Kharshiing, 2017). Protein molecules known as signaling photoreceptors, directly absorb the light that will change behavior. The majority of photoreceptors are located in the cytoplasm and are water soluble since membranes are essentially transparent to light. The energy from absorbing a photon causes an electrochemical potential gradient across a membrane in other important light-absorbing molecules, such as light-harvesting complexes or photosynthetic reaction centers, which can be used to power energy-intensive chemical activities (Moglich et al., 2010).

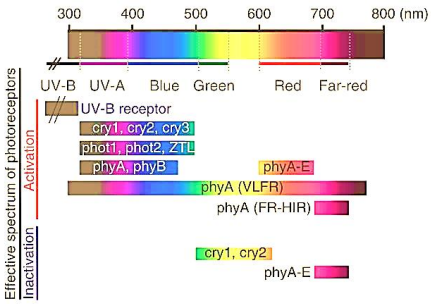

Fig.1 Effective spectrum of photoreceptors for activation and inactivation.

A recent molecular genetic approach in Arabidopsis revealed that multiple photoreceptors, including Phytochromes (phy), Cryptochromes, Phototropins (Phots), and Zeitlupe Family Proteins, operate as light sensors, perceiving distinct light wavelengths.

2.1. Phytochromes (Phy)

Plant phytochromes were the first light-sensing molecules to alternate between two distinct photoreversible forms in vivo - R (Red) light (650-670 nm).Light absorption (Pr) and far-red (FR) light (705-740 nm) absorption (Pfr) - phytochromes, which are soluble proteins that function as phytochromobilin chromophores (Fig.2). Typically, Pr absorbs R light and transforms into Pfr, which produces a variety of physiological reactions. Pfr transforms into an inactive form of Pr after absorbing FR light. This reversible R:FR reaction, a typical phytochrome reaction, is categorized as an LFR because It takes place during seed germination and reactions that occur at night. with brief light pulses (0.0001 to 0.05 mol/m2). High-irradiance responses (HIR) and very-low-fluence responses (VLFR) are two additional phytochrome responses to LFR (Casal et al., 1998). De-etiolation (inhibition of hypocotyl elongation and stimulation of cotyledon growth) and anthocyanin accumulation responses are instances of HIR.

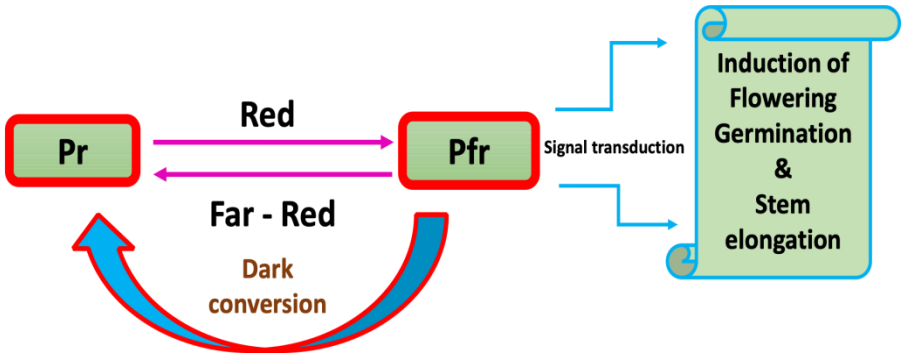

Fig.2. Phytochrome theory

Phytochromes are categorized into two groups (type I and II) based on their protein stability in light. Table 1.

Table 1. Types of Phytochromes

Types	**Phytochromes**	**Remarks**
Types I	PhyA	It builds up in the dark and breaks down quickly when exposed to light.

Types II	PhyB, PhyC, PhyD, PhyE	Under light or dark conditions, it accumulates rather regularly and is light-stable (Sharrock and Clack, 2002).

The R:FR reversible LFR and/or R:FR ratio response, commonly known as the shade-avoidance response, is mediated by PhyB, PhyD, and PhyE (Li et al., 2011). R light causes HIR in seedling de-etiolation via the activity of phyC (Franklin et al., 2003). In the photoperiodic control of flowering, phyA mediates the promotion of blossoming by blue and FR light, while phyB mediates the suppression of flowering by R light (Table 2).

Table 2. Physiological responses altered by phytochromes

Physiological response	**Light**	**Phytochromes**	**References**
Induced germination	Broad wavelength (320 – 780 nm)	phyA	(Shinomura *et al.*, 1996)
	Red	phyA and B	(Shinomura *et al.*, 1994)
	Far-red	phyA	(Shinomura *et al.*, 1994)
Preventing germination	Far-red	phyB	(Shinomura *et al.*, 1994)
De-etiolation Inhibition of Hypocotyl Growth	UV-A & blue	phyA phyC	(Shinomura *et al.*, 2000) (Franklin *et al.*, 2003)
	Red	phyA	(Shinomura *et al.*, 2000)
	Far-red	phyA	(Shinomura *et al.*, 2000)

2.2. Cryptochromes (Crys)

The widely distributed blue light photoreceptors known as cryptochromes are involved in a variety of reactions in both plants and animals (Moglich *et al.*, 2010). The cryptochrome C-terminus (CCT) domain, which is necessary for signal transduction, and the N-terminal photolyase homology region (PHR) domain, which binds chromophores, are both present (Fig.3). Arabidopsis contains two cryptochromes (cry1 and cry2), which are blue

(B)/UV-A photoreceptors involved in a variety of biological processes such as hypocotyl elongation suppression, circadian clock entrainment, stomata opening, pigment production, and photoperiodic flowering (Yu et al., 2010). Cry1 protein is light stable, but cry2 protein is light unstable. The cry2 protein has diurnal cycles because it accumulates in the dark and degrades when exposed to blue light. By stabilizing the CONSTANS (CO) protein, during the long day, florigen is positively regulated. (LD) evening, Cry2 promotes flowering. +(Valverde *et al.*, 2004).

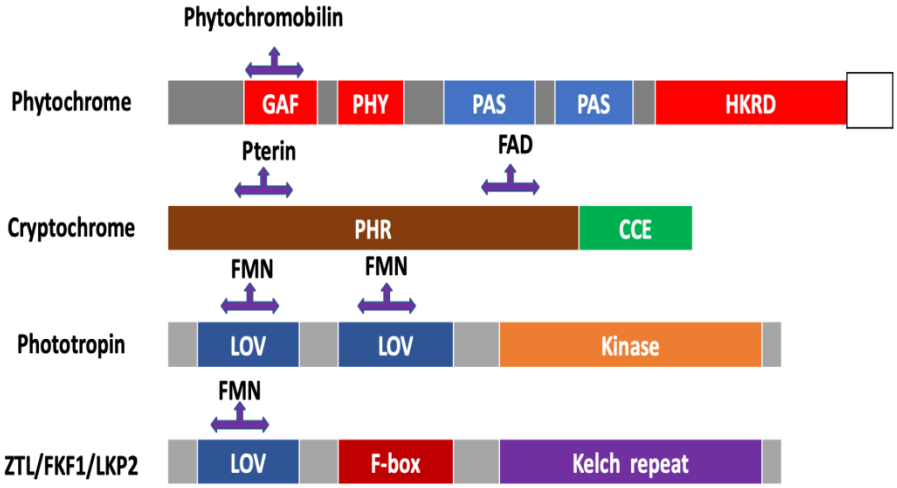

Fig.3 Structure of photoreceptor proteins

2.3. Phototropins (Phots)

Phototropin was identified to be a photoreceptor in Arabidopsis that mediates a blue-light-induced phototropic response. At their N-terminus, phototropins have two LOV domains (LOV1 and LOV2) that bind FMN as chromophores, and at their C-terminus, they have a Ser/Thr kinase domain. To maximize photosynthetic activity, Arabidopsis possesses two phototropins (phot1 and phot2) that regulate a wide range of blue/UV-A-induced responses such as phototropism, chloroplast translocation, leaf flattening, and stomatal opening (Christie, 2007). Phototropins 1 and 2 functions at a wide range of light intensities, whereas phototropins 1 and 2 function primarily at intense levels of light (Christie et al., 2014).

2.4. Zeitlupe Family Proteins

ZEITLUPE (ZTL), FLAVIN-BINDING KELCH REPEAT F-BOX 1 (FKF1), and LOV KELCH REPEAT PROTEIN2 (LKP2) are three new blue-light receptor proteins found recently. It includes numerous Kelch repetitions, an F-box domain, and a LOV domain. These

proteins play a significant role in the photoperiodic production and/or accumulation of crucial proteins that control the circadian clock and flowering onset by mediating ubiquitin-dependent protein degradation in a light-controlled manner (Ito *et al.*, 2012).

3. Light Quality- A Deciding Factor?

3.1. Light quality on *in vitro* gene expression

The quality of light controls plant growth and development through a variety of mechanisms, which includes the specific activation of specific light receptors, such as phytochromes by red and far-red light, cryptochromes and phototropins by blue light, and UV-B receptors by ultraviolet light. Photochemical control of light quality influences the synthesis of nucleic acids, amino acids, organic acids, sugars, and lipid peroxidation, which are required for cell maintenance, division, respiration, and reproduction in *In vitro* metabolic pathways. Explants that have undergone in vitro alterations in response to stress and reorientation of their developmental programme, which aid in adaptability, express protein kinases, transcription factors, and structural genes. Plants grew with smaller leaves and long petioles that stretched towards the light as a result of low irradiance. Plants grown in medium and high irradiance had well-developed root systems and grew more quickly.

Vitis vinifera 'Manicure Finger' in vitro developed plantlets exhibit diverse genetic expression when exposed to white, blue, red, and green LED lights. Specific light treatments have been connected to the expression of an extensive list of genes, including those involved in glucose, starch, and sucrose production. Blue light favorably influenced microtubule synthesis-related genes, serine carboxypeptidase, chlorophyll synthesis, sugar degradation, and numerous resistance-related genes in grapes. The red and green lights appear to subject the plantlets to "shade stress" and to strongly affect the expression of defense-related genes. It's worth noting that 1601 genes displayed differential expression, with more genes expressed in green light than in blue or red light (Kozai, 2010). The influence of light on micropropagation is shown in Table 3.

Table 3. The effect of light on micropropagation

S.No.	Crops	Morphogenic pathway	Aim of the Work	Light type and quality of LED	Conclusion	Reference
1.	Carnation - *Dianthus caryophyllus var.* 'Green Beauty', 'Purple Beauty', and 'Inca Magic'	Organogenesis	Effect of light on the reduction of hyperhydricity	Red and blue	Reduced hyperhydricity as an effect of light	(Muneer *et al.*, 2018)
2.	Potato - *Solanum tuberosum*	Organogenesis	Check to see if the spectral quality of the light used before cryopreservation influence the final result.	White, blue, red, and 90% red + 10% blue	Red light alone is not optimal for pre-cryopreservation cultivation, however blue light can increase the efficacy of cryopreservation.	(Edesi *et al.*, 2017)
3.	Jatropa - *Jatropha curcas*	Organogenesis	Enhance the roots of newly emerged plants	Blue, red, 50% red + 50% blue	Additional advantages of red LED light for plant regeneration and shoot growth	(Daud *et al.*, 2013)
4.	Orchid - *Dendrobium officinale*	Organogenesis	Effect of light on the development, growth, and production of shoots	Red, blue, 50% red + 50% blue, 67% red + 33% blue, & 33% red + 67% blue	In vitro, the colours blue or 33% red + 67% blue considerably stimulate shoot production, boost dry matter, and accumulate shoot dry matter.	(Lin *et al.*, 2011)

5.	Grapes – *Vitis vinifera*	Organogenesis	Effect of light on the growth of roots and shoots	Red and blue	The longest shoots with the longest internodes and the highest rooting percentage were produced by the plants. Additionally, more stomata were produced by blue light.	(Poudel *et al.*, 2008)

3.2. *In vitro* competency for photosynthesis

Light is the primary energy source for plant growth and development, and LED lamps are an appropriate artificial lighting source that can influence physiological processes in plants such as photosynthesis and morphogenesis (Darko et al., 2014).Practically the full visible spectrum is covered by photosynthetically active radiation (PAR) (400-700 nm). However, it is thought that the red and blue areas are most crucial for photosynthesis. Red light plays a significant part in the entire process because it contains low-energy photons that can be easily used by photosynthetic apparatus. Blue light stimulates photosynthesis by increasing stomatal opening, controlling chloroplast translocation, and regulating chloroplast transcription in addition to providing energy to the photosystems. High light levels, however, have been discovered to hinder the manufacture of chlorophyll, which slows down photosynthesis by causing photooxidative damage to the leaves.

The process of photosynthesis is a photo biochemical process that converts carbon dioxide into various organic compounds by using light energy. The chlorophylls a and b and carotenoid molecules that make up the light-harvesting antenna of photosystems initiate photosynthesis by receiving light energy and converting it into chemical energy (Caffarri et al., 2014). Photosynthesis is strongly influenced by red, blue, and red plus blue colors of LED lamps (Manivannan *et al.*, 2017).

Plants grown in vitro under LED lights, *Dendranthema grandiflorum and Withaniasomnifera*, showed higher chlorophyll content and photosynthetic rates under blue plus red LED light compared to fluorescent or LED light of only blue, red, distant blue, or far-red wavelengths (Lee et al., 2007). When compared to yellow and green LED or fluorescent lamps, *Oncidium* plantlets had higher pigment content under blue LED and higher starch content under red LED (Mengxi*et al.*, 2011). Plants are commonly exposed to high relative humidity inside the vessels, poor gas exchange, low CO2 concentration during the photoperiod, and high quantities of carbohydrates, nitrogen, and growth regulators during micropropagation. These parameters have a direct impact on several biological and physiological processes, including *in vitro* photosynthesis in plants. Better light quality, such as that given by LED lights, and increased gas exchange (whether through forced or natural ventilation), on the other hand, can be employed to improve photosynthetic performance (Kozai, 2010).

Plantlets produced in vitro under a 4:1 red/blue LED ratio of Eucalyptus, Musa acuminata, and Spathophyllum grew faster than white light (Nhut and Nam, 2010). Brassica napus had a higher amount of soluble sugar and chlorophyll under a 3:1 blue/red LED ratio than red LED or fluorescent illumination (Li et al., 2013).

In contrast to white or red light, blue light illumination of chloroplasts in cucumber cultivated in low radiation produced more stacked thylakoid membranes and grana lamellae (Wang *et al*., 2014). Light quality can alter light absorption and, as a result, indirectly affect the ability of the entire plant to photosynthesize through its effects on leaf area, leaf orientation, and branching. At the molecular level, blue light increases the expression of the genes for MgCH, GluTR, and FeCH, which control the production of enzymes necessary for chlorophyll biosynthesis, and so encourages the accumulation of chlorophyll (Lobiuc*et al*., 2017). The reduction in the tetrapyrrole precursor 5-amino levulinic acid under red light, however, prevents the production of chlorophyll (Sood *et al*., 2005)

3.3. Effect on growth Physiology

The action of several cellular compartments whose activities are unknown is required for cell wall biosynthesis. For example, cellulose is produced in the plasma membrane, but hemicelluloses, pectins, proteins, and glycoproteins are produced in the golgi bodies and transported to the cell wall (Oikawa et al., 2013). Tobimatsu et al. (2011) investigated the copolymerization of lignin monomers by peroxidases in Zea mays L. (corn) suspension cells in several types of in vitro studies aimed at comprehending lignification using fluorescence-tagged monolignols and expanded the opportunity to study the transport and deposition of monolignols in other biological systems.

Light's spectral quality affects growth and morphogenesis, and as a result, it regulates the expression of genes involved in cell wall biosynthesis. In vitro growth of Arabidopsis thaliana under diverse light conditions, including far-red, red, and blue light, revealed more than 26 cellular pathways that were coordinatedly regulated by light. The light-regulated pathways increased cell wall biosynthesis and phenylpropanoid pathways. White light promoted the downregulation of genes that produce hydrolytic cell wall enzymes in this study. Cell wall loss has been connected to expansin, endo-1, 4-D-glucanase, and xyloglucan endo transglycosylase. As a result, the composition of lignocellulosic biomass varies and may change in response to abiotic circumstances such as light quality (Ma *et al*., 2001).

At the transcriptional level, genes and enzymes directly involved in the cell wall, such as PAL, a critical enzyme in the phenylpropanoid pathway, respond to variations in light quality or intensity.When Prunus sp. was cultivated in vitro under fluorescent lighting, PAL expression increased, causing soluble phenolic compounds to increase and lignification to decrease (Pina and Errea, 2008).

The PAL enzyme activity in Dianthus caryophyllus (Carnation) cultivated in vitro was significantly increased by red LED, but fluorescent light caused significantly lower levels of activity (Manivannan*et al*., 2017).According to research on *Gossypium hirsutum in vitro,* fibres from an ovule cultivated under light contained more carbs, cellulose, and expressed more cellulose synthesis genes than cultures created under darkness. (Qian *et al*., 2016)

3.4. Production of secondary metabolites

Secondary metabolite production is regulated by light, which impacts plant growth and immunity to herbivores, pathogens, and oxidative stress. (Table 4). Primary metabolites have an active role in growth, development, and reproduction. Plants, on the other hand, build more substances known as secondary metabolites. Secondary metabolites help plants adapt to their changing environment by improving their flexibility. Many environmental factors, particularly light qualities, influence secondary metabolite formation and accumulation.

Maximizing pigmentation is crucial for horticulture output since colored leaves, flowers, or fruits are distinctive and desired. The accumulation of flavonoids (including anthocyanidins), carotenoids, and betalains is the primary cause of plant colour (Tanaka *et al*., 2008). According to Zoratti*et al*., (2014), blue and ultraviolet wavelengths are particularly effective at promoting flavonoid accumulation by upregulating the expression of pathway genes. Flavonoid synthesis is sensitive to changes in light quality.

According to Li and Kubota (2009), supplemental blue light enhances the anthocyanin and carotenoid concentration while supplemental far-red light decreases the anthocyanin, carotenoid, and chlorophyll concentration in lettuce when compared to white light control. In a study by Jeong *et al*. (2012) on the effect of light quality on the biosynthesis of polyphenols in Chrysanthemum, nine polyphenols were identified and their concentrations under green or red light were found to be maximum, indicating favorable effects on the biosynthesis of polyphenols. Compared to white light treatments, blue light was found to increase the oil content in basil leaves (Amaki*et al*., 2011). Additionally, the biosynthesis of secondary metabolites is influenced by light intensity, with increased light intensity increasing the production of polyphenols in plants (Manukyan, 2013)

Table 4. The effect of light on secondary metabolics production

S.No.	Crops	Light type and quality of LED	Conclusion	Reference
1.	Cabbages (*Brasicaolearacea* var. capitata L.) ʾKinshun ʻ (green leaves) and ʾRed Rookie ʻ(red leaves)	660 nm LEDs, PPFD 50 µ mol m^{-2} s^{-1} ; PP 16 hours	Anthocyanin content and leaf pigmentation in red leaf cabbages increased as compared to FL, 470-, 500-, and 525 nm LEDs.	(Mizuno *et al.*, 2009)
2.	Baby leaf lettuce (*Lactuca sativa* L.) ʾRed Cross ʻ	Blue LEDs (476 nm, 130 µ mol m^{-2} s^{-1} supplemental for cool white fluorescentlamps	The concentration of anthocyanins increased by 31%, whereas the concentration of carotenoids increased by 12%.	(Q. Li and Kubota, 2009)
		UV-A LEDs (373 nm, 18 ±2 µ mol m^{-2} s^{-1} supplemental for cool white fluorescentlamps	The concentration of anthocyanin increased by 11%.	(Q. Li *et al.*, 2009)
3.	*Alternanthera sessilis*, *Alternanthera philoxeroides*, *Alternanthera tenella*, and *Alternanthera brasiliana*	Red, blue, and white LEDs	The level of secondary metabolites can be increased by controlling the light quality with the right amounts of white, blue, or red.	(Reis *et al.*, 2015)
4.	*Beta vulgaris* cv. Detroit dark red	Red, blue, red plus blue (1:1 photon flux density, PFD),blue plus far-red (1:1 PFD), red plus far-red (1:1 PFD) LEDsand white fluorescent	Blue plus far-red LED (betalain production decreased with white fluorescent, red and red plus LED)	(Shin *et al.*, 2003)

3.5. Production of pigments and bioactive compounds

Light affects plant growth and defence systems against herbivores, pathogens, and oxidative stress via regulating the production of secondary metabolites. The biosynthesis pathways for bioactive chemicals including phenols (phenolic acids, anthocyanins, and flavonoids), glucosinolates, and terpenoids, as well as pigments (carotenoids like lutein and beta-carotene), have been connected to the quality of the light. This control is accomplished by modulating certain photoreceptor genes, transcription factors, and enzyme expression (Amaki*et al*., 2011). Table 5. represent the effect of light on plant pigments response.

Table 5. The effect of light on plant pigments response

S.No.	Crops	Light type and quality of LED	Conclusion	Reference
1.	Lettuce (*L. sativa* var. crispa) ʾGreen Oak Leaf ʻ	660 nm (30 µ mol m^{-2} s^{-1}) with white LEDs (peak 449, 548 nm, 30% or B); total PPFD 135 µ mol m^{-2} s^{-1}h	Increased chlorophyll and carotenoid pigments	(Chen *et al.*, 2016)
2.	Kale (*Brassica oleracea var. acephala* L.)	640 nm red LEDs (253 µ mol m^{-2} s^{-1}) applied 7 days before harvesting (pre-treatment with WF and incandescent irradiance at 275 µ mol m^{-2} s^{-1}) incontrolled environment	Enhanced the chlorophyll A, B and lutein accumulation	(Kopsell *et al.*, 2008)
		Sole 440 nm blue LEDs (10,6 µ mol m^{-2} s^{-1} 7 days before harvesting (pre-treatment with cool white fluorescent and incandescent irradiance at 275 µ mol m^{-2} s^{-1}	Enhanced β - carotene contents	(Kopsell *et al.*, 2008)
3.	Banana - *Musa acuminata*	White and deep red/white	LED light increased the chlorophyll levels and number of stomata	(Do Nascimento Vieira *et al.*, 2015)
4.	Cymbidium var. Sleeping Beauty, Golden Bird	Red and blue	Red light increased leaf growth while decreasing chlorophyll content; however, blue light reversed this trait.	(Tanaka *et al.*, 1998)
5.	*Cucumber – Cucumis sativus* cv. Cumlaude	RL (661 nm), BL (455 nm), RL + BL (various combinations), RL + BL + GL (532 nm; 52:28:20)	A reduced leaf area and plant height was obtained with increasing proportion of BL.	(Do Nascimento Vieira *et al.*, 2015)

4. Light-emitting diodes

Light is one of the primary signals that provides energy for the physiological activities of crops. One of the agricultural production techniques that uses the maximum light energy is cultivation of horticultural crops in controlled conditions (Tahkamo and Dillon, 2014). Fluorescent lights (FL) and high-pressure sodium (HPS) lamps, which have a relatively high energy conversion efficiency and are very inexpensive but create heat that aids in greenhouse heating, are examples of typical lighting equipment used in production. (Riikonen*et al*., 2016). In order to lower the high electricity costs of lighting (Goto, 2012), LED was first used in plant cultivation in the 2000s (Pioven*et al*., 2015), and it is now widely used in plant factories due to its advantages over conventional lighting (D'Souza *et al*., 2015), including its small size, durability, long lifespan, cool emitting temperature, and the ability to choose specific wavelengths for a targeted plant response (Gupta and Agarwal, 2016).

The physical phenomenon of electroluminescence, first described by Round (1907), served as the foundation for the development of light-emitting diodes (LEDs) in the early twentieth century. They also do not contain mercury or other elements that might be hazardous to the environment. Following that,The first LED was demonstrated by Oleg Vladimirovich Losev, who made a crystalline diode out of silicon carbide and zinc oxide. In horticulture and plant tissue culture, LED has a variety of uses inducing quality and quantity in development of plants (Higuchi and Hisamatsu 2016). As technology advances and LED prices decrease, there is a trend towards replacing fluorescent lighting with LED lighting. Numerous studies also shown that in vitro plants grown under LED illumination settings are more robust. Table 6 displays thecommercially available LEDs with wavelength and semiconductor material.

Table 6. Commercially available LEDs with colors, wavelength range, and material used

S.No.	Wavelength range (nm)	Colour	Voltage drop (ʌv)	Semiconductor material
1.	<400	Ultraviolet	3.1-4.4	Aluminium nitride (AIN) Aluminium Gallium Nitride (ALGaN)
2.	400-450	Violet	2.8-40	Indium Gallium Nitride (INGaN)

3.	450-500	Blue	2.5-3.7	Indium Gallium Nitride (INGaN) Silicon carbide (SiC)
4.	500-570	Green	1.9-4.0	Gallium Phosphide (Gap) Alluminium Gallium Indium Phosphide (AlGaInP)
5.	570-590	Yellow	2.1-2.2	Gallium Arsenide Phosphide (GaAsP) Gallium Phosphide (GaP)
6.	590-610	Orange / Amber	2.0-2.1	Gallium Arsenide Phosphide (GaAsP) Alluminium Gallium Indium Phosphide (AlGaInP)
7.	610-760	Red	1.6-2.0	Aluminium Gallium Arsenide (AlGaAs)
8.	>760	Infrared	<1.9	Gallium arsenide (gaAs) Alluminium gallium Arsenide (AlGaAs)

LED systems may supply a wide range of light spectra for horticulture production. A combination of red and blue light is widely utilized to improve photosynthetic pigment absorption (Table 7). Numerous studies have shown that more blue photons are advantageous to plant growth. Combination red/blue light was advantageous for biomass accumulation in the growing of leafy plants such as lettuce, radish, and spinach (Yorio*et al.,* 2001). Samuolien*et al*., (2010) found that adding blue light to strawberry production resulted in larger fruits with increased sugar content, but using red light alone restricted flowering.

Kaiser *et al*., (2019) provided tomato with various proportions of blue light (0, 6, 12, and 24%, in addition to red light) with sunlight as the background, resulting in an increase in total biomass and fruit number, with the increase in blue light percentage to an optimum (12%). Although blue light is widely accepted, the appropriate red/blue ratio varies by species and genotype. There were both inter- and intraspecific variances in the red/blue ratio. For example, in lettuce, decreasing R/B ratio increases leaf photosynthetic capacity and rate, which is associated with increased stomatal conductance (gS) and enhanced shoot dry weight (Wang *et al*., 2016).

Nazninet *al*., (2019) studied the effect of R/B ratio on lettuce, spinach, kale, basil, and pepper and concluded that combining blue and red light is necessary to promote growth, pigmentation, and antioxidant content in these vegetable plants, though the optimal ratio varies by species. Another point of contention is whether monochromatic blue light is beneficial or harmful to plant development. Certain studies found that monochromatic blue light decreased photosynthetic rates and biomass buildup when compared to R/B mixed or broad-spectrum light.

Table 7. Plant growth influenced by different light spectrums

Blue Photons (400-499 nm)	Green Photons |(500-569 nm)	Orange - Red Photons (600-700 nm)	Far Red Photons (701-750 nm)
▪ Assist with the production of nutrients and the growth of nutrients. ▪ Encourage gas exchange and chlorophyll pigment production.	▪ Produce the lowest amount of growth per photon. ▪ Optimum penetration for inter-canopy growth. ▪ Permitting the detection of microorganisms and visual health evaluation.	▪ The largest absorption of chlorophyll. ▪ Are essential for controlling day length and flowering. ▪ The most efficiently promote plant growth.	▪ Encourage full plant growth. ▪ Amplify the photosynthetically active wavelengths efficiency.

5. Conclusion and future thrust

Light conditions influence the *In vitro* morphogenetic responses of cultured cells and tissues, however the irradiance used in the protocols and the spectral quality are not clearly

specified. Many photoreceptors' identities, structures, and photochemistry have only lately been understood. The discovery of new members of established photoreceptor families has been made significantly easier thanks to developments in DNA technology.

A growing demand for these light devices is projected in plant cell, tissue, and organ cultivation because they not only last longer and provide better lighting conditions, but also generate fewer waste products. The environmental challenges and worries about fluorescent bulbs, which generate a lot of waste from their auxiliary components like starters and ballasts, as well as the presence of phosphor and hazardous mercury, are well-known. LED technology, which delivers enough PARs in a wide range of spectral characteristics, is well suited to the implementation of scaled-up mass propagation in liquid systems in bioreactors and in vitro photoautotrophic systems. LED technology has enormous promise for secondary metabolite production, and this strategy will lead to a better knowledge of the biosynthesis routes of commercially significant bioactive compounds.

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