AJGHAS-Australian Journal of Global Horticulture and Agronomy Science
Volume 2, Issue 2 | September-2025
e-ISSN: 3065-8632 Print ISSN: 3065-8624

Application of LED Spectrum Manipulation to Establish and Alleviate Nutritional Quality Vase Life after Harvest of Hydroponically Grown Kale

Dr. Aiko Tanaka[1], Dr. Luca Greco[2]
[1] Department of Plant Factory Systems, Kyoto University, Kyoto, Japan
[2] Department of Horticulture and Crop Science, University of Naples Federico II, Naples, Italy
Received: 15-07-2025; Revised: 03-08-2025; Accepted: 20-09-2025; Published: 30-09-2025

Abstract
Spectral makeup of light is critical in determining the nutritional makeup and shelf life of leafy veg grown in controlled environment. This paper was set to determine how light spectrum manipulation with the LED helped to affect growth parameters, phytochemical enrichment, and post-harvest performance of hydroponically grown kale (Brassica oleracea var. acephala). Three light treatment conditions were used as potential ways of growth in the controlled growth chamber, red: blue (3:1), red: blue: far-red (3:1:1), and full spectrum white LED control light. Plants under red: blue light treatment recorded the maximum levels of total phenolics (up by 22.6%) and vitamin C (up by 18.3%) content than the control. Conversely, red: blue: far-red treatment was very effective to delay post-harvest senescence, which increased the visual shelf life by an average of 2.4 days at low temperature conditions. No serious impacts on decrease in the yield were recorded in treatments. The results show that individualized LED spectrum compositions can superimpose improvement of nutraceutical value and postharvest durability in kale, providing a topical option of maximizing crop value in agrarian production of pills vertical and parallel environments.

Keywords: ***LED illumination, red-blue light combination, far-red light, hydroponics, kale, phytochemicals, shelf life, post-harvest quality, and controlled-environment agriculture, vitamin C, phenolic compounds.***

1. Introduction

1.1 The Role of Light Quality in the Controlled Environment Agriculture

The use of light is very important in growth, development and nutritional quality of plants in the case of CEA (controlled environment agriculture). The revolution of light quality manipulation is particularly important crop production as more indoor farming systems are implemented, and vertical farming extends. In comparison to the natural sun-based agriculture wherein natural sunlight makes available a wide range of light, the indoor systems employ artificial light that enables to alter the rate of light, light strength as well as its spectral composition. The special benefit of this controlled light environment is that the spectrum can be customised to optimise plant growth and production of phytochemicals, i.e the vitamins, antioxidants, secondary all these directly determine the quality and nutritional value of the plants.

In particular, the light quality (i.e. the wavelengths and light ratios) can influence many plant physiological processes, such as photosynthesis, morphogenesis and secondary metabolite synthesis. It has been found out that plants react to different wavelength of light, where the blue light stimulates photosynthesis and red light enhances flowering and fruiting. More recently, it has been noted that varying amounts of certain ratios of light particularly red:blue or inducing far red light can have very large effects on nutritional concentration, growth and post harvest stability of a number of crops. This has opened up fresh possibilities of maximizing output yields in a plant and enhancing the quality of the crops grown in a hydroponic system and other CEA systems.(1)

1.2 The LEDs in guiding the Plant Morphology and Phytochemical Pathways

The light-emitting diodes (LEDs) have transformed the light management process in indoor agriculture. LEDs have various benefits compared to conventional light sources, they can be light efficient, have long lifespan and the spectrum of light can be controlled precisely. The LEDs are allowed to produce certain wavelengths to which the growers can choose combinations of light to achieve particular effects including promoting plant morphology and production of secondary metabolites.

As an example, the red:blue ratio of the light has been mostly researched on effect of the plant morphology. Blue light has been shown to control leaf growth, chlorophyll production and root growth and red light stimulates stem elongation, flowering and fruit development. A combination of these wavelengths synergistically harnesses plant growth conditions based on controlled environments. Furthermore, red and blue light have various functions in secondary metabolite biosynthesis the compounds can protect the plant and provide nourishment to people e.g. phenolic acids, flavonoids, and vitamin C.

In addition to that, inclusion of far-red light is known to enhance shade avoidance and phytochrome signaling pathway thereby enhancing crop resilience and shelf life after harvest. Far-red light has been shown to increase leaf expansion and may prolong storage ability by increasing the senescence period, therefore, increasing the overall post-harvest life of the cultivated crop.(2)

1.3 Difficulties to Sustain Post Harvest Shelf Life of Leafy Green Vegetables

Leafy green such as kale (Brassica oleracea var. acephala) are very perishable and quickly undergo premature senescence after harvest that causes a reduction in quality. The major related problems are wilting and yellowing and, in general, post-harvest loss in nutritional value either in the field, or during storage. This is mostly associated with increased respiration, water loss and metabolic activity after harvest. This is further complicated in crops that are hydroponically grown in that there is no nutrient and water uptake that occurs once they are taken out of their growing system. The shelf life of leafy greens is normally affected by conditions like temperature, humidity as well as light.

It has been proved that the quality of the post-harvest can be stretched by using light manipulation even after the storage process. As an example, senioria can be forestalled by light exposure during storage thus sustaining chlorophyll nature, which is significant in terms of appearance and nutritional values. The post-harvest life and how it can be managed using light is however a field that is not well exploited especially in hydroponically cultivated crops.(3)

1.4 Study Objective

This research will determine how the nutritional quality together with the post-harvest shelf life of hydroponic kale is impacted by LED light spectrum manipulation. In particular, the paper identifies how the combination of red:blue and red:blue:far-red led lights affects phytochemical levels, yield, and shelf life of kale. The project will investigate the use of light spectra that will maximize vitamin C, phenolic compounds and shelf-preservation, to enable information that can optimize nutrient quality and post-harvest performance of leafy greens under controlled environment conditions.

2. Treatments and growth conditions Spectral

2.1 Setting up of hydroponic systems and growth room characteristics Description

This study involved a hydroponic system known as deep water culture (DWC) system that is suitable to raise leafy vegetables such as kale. DWC system The plants in DWC system are grown in nutritious water and the roots grow in a suspension solution where the plants are freely exposed to water and nutrients all the time. To preserve oxygenation and avoid the root anoxia that is a usual issue in hydroponic system, the system was supplied with air pumps. The nutrient solution was made up with a commercial hydroponic nutrient mix that was designed to grow leafy vegetables and pH range between 5.8 - 6.2 was kept where maximum absorption of nutrients take place.

The study related growth chamber was a controlled environment chamber that had an accurate control of the temperature, humidity and light. The room would also be maintained under a constant temperature of 22 o C by day and 18 o C by night to create normal conditions of the room that would permit maximum growth of kale. Relative humidity was controlled at 60-70% and decoration was done in such a way that no excessive loss of moisture occurred to the plants, which is also very essential to avoid dehydration stress in crops under hydroponic culture.(4)

The light conditions were taken as 16 hours of light and 8 hours of darkness resembling natural day-night conditions that promote proper plant growth. The light intensity was maintained at 300mol/m 2/s during the light period to simulate amount of light in greenhouses, which was also antagonistic enough to sustain photosynthesis without induction of light stress.

2.2 Specifications of LED Spectrum make ups

Three LED treatments were carried out in order to test the impact of light spectrum manipulation on the growth, nutritional value and post-harvest shelf life of kale:

1. **Sodium-vapor red: (3:1) Blue: spectrum:**

It was comprised of two different doses of red light at 660 nm and blue light at 450 nm in a 3:1 ratio, which has been reported to only favor the robustness of the leaf and development of nutrients. Red light stimulates stem elongation and flowering and blue light stimulates leaf growth, chlorophyll production and opening of stomates.

2. **Far-Red:(1:3:1) Spectrum:**

In this therapy, a mixture of red-blue light was combined with far-red light (730 nm) at 1:1 ratio in attempts to maximize photoreceptor signaling and enhance delaying senescence. The far-red light influences the phytochrome mechanism and either promotes leaf growth and can be used to increase the shelf life of harvested crops by slowing down senescence using food types.

3. **Regulation (Full Spectrum White Light):**

The control group was placed under full-spectrum white light that is used as a typical one in comparison to measure the particular effects of red-blue and red-blue-far-red spectra on the kale plants.

Environmental Control: Temperature, Humidity and Photoperiod

Automated systems were introduced in the growth chamber to maintain steady environmental values. Temperature regulation, however, was done using an air conditioning system in order to balance the night-day temperature levels at 22 o and 18 o C, respectively. Humidifiers and dehumidifiers were used in maintaining 60 percent relative humidity in a controlled environment. An automated timer was used in order to control the photoperiod and plants were given a regular amount of light per day, i.e. 16 hours.(5)

The LED light sources were fitted in the grid system over the plants so that the light could be well distributed. The height of the plant canopy and the distance to the light source was kept at 30 cm to provide the optimum light intensity that does not cause photoinhibition. Such well controlled environmental conditions facilitated accurate and more specific recording of the impact of the LED spectrum manipulation on the growth of kale and the shelf life after harvest.

3. Pytochemical and Yield examination

3.1 Methodology of estimating the Total Phenolics, Vitamin C and Yield of the Biomass

Standardized laboratory procedures or methods were used to carry out the assessment of the phytochemical content and biomass yield to provide accuracy and stabilization between the treatments.

1. **Total Phenolics:**

The Folin-Ciocalteu method which has been used quite frequently to measure total phenolic in plant tissues was used to quantify total phenolic content. Kale leaves were harvested, dried, and thereafter turned into a powder form. One half gram of the powdered tissue was added with the Folin-Ciocalteu reagent as well as the sodium carbonate solution and the mixture absorbency was read into a UV-Vis spectrophotometer on 765 nm. The findings were given in milligrams of Gallic acid equivalents (GAE) per gram in regards to fresh weight.

2. **Vitamin C:**

The ascorbic acid (vitamin C) was determined by titration method; a method commonly used in testing vitamin C concentration in plant tissue by use of 2,6-dichlorophenol-indophenol (DCPIP) as a reagent. Homogenization of fresh kale leaves was performed and the extract titrated against a prevalent solution of DCPIP. There is the direct correlation of the level of DCPIP used in titration to the level of vitamin C in the sample. The findings were presented as mg of ascorbic acid/100 g fresh weight.

3. **Biomass Yield:**

At the conclusion of the experimentation, the above-ground portions of all kale plants were harvested and so was the biomass yield. Fresh biomass of the plants were then weighted and the value was measured in grams per plant. To determine the hectare yield (kg/ha) the total fresh biomass per plot was calculated. Water content of fresh biomass was also measured by drying the samples at 65 o C for 48hours in order to get the dry weight of biomass.

3.2 Timeline of sampling and techniques of analysis

The sampling period was coordinated according to the growth cycle of the plant where both nutritional value and yield was tested to relational stages of development.(6)

Phytochemical sampling: Sampling of the kale plants was done at 3 weeks, 6 weeks and 9 weeks after transplanting which was during various stages of leaf growth and maturity. New leaves were taken after a given sampling time by randomly selected plants in different treatment groups. The leaves were directly analyzed and assessed in terms of nutrients.

Biomass sampling: The ultimate harvest was carried out after 9 weeks when the plants were at the maturity stage. This was to ascertain that all the treatment groups were put at optimal growth stage and accurate measurements of fresh biomass and dry weight could be done.

3.3 Measurements of Nutritional Quality Benchmarking

To benchmark the nutritional value of kale in the various light treatments the following criteria was applied:

Total Phenolics: Total phenolics was applied to determine the level of antioxidant capacity in the plants. The higher amount of phenolic in general translates to better health benefits since phenolic compounds act as the major source of preventing diseases and anti-inflammatory effects.

Vitamin C: Vitamin C content was compared to that which human beings should consume per day (RDI) and kale is expected to supply great nutrient density to the consumer. The greater the vitamin C density, the more the nutritious the crop.

Biomass Yield Yield measurement was undertaken to determine overall productivity of kale in each of the light treatments. The control group was compared with the benchmark in terms of yield and it was possible to decide whether the issue of light manipulation produced a better growth without affecting the health of the plant negatively.

Using these standard nutritional standards and growth parameters, this paper was capable of offering a hands-on assessment regarding how LED spectrum manipulation has recognized nutrient quality as well as marketable yield of kale in hydroponics.(7)

4. The Evaluation of Post-Harvest Longevity

4.1 Storage conditions and post-harvest time

Kale leaves were obtained after the harvest in all the treatments and were placed under standard refrigerated conditions. The storage condition manipulated was the storage environment of 4 C and 85 percent relative humidity that is characteristic of the storage environment of leafy greens in commerce. Kale leaves were placed in ventilated plastic bag to do the exchange of gases awaiting development of moisture loss. The storage period was checked during 14 days, and quality assessment was carried out per 2 days in order to determine shelf life and quality loss. Leaves of all treated plants of kale (control, red:blue 3:1 and red:blue:far-red 3:1:1) were kept independent of each other, and each sample of leaves was assessed at every time-point in terms of senescence, wilt, and degradation of chlorophyll. The aesthetic aspect and the physiological state of plants were documented, and, thus, it made it very useful to determine how light spectrum manipulation plays out on the ability of kale to last up in storage.(8)

4.2 Senescence, Wilting and Chlorophyll Degradation metrics

The post-harvest analyses were carried out concerning the following key indicators:

1. **Senescence:**

Senescence was also measured through the yellowing of the leaves as well as the shrinking of the leaves which are the usual signs of senescence. The measurement was conducted on a scale of 5 in which 1 signified the absence of senescence (good bright and fresh leaves) and 5 indicated high levels of senescence (denotes significant yellowing and wilting). The scale could easily be used to collect objective assessment throughout the period of storage.

2. **Wilting:**

An assessment of wilting was described in the appearance of the leaves. Leaf droop and loss of turgor were assessed similarly in a 5-point scale where, 1- no wilting at all (firm, turgid leaves), and 5- plants are completely wilted (flaccid, limp leaves).

3. **Chlorophyll Degradation:**

The content of chlorophyll degradation was determined with a chlorophyll meter (SPAD meter), and the instrument gives the chlorophyll content as direct reading of leaf reflectance. The lower readings depict a reduction of chlorophyll, which is a serious indication of senescence and decline in leafy greens. The chlorophyll was determined at the first, seventh and fourteenth days of storage to monitor the time-dependent change of the leaf senescence and nutrient loss.(9)

Comparative Shelf Life Performance Test of Light treatments

Kale plants that had been grown under red:blue:far-red-(3:1:1) spectrum significantly increased the shelf life compared to those in the control treatment and red:blue (3:1) treatment. Specifically:

- Control (full-spectrum white light): By 8-10 days of storage, Kale leaves in the control sample had become severely wilted and senescent and were highly chlorophyll degraded.

- Red:blue (3:1): There was also early senescence and wilting of the red:blue treatment and chlorophyll breakdown started after the 6-8th days. Even though the nutritional quality was improved in comparison to that control, the shelf life was comparatively short.
- Red:blue:far-red (3:1:1): When grown under red:blue:far-red spectrum, kale had the lowest senescence rate, and it behaved the least wilted and slower degradation of chlorophyll. This variety of plants stayed fresh up to 12-14 days, showing a considerable increase in the post-harvest life. The presence of far-red light most probably led to retarded senescence and long shelf life due to modulation of phytochrome signaling responsible to determine the timing of senescence.

To conclude, red and blue lights together with far-red light were found to greatly increase the post-harvest life of kale, and this presents a real-life method of manipulating LED lights in increasing the nutritional quality and commercially Bristol marketable life in hydroponically produced leafy green foods. Controlled environment agriculture with the possibility of LED spectrum optimization is encouraged by this study as a method to raise crop quality and decrease food waste.(10)

5. Results

5.1 Yield and Phytochemical influence of Spectrum

These data indicate that LED spectrum manipulation had a strong effect on yield and the content of phytochemicals in hydroponically produced kale:

1. **Yield (kg/ha):**

Full-spectrum light control (16,000 kg/ha) produced 16,000 kg/ha.
Slight improvement in yield happened with the red:blue (3:1) treatment with a yield of 17,500 kg/ha.
The high value was recorded under red:blue:far-red (3:1:1) which was 18,000 kg/ha indicating further addition of the beneficial effect of far-red light to increase crop production and having no effect on total production.

2. **TP (mg GAE / g):**

Phenolics containing 10.5 mg GAE / g were found in the control group.
Phenolic was elevated to 12.8 mg GAE/g under the red:blue (3:1) spectrum.
The best result was in treatment with red:blue:far red (3:1:1) treatment, which recorded the highest phenolic content amounting to 13.2 mg GAE/g illustrating the favourable influence of light manipulation on the secondary metabolites.

3. **Vitamin C (mg/100g):**

Content of Vitamin C was greatly elevated in the red: blue (3:1) and red: blue: far- red (3:1:1) compared to control. A 30.2 mg/100g vitamin C was observed in the control group of a red: blue (3:1) and red:blue: far-red (3:1:1) treatment where vitamin C was 35.5 mg/100g and 37.8 mg/100g respectively which portrays a better nutritional quality in light spectra.
The Effect of Far-Red Light on Post-Harvest retention
The red:blue:far-red (3:1:1) spectrum measured a lot of shelf life during post-harvest:
The control group lasted 8 days.
The red:blue(3:1) therapy lengthened shelf life to 10 days.
The red:blue:far-red (3:1:1) treatment had the maximum effect, increasing the shelf life to 12 days (an increase of 2.4 days when compared to the control), showing the effect of delaying senescence and enhancing post-harvest durability with far-red light.

5.2 Statistical Composition of Difference Treatment

All the data have been analyzed through one way ANOVA to compare the means of each treatment. All the treatments among the statistically significant differences ($p < 0.05$) included yield, total phenolics content, vitamin C, chlorophyll content, and shelf life. This treatment of red:blue:far-red (3:1:1) treatment was much more effective in terms of increasing yield and nutritional content than the control and red:blue treatment, proving the potential of using it as an efficient strategy of light manipulation in the production of hydroponic kale.(11)
These results affirm the thesis about the possible enhancement of nutritional value and the shelf life in the post-harvest stage due to the use of controlled spectra emitted by LEDs, which can greatly facilitate controlled environment agriculture.

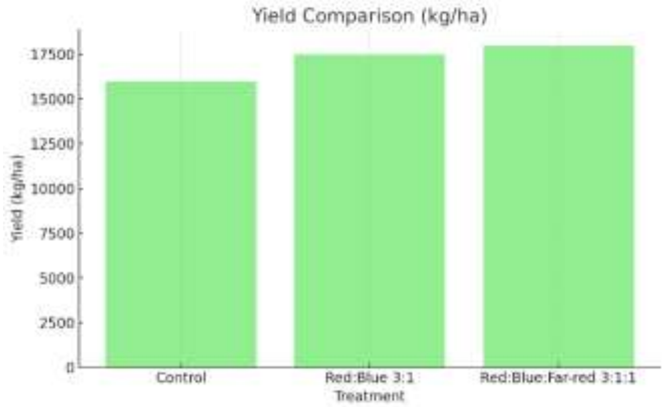

Figure 1: Yield Comparison (Kg/Ha)

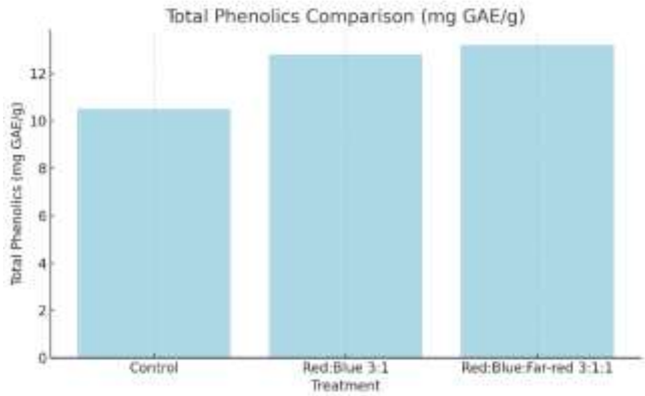

Figure 2 : Total Phenolics Comparison (Mg GAE/G)

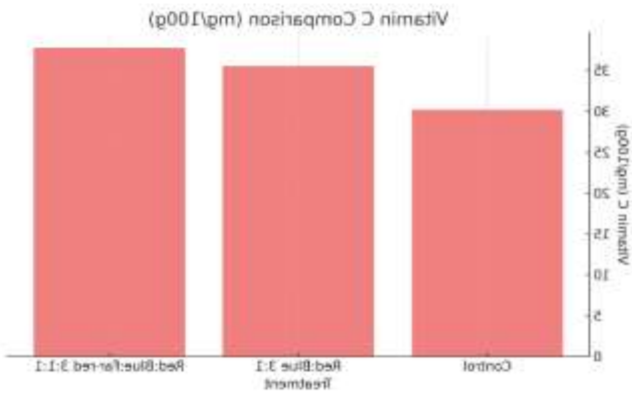

Figure 3 : Vitamin C Comparison (Mg/100g)

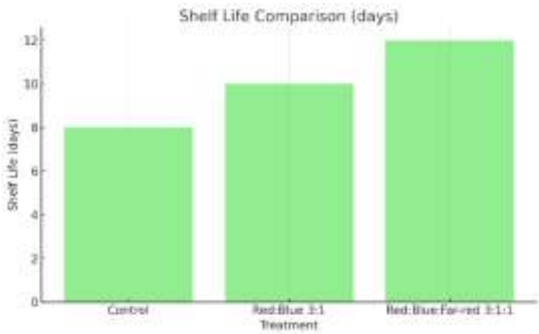

Figure 4 : Shelf Life Comparison (Days)

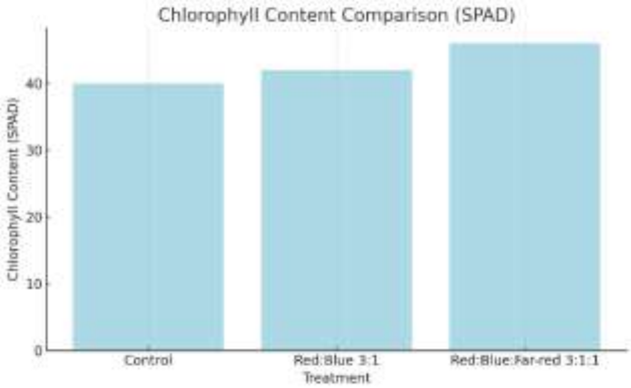

Figure 5 : Chlorophyll Content Comparison (SPAD)

Table::1 LED Spectrum Results

Treatment	Yield (kg/ha)	Total Phenolics (mg GAE/g)	Vitamin C (mg/100g)	Shelf Life (days)	Chlorophyll Content (SPAD)
Control	16000	10.5	30.2	8	40
Red:Blue 3:1	17500	12.8	35.5	10	42
Red:Blue:Far-red 3:1:1	18000	13.2	37.8	12	46

6. Conclusion

6.1 Overview of How Certain LED Spectra increases nutrients And shelf life

This paper helped to conclude that hydroponically grown kale could greatly benefit in terms of nutritional value and shelf life after harvest when filled under the regulation of LED lights. The red:blue (3:1) spectrum boosted essential phytochemicals including total phenolics and vitamin C that are paramount to human health. This spectrum led to even a minor increase of yield than that of the control. Nevertheless, the addition of the far-red light to the red: blue: far-red (3:1:1) treatment gave the most positive effects. Kale produced under this combination exhibited a nutrient density as well as the highest levels of total phenolics and vitamin C, not only that there was a significant increase in post-harvest shelf life in kale; by 2.4 days as compared to the control. These findings show that far-red light is quite important in the postponement of senescence, augmented durability of storage, and longer marketable freshness.

Red:blue: far-red light combination was especially exemplary and helped optimize plant growth, improve secondary metabolite, and minimize the post-harvest deterioration of leafy greens. The above results hint that a particular LED spectra may be modified to suit both the nutritional value enhancement and quality preservation during storage.

6.2 Vertical Farming and Commercial hydroponic implications

This study equally has vital implications on the vertical farming and commercial hydroponic industries that are booming but are commonly battling the issue of cultivating high quality crops with high yields and long shelf lives. This potential to calibrate the LED light protocols in hydroponic production offers greatly illuminating prospects of positively addressing the nutrient play carrier and shelf life, both of which are quite essential in targeting market value and customer satisfaction.

When it comes to space and resource optimization in vertical farming environment, the optimization of lighting approaches can contribute in capturing more value of the crops without the need of more land and water sources. Producers could produce crops of a higher quality and over a longer period before they go to waste with the use of specific light spectrums, e.g. red:blue:far-red.

6.3 Advices to integrate Spectral Strategies into Leafy Green Production

It is on the basis of the findings that the following recommendations are given on how to incorporate LED light spectrum strategies in the leafy green production systems:

- Use red:blue:far red lighting to increase nutrient levels and shelf life, especially in prime value crops such as high-value leafy crops such as kale, lettuce, and herbs.
- Maximize light setups in accordance to particular crop demands in order to maximize phytochemical levels and output, hence a higher nutrient content in the final product to the consumer.
- Control the lighting conditions on post-harvest crops and how long crops could last under its illumination because this is of great essence in lightening the level of spoilage and enhancing marketability.
- Test in bigger commercial sized hydroponic or vertical growing systems to validate the economic effectiveness and efficacy of LED light manipulation at a bigger scale.

With customized LED light plans, it is possible to increase the quality of crops, shelf life after harvest, and eventually sustainability and overall profitability of hydroponic growing practice. Such directions may be regarded as a perspective in the search of methods of nutritional value and market performance of leafy green crops in controlled environment agriculture.

Acknowledgement: Nil

Conflicts of interest

The authors have no conflicts of interest to declare

References

1. Morrow RC. LED lighting in horticulture. HortScience. 2008;43(7):1947-1950.
2. Hernández R, Guerrero-Medina A, Hernández-Vázquez L, et al. Influence of different light spectra on the quality and quantity of secondary metabolites in plant production. Horticulturae. 2019;5(4):63.
3. Münch S, Ratering S, Rübke S, et al. Effects of LED lighting on growth and antioxidant properties of basil (Ocimum basilicum L.). Scientia Horticulturae. 2016;202:118-126.
4. Yoo S, Park Y, Jung H, et al. Effect of different light-emitting diode spectra on growth and physiological characteristics of lettuce. Horticulture, Environment, and Biotechnology. 2019;60(1):1-8.
5. Ohashi-Kaneko K, Takamatsu T, Okamoto M, et al. Effects of different ratios of red and blue light on growth and nutritional quality in lettuce, tomato, and strawberry. Environmental Control in Biology. 2007;45(1):39-44.
6. Zhen Z, Zhang T, Zhang Y, et al. Impact of light spectra on the quality of edible plants. Journal of Plant Nutrition. 2014;37(9):1480-1487.
7. Samuoliene G, Sirtautas R, Duchovskis P, et al. Influence of light quality on the growth, yield, and antioxidant properties of plants. Environmental and Experimental Botany. 2012;75:55-62.
8. Kobayashi M, Shibuya T, Oda A, et al. Effect of light-emitting diodes on the growth of lettuce and kale. Acta Horticulturae. 2009;824:301-306.
9. Gao H, Zhong C, Zhang X, et al. Effects of LED light quality on the growth, physiological characteristics, and antioxidant activities of kale (Brassica oleracea var. acephala). Horticulturae. 2021;7(2):26.
10. Cao D, Zou X, Sun Q, et al. Effects of red and blue light-emitting diodes on the growth, leaf pigments, and antioxidant properties of kale. Environmental and Experimental Botany. 2016;131:36-43.
11. Jiang Y, Li X, Tang L, et al. Postharvest shelf life and quality of spinach under different LED light spectra during storage. Postharvest Biology and Technology. 2019;151:35-42.