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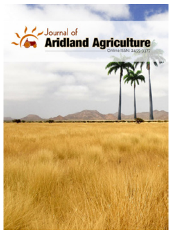
Research Article



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Effects of light-emitting diodes on the morphology and accumulation of glucosinolates, carotenoids and phenolic acids in red kale sprouts

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ABSTRACT

Kale (*Brassica oleracea* var. *acephala*) has gained popularity as a nutritious and phytochemical-rich vegetable. This study has investigated the effects of three LED treatments (white, blue, and red) on the accumulation of secondary metabolites in kale sprouts. Ten DAS, the kale sprouts were harvested, and growth measurements were measured. Furthermore, selected sprouts were stored at -80 °C for further biochemical analysis, namely, phenolic acids, glucosinolates, and carotenoids. Sprouts irradiated with red LED light showed the best SL, RT, and FW values. For total GSLs, we found that kale sprouts irradiated with white LED lights showed the best results (41.59±0.41 μmol/g DW). Among the aliphatic GSLs, we found that progoitrin presented the best results under blue LED light (17.93±0.49 μmol/g DW), and among the indolic GSLs, glucobrassicin showed the best results under white and red LED light. The highest concentration of total carotenoids was found in kale sprouts under white LED light exposure (3341.27±206.96 μg/g DW). Individually, β-carotene was observed in high concentration under white LED light (1935.13±87.21 μg/g DW). Among the PAs, chlorogenic acid was found in the highest concentration in the treatments under white LED light (45.78±0.73 μg/g DW). In general, kale sprouts irradiated with white LED light showed high contents of GSLs, carotenoids, and PAs. Regarding morphological characteristics, kale sprouts under red LED light showed the most promise. This research offers a valuable approach to enhancing the phytochemicals found in kale sprouting.

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KEYWORDS: Kale sprouts, LED irradiation, Phytochemical composition, Secondary metabolites, HPLC

INTRODUCTION

Kale (*Brassica oleraceae* var. *acephala*) is a cool-season crop from the Brassicas family. Its leaves, rich in vitamins and essential mineral components, are commonly used alone or together for human and animal feed (Life, 2024). In recent years, kale has gained the scientific community's attention due to its nutritional composition (Ware, 2020), and consumer acceptance (Adeyeye *et al.*, 2018). In addition, due to its high content of bioactive compounds such as vitamins (Becerra-Moreno *et al.*, 2014), glucosinolates (Bhandari *et al.*, 2015; Liu *et al.*, 2022), flavonoids (Lännenpää, 2014; Panche *et al.*, 2016), phenolics (Ayaz *et al.*, 2008; Cartea *et al.*, 2011; Bianchi *et al.*, 2024), micro and minerals (Sikora & Bodziarczyk, 2013; Thavarajah *et al.*, 2016). Notwithstanding, kale has been used in traditional medicinal systems to treat several diseases, including diabetes, rheumatism, and hepatic diseases (Raiola *et al.*, 2017; Chen *et al.*, 2018; Šamec *et al.*, 2019; Luang-In *et al.*, 2020).

A sprout is a young plant that has germinated seeds. There are several varieties of them and they are usually eaten raw (Healthline, 2024). Unsurprisingly, sprouts are nutrient-dense and contain beneficial plant compounds despite their low-calorie content. Depending on the variety, they contain different amounts of vitamins and minerals (Chang *et al.*, 2019). Nutrient levels in sprouted grains, legumes, vegetables, and seeds tend to increase. It is also easier for the human body to absorb all the nutrients in sprouts because they contain fewer antinutrients (Singh *et al.*, 2015; Ghumman *et al.*, 2016; Sibian *et al.*, 2017).

Plants produce primary metabolites as well as secondary metabolites. Secondary metabolites are phytochemicals with no direct function at specific points, but they can play critical roles, such as preventing plants from pathogens and herbivore attacks and attracting pollinators (Wani *et al.*, 2022). In addition, many of the secondary metabolites have been used as active compounds to develop drugs, antibiotics, pesticides, and herbicides (Wani *et al.*, 2022). Among the known phytochemicals, we can highlight polyphenols, flavonoids, anthocyanidins, carotenoids, glucosinolates, and fibres. The presence and secretions of these organisms are found naturally in plants (Altemimi *et al.*, 2017).

Glucosinolates are a large group of secondary metabolites found in plants with nutritional effects and biologically active compounds (Favela-González *et al.*, 2020). Brassicaceae, which includes many cruciferous species, are the most abundant sources of glucosinolates (Barba *et al.*, 2016; Prieto *et al.*, 2019). Recent studies have shown the beneficial effects of glucosinolates, including regulatory functions in inflammation (Connolly *et al.*, 2021), plant stress response, antioxidant activities, and antimicrobial properties (Abdel-Massih *et al.*, 2023).

Phenolic compounds are the most abundant plant secondary metabolites and are ubiquitously present in most plants. They play vital roles in plant defences against various biotic and abiotic stresses and contribute to the development of plant colour (Mark *et al.*, 2019; Kumar *et al.*, 2020; Albuquerque *et al.*, 2021). They are known to have antibacterial (Oussaid *et al.*, 2017), antioxidant (Singh *et al.*, 2017), anti-inflammatory (Velmurugan *et al.*, 2018), and anticarcinogenic activities (Wang *et al.*, 2020). Because of that, plant-based foods rich in phenolic compounds are recommended to enhance human health.

A plant's carotenoids can serve a variety of functions and are secreted by both primary and specialised metabolites, respectively, while in green tissues carotenoids are essential for plant survival as primary metabolites (Liang *et al.*, 2018; Sun & Li, 2020). Previous studies have shown that carotenoids play a role in plant defence response (Uarrota *et al.*, 2018), photo protection (Hashimoto *et al.*, 2016), photosynthesis (Chauhan *et al.*, 2023), plant development and signalling (Dickinson *et al.*, 2019; Felemban *et al.*, 2019). Additionally, carotenoids are essential accessory pigments to enhance nutrition (Giuliano, 2017; Zheng *et al.*, 2020) and reduce the risk of various chronic diseases (Eggersdorfer & Wyss, 2018).

Among various environmental factors, light quality is crucial for photosynthesis, plant growth, and development (Hasan *et al.*, 2017; Song *et al.*, 2020). In plants, light emitting diode (LED) affects the metabolites significantly and plays a vital role in their physiology (Lee *et al.*, 2016). Additionally, Lee *et al.* (2023), in a short-term LED treatment, found a potentially effective enhancement accumulation of phytochemicals. Most sprouts can be easily cultivated indoors and contain higher amounts of phytochemicals. As sprouts are generally consumed raw and cooked lightly, there is no thermal degradation of micronutrients through food processing. Thus, it is required to investigate optimal light conditions to enhance the growth and accumulation of phytochemicals in the sprouts. Therefore, this study aims to examine the effects of three LED treatments on the accumulation of different types of secondary metabolites in *Brassica oleracea* L. var. *acephala* sprouts.

MATERIALS AND METHODS

Plant Materials and Growth Conditions

Kale seeds were purchased from Asia Seed Co., Ltd (Seoul, Korea). The experiment was arranged in a completely randomised design (CRD) with three replications for each treatment. Sprouts were established by immersing 20 seeds in sterile water for 24 hours before they were placed in vermiculite-filled plastic pots. The sprouts were grown in a growth chamber at 25 °C under irradiation with white (450-660 nm), blue (450 nm), and red (660 nm) LED lighting with a flux rate of 90 μmol m^{-2} s^{-1} and 16 h photoperiod (PGL-PFL series, PARUS LED Co., Cheonan, Korea). The sprouts were harvested ten days after sowing (DAS). For growth measurements, 10 DAS and ten plants from each subspecies were selected randomly, and growth measurements were taken. The shoot length (SL) and root length (RL) were measured in cm using a meter ruler. To determine the fresh weight (FW), the kale sprouts were weighed in mg using a balance. After harvesting, all sprout samples were frozen in liquid nitrogen, stored at -80 °C, and freeze-dried for high-performance liquid chromatography (HPLC). Glucosinolates and phenolic compounds in sprout mixtures were analyzed by HPLC using samples from three independent replications.

Glucosinolates Extraction and HPLC Analysis

Following previously reported procedures by Lee *et al.* (2023), glucosinolates (GSLs) were extracted with some modifications. An Eppendorf 2 mL tube containing 100mg of the freeze-dried powdered sample was filled with 1.5 mL of MeOH. Water baths at 70 °C were used for 5 minutes to heat the tubes. A collection of supernatants followed centrifugation at 12000 rpm for 10 minutes at 4 °C in a new 5 mL Eppendorf tube. GSL extracts were prepared from residues by combining the supernatants from both extractions. For desulphating the extracts, 75 μL of aryl sulphatase solution was combined with DEAE-Sephadex A-25 on a Mini column. Then, microcentrifuge tubes filled with 2 mL of H_2O were used to elute DS-GSLs with 0.5 mL ultrapure H_2O, and for the elution, three replicates were performed. Furthermore, GLSs were detected and computed by HPLC peak area ratios, retention times, and response factors using desulpho-sinigrin (Sigma-Aldrich Co., Ltd., St. Louis, MO, USA) as an external standard.

Phenolic Acids Determination

A previous method described by Lee *et al.* (2023) was utilised to analyse phenolic acids (PAs). Aqueous MeOH was added to 100 mg of dried sprout powder samples. Sonication was performed for one hour at 25 °C. The supernatant was transferred to a new tube after centrifugation at 10,000 rpm for 10 minutes. A further two extractions removed sludge. PTFE syringe filters were used to filter the supernatant collected after centrifugation for 15 minutes at 10,000 rpm. According to Lee *et al.* (2023), the HPLC analysis system, gradient program, and conditions were based on their study. The retention times and spiking tests were used to calibrate calibration curves.

Extraction and Analysis of Carotenoids

Carotenoids were obtained using the methods outlined in Park *et al.* (2012) study. First, 10mg of sprout powder was combined with 3 mL of 0.1% (w/v) ascorbic acid dissolved in EtOH. The mixture was then vigorously mixed for 20 sec and placed in an 85 °C water bath for incubation. After 5 min, 120 μL of NaOH with a concentration of 80% (w/v) was introduced, then for 20 sec, the samples were vortexed and incubated in the 85 °C water bath for 10 min. The samples were then put on ice for 5 min, then 1.5 mL of C_6H_{14}, 1.5 mL of distilled H_2O, and 0.1 mL of the internal standard (β-apo-8′-carotenal in EtOH; 25 μg/mL) were added to each. Each sample's top C_6H_{14} layer was moved to a fresh tube after a 5 min centrifugation at 1200 rpm and 4 °C. The centrifugation process was carried out once again for re-extraction. After being dried with nitrogen gas, the supernatants were dissolved in 0.25 mL of a $MeOH\text{-}CH_2CL_2$ solution that was 50:50 (v/v) in concentration, provided the specifications for the HPLC analysis, including the condition, system, and gradient program.

Statistical Analysis

SAS software version 9.2 (SAS Institute Inc., Cary, NC, USA) was used with Duncan's multiple range test at $p<0.05$ to analyse the data. Standard deviations and mean values are shown. Three repetitions were performed for each experiment.

RESULTS

Phenotype of Kale Sprouts Irradiated with Different LED Lights

Ten DAS sprouts under red LED light presented the best SL, RT, and FW (8.4 cm, 13.01 cm, and 890 mg, respectively). Kale sprouts irradiated with white LED showed the lowest values in this study. A difference in plant development among treatments was observed, and it was clear that the kale sprouts under red LED light presented better phenotypic characteristics than the others, namely leaf development and plant height (Figure 1).

Content of GSLs in Kale Sprouts Irradiated with Different LED Lights

By HPLC analysis, were identified and quantified a total of 16 GLSs, where 11 aliphatic GSLs (glucoiberin, progoitrin, glucoraphanin, glucoalyssin, gluconapoleiferin, gluconapin, glucobrassicanapin, glucoerucin, glucohirsutin, glucoraphasatin, and glucoberteroin), one aromatic GSLs (gluconasturtiin), and four indolic GSLs (4-methoxyglucobrassicin, glucobrassicin, neoglucobrassicin, and 4-hydroxyglucobrassicin) (Table 1). Progoitrin presented the best results by far in GSL content (white LED, 17.31±0.12 μmol/g DW, blue LED, 17.93±0.49 μmol/g DW, and red LED, 13.57±0.06 μmol/g DW) compared to other detected. For total GSLs, we found that kale sprouts irradiated with white LED lights showed the best results (41.59±0.41 μmol/g DW).

Carotenoid Content in Kale Sprouts Irradiated with Different LED Lights

Statistical analysis results showed differences in all carotenoids detected (Table 2). The highest concentration of total carotenoids was found in kale sprouts under white LED light exposure (3341.27±206.96 μg/g DW). Individually, β-carotene was found in high concentration (white LED, 1935.13±87.21 μg/g DW, blue LED, 1809.35±58.44 μg/g DW, and red LED, 1678.86±26.10 μg/g DW), followed by lutein. According to these results, it is assumed that the kale sprouts irradiated under white and red LED light may be a better source of β-carotene and lutein, respectively.

Phenolic Acid Content in Kale Sprouts Irradiated with Different LED Lights

Three PAs, two hydroxycinnamic acids (chlorogenic acid and ferulic acid), and one hydroxybenzoic acid (benzoic acid) were detected and quantified in the three LED light treatments (Table 3). Among the PAs, chlorogenic acid was found in the highest concentration in the treatments: white LED (45.78±0.73 μg/g DW), red LED (42.01±0.81 μg/g DW), and blue LED (39.63±0.56 μg/g DW). According to these results, chlorogenic acid occupies an essential position in kale sprout phenolic composition. Overall, the kale sprouts treatment irradiated with white LED light presented the best content in Pas compared with other LED light treatments.

DISCUSSION

In plants, light is a powerful abiotic stimulus that influences growth, development, and morphogenesis (Tariq *et al.*, 2014; Adil *et al.*, 2019). In addition to controlling primary and secondary metabolism, light plays a vital role in ensuring optimum plant growth (Samuolienė *et al.*, 2013; Park *et al.*, 2020a). Our results showed that in kale sprouts grown in 10 days submitted to three different LED light irradiations, those under red LED light irradiations presented the best SL, RL, and FW values. Similar results were found by Park *et al.* (2019), who reported that the highest shoot length and fresh weight were obtained in canola sprouts exposed to red LED light and for root length. Kochetova *et al.* (2022) also found the best values in seedlings exposed to red LED light. Additionally, according to a study conducted by Manivannan *et al.* (2015), *R. glutinosa* exhibited notable growth improvements when exposed to blue or red LED treatments, as opposed to white light. Furthermore, Thwe *et al.* (2014) in buckwheat sprouts found that the highest

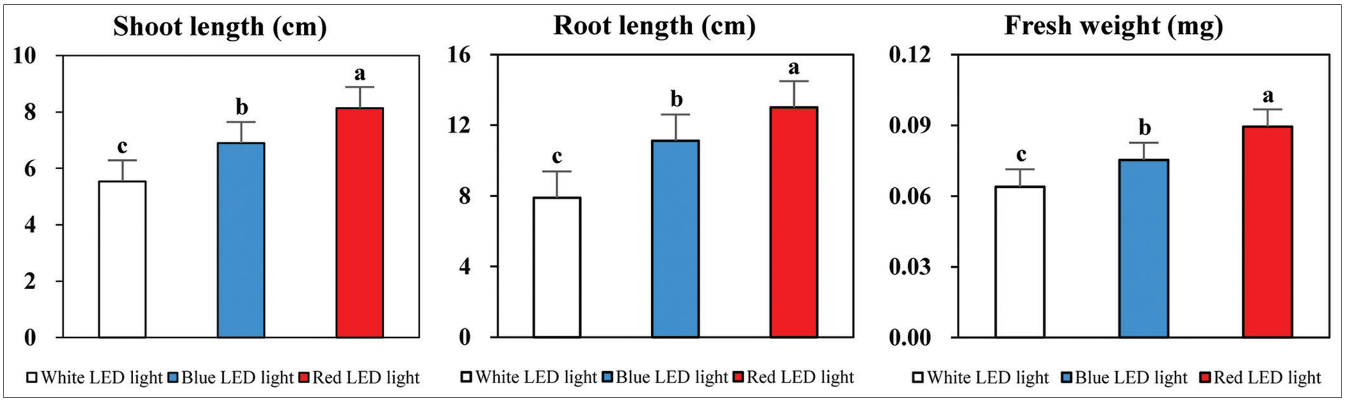

Figure 1: Morphological parameters SL, RT, and FW observed 10 DAS in growth chambers under three different LED light irradiations. Duncan's multiple range test reveals that using different letters signifies a notable distinction in means ($p<0.05$)

Table 1: The concentration of GSLs (μmol/g DW) in kale sprouts irradiated with white, blue, and red LED light 10 DAS

Glucosinolates	Concentration (μmol/g DW)		
	White-LED	Blue-LED	Red-LED
Glucoiberin	0.36 ± 0.04^{a}	0.30 ± 0.03^{b}	0.36 ± 0.00^{a}
Progoitrin	17.31 ± 0.12^{b}	17.93 ± 0.49^{a}	13.57 ± 0.06^{c}
Glucoraphanin	0.89 ± 0.01^{b}	0.97 ± 0.02^{a}	0.72 ± 0.02^{c}
Glucoalyssin	0.82 ± 0.04^{b}	0.90 ± 0.01^{a}	0.68 ± 0.01^{c}
Gluconapoleiferin	1.33 ± 0.01^{b}	1.39 ± 0.01^{c}	1.24 ± 0.01^{a}
Gluconapin	1.69 ± 0.01^{a}	1.53 ± 0.02^{b}	1.04 ± 0.01^{c}
4-Hydroxyglucobrassicin	2.07 ± 0.39^{a}	1.03 ± 0.56^{b}	1.68 ± 0.25^{ab}
Glucobrassicanapin	0.27 ± 0.01^{a}	0.26 ± 0.01^{a}	0.24 ± 0.00^{b}
Glucoerucin	0.70 ± 0.11^{ab}	0.60 ± 0.02^{b}	0.80 ± 0.02^{a}
Glucohirsutin	0.25 ± 0.13^{a}	0.11 ± 0.02^{a}	0.17 ± 0.02^{a}
Glucoraphasatin	0.02 ± 0.02^{b}	0.12 ± 0.01^{a}	0.03 ± 0.00^{b}
Glucobrassicin	6.87 ± 0.09^{a}	4.96 ± 0.15^{b}	6.92 ± 0.19^{a}
4-Methoxyglucobrassicin	5.62 ± 0.11^{a}	3.37 ± 0.19^{b}	5.51 ± 0.28^{a}
Glucoberteroin	0.50 ± 0.02^{b}	0.39 ± 0.01^{c}	0.53 ± 0.00^{a}
Gluconasturtiin	0.50 ± 0.03^{ab}	0.53 ± 0.05^{a}	0.44 ± 0.00^{b}
Neoglucobrassicin	2.30 ± 0.01^{c}	2.74 ± 0.13^{b}	3.20 ± 0.00^{a}
Total	41.59 ± 0.41^{a}	37.24 ± 0.21^{b}	37.21 ± 0.67^{b}

Duncan's multiple range test reveals that using different letters signifies a notable distinction in means ($p<0.05$).

Table 2: The concentration of carotenoids (μg/g dry wt.) in kale sprouts irradiated with white, blue, and red LED light 10 DAS

Carotenoids	Concentration (μg/g DW)		
	White-LED	Blue-LED	Red-LED
Violaxanthin	59.38 ± 2.45^{b}	41.43 ± 3.75^{c}	71.20 ± 1.52^{a}
Lutein	1034.72 ± 83.26^{a}	947.49 ± 48.97^{a}	1052.06 ± 2.46^{a}
Zeaxanthin	16.05 ± 1.18^{c}	22.06 ± 1.19^{b}	53.70 ± 0.92^{a}
13-cis-β-carotene	148.08 ± 9.08^{a}	114.60 ± 4.46^{b}	113.50 ± 3.63^{b}
α-carotene	31.05 ± 1.66^{a}	28.45 ± 1.44^{ab}	25.69 ± 0.40^{b}
β-carotene	1935.13 ± 87.21^{a}	1809.35 ± 58.44^{b}	1678.86 ± 26.10^{c}
9-cis-β-carotene	116.86 ± 9.79^{a}	104.24 ± 5.81^{ab}	96.45 ± 0.68^{b}
Total	3341.27 ± 206.96^{a}	3067.64 ± 116.37^{b}	3091.44 ± 27.87^{b}

Duncan's multiple range test reveals that using different letters signifies a notable distinction in means ($p<0.05$).

Table 3: The concentration of phenolic acids (μg/g dry wt.) in kale sprouts irradiated with white, blue, and red LED light 10 DAS

Carotenoids	Concentration (μg/g DW)		
	White-LED	Blue-LED	Red-LED
Chlorogenic acid	45.78 ± 0.73^{a}	39.63 ± 0.56^{c}	42.01 ± 0.81^{b}
Ferulic acid	4.84 ± 0.05^{a}	5.35 ± 0.43^{a}	4.80 ± 0.11^{a}
Benzoic acid	7.48 ± 0.62^{a}	2.52 ± 0.18^{b}	1.92 ± 0.09^{b}
Total	52.10 ± 5.71^{a}	44.98 ± 0.78^{b}	46.81 ± 0.83^{b}

Duncan's multiple range test reveals that using different letters signifies a notable distinction in means ($p<0.05$).

length and fresh weight were achieved in sprouts irradiated with red LED light. However, these findings do not agree with Li *et al.* (2012), Park *et al.* (2020b), and Tan *et al.* (2020), who found that blue LED light benefits vegetation and promotes elongation growth in brassicas plants, whereas red LED light supports reproductive growth.

LED lights influence GSL content. However, the response varies depending on the type of glucosinolate (Demir *et al.*, 2023). Similar results were found in the present study, where the content of GSLs varied in different LED light exposures. Furthermore, Cartea and Velasco (2008) found that the structure and amount of glucosinolates varied significantly between *B. oleracea* sprouts. We found a high content of aliphatic GSLs (progoitrin), and sprouts submitted to a white LED light irradiation presented the high total content of GSLs in the current study. These results do not agree with those of Cartea and Velasco (2008), who found that different *B. oleracea* varieties contain glucobrassicin and glucoiberin, which essentially contain significant quantities of sinigrin. Additionally, Lee *et al.* (2016) found that kale, under blue and red LED light irradiation, produced considerably high levels of GSLs. However, according to Park *et al.* (2019), sprouts of *B. napus* grown under white, blue, and red LEDs contained similar levels of total GSLs. Qian *et al.* (2016) discovered that the roots of Chinese kale sprouts experienced an increase in the beneficial glucoraphanin content when exposed to blue LED light. Additionally, this light source had the advantage of reducing the unwanted gluconapin in the shoots. These effects were not observed with dark, white, or red lights. These results are similar to those we found in the present study. According to Sathasivam *et al.* (2023), the individual GSLs content, such as 4-hydroxyglucobrassicin, glucoerucin, 4-methoxyglucobrassicin, and neoglucobrassicin, were improved in kohlrabi sprouts exposed to blue LED light compared to those exposed to white and red LED light. These results are far different from those found in the current study. The findings indicate that most *Brassicas* have similar GSL compounds. Nevertheless, varying LED lights can influence individual and total GSL content accumulation.

Carotenoids are plant pigments categorised as secondary plant compounds that play a crucial role in enhancing human well-being and are thus significant for the overall quality of vegetables (Cazzonelli, 2011; Fiedor & Burda, 2014). In the present study, we found β-carotene as a carotenoid observed in high levels, and it belonged to kale sprouts exposed to white LED light irradiation, followed by rutin in red LED light. Similar results were found by Sathasivam *et al.* (2023), who observed that the highest amount of total carotenoid was in kohlrabi sprouts irradiated with white LED light, and the individual carotenoids found with the highest contents were β-carotene and lutein. Likewise, Frede *et al.* (2018) observed that higher carotenoid quantities were measured under white LED compared to blue or red LED light irradiation. Another study found that lettuce and Komatsuna had higher total carotenoid levels when exposed to white and red lights. In contrast, when exposed to blue light, spinach had the highest carotenoid levels (Ohashi-Kaneko *et al.*, 2007). However, Li *et al.* (2012) discovered contrasting outcomes, as they observed that exposing Chinese cabbage microgreens to blue LED light resulted in an augmentation in carotenoid production. Additionally, in lettuce and broccoli sprouts, blue light increased the carotenoid content (Johkan *et al.*, 2010; Kopsell & Sams, 2013). Furthermore, (Frede *et al.*, 2023) found that blue light increases the transcription of carotenoid biosynthesis genes in five *Brassica* spouts. Based on current and past findings, choosing the proper LED lighting to enhance plants' overall and individual carotenoid levels may vary depending on the species.

The content of PAs in *Brassica* microgreens grown under different LED light quality conditions varies widely. We detected and quantified three PAs, including chlorogenic acid, in high quantities in kale sprouts under white LED light irradiation. Similar results were found with Sathasivam *et al.* (2023), who found high levels of chlorogenic acid in kohlrabi sprouts in white LED light conditions compared to red and blue LED light. However, the total PAs were found in sprouts irradiated with blue LED light treatment. Different results from Olsen *et al.* (2009) and Lin and Harnly (2010) the most common PAs in *Brassica* vegetables are *p*-coumaric, sinapic and ferulic acids. Additionally, Kim *et al.* (2015) Discovered that in *B. rapa* subsp. *pekinensis*, *p*-hydroxybenzoic acid was the most abundant PA measured under blue LED light, followed by chlorogenic acid under white LED light. Furthermore, Yeo *et al.* (2018) stated that cowpea sprouts grown under white LED light presented the lowest level of PAs. In another study, Cuong *et al.* (2019) showed that most of the PAs found were quercetin and gallic acid in wheat sprouts under white LED light irradiation. According to Park *et al.* (2020b), *A. rugosa* plantlets exposed to white LED lights accumulated the highest amounts of rosmarinic acid and tilianin. Additionally, Park *et al.* (2020a) observed that in *B. juncea* sprouts, exposure to a blue LED light enhanced the production of most PAs. Researchers can potentially improve the concentration of a particular compound by cultivating kale sprouts under appropriate LED lighting. These findings offer potential avenues for improving the quality of these compounds in kale sprouts.

CONCLUSION

Artificial light can be used as a replacement for natural light in plants. Different light sources have varying effects on plant morphology and the accumulation of certain compounds. White LED light positively affected the concentration of GSLs, carotenoid and PAs in kale sprouts, while red LED light positively affected morphology. This study provides a strategy for improving phytochemicals in kale. Future studies can explore other types or combinations of LED light for further insights. Additionally, there is a need for more research on the effects of LED illumination on other plant compounds such as chlorophyll, anthocyanin, protein, vitamin, mineral and antioxidant activity.

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REFERENCES

Abdel-Massih, R. M., Debs, E., Othman, L., Attieh, J., & Cabrerizo, F. M. (2023). Glucosinolates, a natural chemical arsenal: More to tell than the myrosinase story. *Frontiers in Microbiology, 14*, 1130208. https://doi.org/10.3389/fmicb.2023.1130208

Adeyeye, A., Ayodele, O. D., Akinnuoye, G. A., & Sulaiman, W. (2018). Proximate composition and fatty acid profiles of two edible leafy vegetables in Nigeria. *American Journal of Food, Nutrition and Health, 3*(2), 51-55.

Adil, M., Ren, X., & Jeong, B. R. (2019). Light elicited growth, antioxidant enzymes activities and production of medicinal compounds in callus culture of *Cnidium officinale* Makino. *Journal of Photochemistry and Photobiology B: Biology, 196*, 111509. https://doi.org/10.1016/j.jphotobiol.2019.05.006

Albuquerque, B. R., Heleno, S. A., Oliveira, M. B. P. P., Barros, L., & Ferreira, I. C. F. R. (2021). Phenolic compounds: current industrial applications, limitations and future challenges. *Food and Function, 12*(1), 14-29. https://doi.org/10.1039/d0fo02324h

Altemimi, A., Lakhssassi, N., Baharlouei, A., Watson, D. G., & Lightfoot, D. A. (2017). Phytochemicals: Extraction, isolation, and identification of bioactive compounds from plant extracts. *Plants, 6*(4), 42. https://doi.org/10.3390/plants6040042

Ayaz, F. A., Hayırlıoglu-Ayaz, S., Alpay-Karaoglu, S., Gruz, J., Valentova, K., Ulrichova, J., & Strnad, M. (2008). Phenolic acid contents of kale (*Brassica oleraceae* L. var. *acephala* DC.) extracts and their antioxidant and antibacterial activities. *Food Chemistry, 107*(1), 19-25. https://doi.org/10.1016/j.foodchem.2007.07.003

Barba, F. J., Nikmaram, N., Roohinejad, S., Khelfa, A., Zhu, Z., & Koubaa, M. (2016). Bioavailability of glucosinolates and their breakdown products: Impact of processing. *Frontiers in Nutrition, 3*, 24. https://doi.org/10.3389/fnut.2016.00024

Becerra-Moreno, A., Alanís-Garza, P. A., Mora-Nieves, J. L., Mora-Mora, J. P., & Jacobo-Velázquez, D. A. (2014). Kale: An excellent source of vitamin C, pro-vitamin A, lutein and glucosinolates. *CyTA - Journal of Food, 12*(3), 298-303. https://doi.org/10.1080/19476337.2013.850743

Bhandari, S. R., Jo, J. S., & Lee, J. G. (2015). Comparison of glucosinolate profiles in different tissues of nine *Brassica* crops. *Molecules, 20*(9), 15827-15841. https://doi.org/10.3390/molecules200915827

Bianchi, G., Picchi, V., Tava, A., Doria, F., Walley, P. G., Dever, L., di Bella, M. C., Arena, D., Ammar, H. B., Scalzo, R. L., & Branca, F. (2024). Insights into the phytochemical composition of selected genotypes of organic kale (*Brassica oleracea* L. var. *acephala*). *Journal of Food Composition and Analysis, 125*, 105721. https://doi.org/10.1016/j.jfca.2023.105721

Cartea, M. E., & Velasco, P. (2008). Glucosinolates in *Brassica* foods: bioavailability in food and significance for human health. *Phytochemistry Reviews, 7*, 213-229. https://doi.org/10.1007/s11101-007-9072-2

Cartea, M. E., Francisco, M., Soengas, P., & Velasco, P. (2011). Phenolic compounds in *Brassica* vegetables. *Molecules, 16*(1), 251-280. https://doi.org/10.3390/molecules16010251

Cazzonelli, C. I. (2011). Carotenoids in nature: insights from plants and beyond. *Functional Plant Biology, 38*(11), 833-847. https://doi.org/10.1071/fp11192

Chang, J., Wang, M., Jian, Y., Zhang, F., Zhu, J., Wang, Q., & Sun, B. (2019). Health-promoting phytochemicals and antioxidant capacity in different organs from six varieties of Chinese kale. *Scientific Reports, 9*, 20344. https://doi.org/10.1038/s41598-019-56671-w

Chauhan, J., Prathibha, M. D., Singh, P., Choyal, P., Mishra, U. N., Saha, D., Kumar, R., Anuragi, H., Pandey, S., Bose, B., Mehta, B., Dey, P., Dwivedi, K. K., Gupta, N. K., & Singhal, R. K. (2023). Plant photosynthesis under abiotic stresses: Damages, adaptive, and signaling mechanisms. *Plant Stress, 10*, 100296. https://doi.org/10.1016/j.stress.2023.100296

Chen, G.-C., Koh, W.-P., Yuan, J.-M., Qin, L.-Q., & van Dam, R. M. (2018). Green leafy and cruciferous vegetable consumption and risk of type 2 diabetes: results from the Singapore Chinese health study and meta-analysis. *British Journal of Nutrition, 119*(9), 1057-1067. https://doi.org/10.1017/s0007114518000119

Connolly, E. L., Sim, M., Travica, N., Marx, W., Beasy, G., Lynch, G. S., Bondonno, C. P., Lewis, J. R., Hodgson, J. M., & Blekkenhorst, L. C. (2021). Glucosinolates from cruciferous vegetables and their potential role in chronic disease: Investigating the preclinical and clinical evidence. *Frontiers in Pharmacology, 12*, 767975. https://doi.org/10.3389/fphar.2021.767975

Cuong, D. M., Ha, T. W., Park, C. H., Kim, N. S., Yeo, H. J., Chun, S. W., Kim, C., & Park, S. U. (2019). Effects of LED lights on expression of genes involved in phenylpropanoid biosynthesis and accumulation of phenylpropanoids in wheat sprout. *Agronomy, 9*(6), 307. https://doi.org/10.3390/agronomy9060307

Demir, K., Sarıkamış, G., & Seyrek, G. C. (2023). Effect of LED lights on the growth, nutritional quality and glucosinolate content of broccoli, cabbage and radish microgreens. *Food Chemistry, 401*, 134088. https://doi.org/10.1016/j.foodchem.2022.134088

Dickinson, A. J., Lehner, K., Mi, J., Jia, K.-P., Mijar, M., Dinneny, J., Al-Babili, S., & Benfey, P. N. (2019). β-Cyclocitral is a conserved root growth regulator. *Proceedings of the National Academy of Sciences of the United States of America, 116*(21), 10563-10567. https://doi.org/10.1073/pnas.1821445116

Eggersdorfer, M., & Wyss, A. (2018). Carotenoids in human nutrition and health. *Archives of Biochemistry and Biophysics, 652*, 18-26. https://doi.org/10.1016/j.abb.2018.06.001

Favela-González, K. M., Hernández-Almanza, A. Y., & De la Fuente-Salcido, N. M. (2020). The value of bioactive compounds of cruciferous vegetables (*Brassica*) as antimicrobials and antioxidants: A review. *Journal of Food Biochemistry, 44*(10), e13414. https://doi.org/10.1111/jfbc.13414

Felemban, A., Braguy, J., Zurbriggen, M. D., & Al-Babili, S. (2019). Apocarotenoids involved in plant development and stress response. *Frontiers in Plant Science, 10*, 1168. https://doi.org/10.3389/fpls.2019.01168

Fiedor, J., & Burda, K. (2014). Potential role of carotenoids as antioxidants in human health and disease. *Nutrients, 6*(2), 466-488. https://doi.org/10.3390/nu6020466

Frede, K., Schreiner, M., Zrenner, R., Graefe, J., & Baldermann, S. (2018). Carotenoid biosynthesis of pak choi (*Brassica rapa* ssp. *chinensis*) sprouts grown under different light-emitting diodes during the diurnal course. *Photochemical and Photobiological Sciences, 17*, 1289-1300. https://doi.org/10.1039/c8pp00136g

Frede, K., Winkelmann, S., Busse, L., & Baldermann, S. (2023). The effect of LED light quality on the carotenoid metabolism and related gene expression in the genus *Brassica*. *BMC Plant Biology, 23*, 328. https://doi.org/10.1186/s12870-023-04326-4

Ghumman, A., Kaur, A., & Singh, N. (2016). Impact of germination on flour, protein and starch characteristics of lentil (*Lens culinari*) and horsegram (*Macrotyloma uniflorum* L.) lines. *LWT - Food Science and Technology, 65*, 137-144. https://doi.org/10.1016/j.lwt.2015.07.075

Giuliano, G. (2017). Provitamin A biofortification of crop plants: a gold rush with many miners. *Current Opinion in Biotechnology, 44*, 169-180. https://doi.org/10.1016/j.copbio.2017.02.001

Hasan, M. M., Bashir, T., Ghosh, R., Lee, S. K., & Bae, H. (2017). An overview of LEDs' effects on the production of bioactive compounds and crop quality. *Molecules, 22*(9), 1420. https://doi.org/10.3390/molecules22091420

Hashimoto, H., Uragami, C., & Cogdell, R. J. (2016). Carotenoids and Photosynthesis. In C. Stange (Eds.), *Carotenoids in Nature* (Vol. 79, pp. 111-139). Cham, Switzerland: Springer International Publishing. https://doi.org/10.1007/978-3-319-39126-7_4

Healthline. (2024). *Raw Sprouts: Benefits and Potential Risks*. Retrieved form https://www.healthline.com

Johkan, M., Shoji, K., Goto, F., Hashida, S., & Yoshihara, T. (2010). Blue Light-emitting diode light irradiation of seedlings improves seedling quality and growth after transplanting in red leaf lettuce. *Hortscience, 45*(2), 1809-1814. https://doi.org/10.21273/HORTSCI.45.12.1809

Kim, Y. J., Kim, Y. B., Li, X., Choi, S. R., Park, S., Park, J. S., Lim, Y. P., & Park, S. U. (2015). Accumulation of phenylpropanoids by white, blue, and red light irradiation and their organ-specific distribution in Chinese cabbage (*Brassica rapa* ssp. *pekinensis*). *Journal of Agricultural and Food Chemistry, 63*(30), 6772-6778. https://doi.org/10.1021/acs.jafc.5b02086

Kochetova, G. V., Avercheva, O. V., Bassarskaya, E. M., Kushunina, M., & Zhigalova, T. V. (2022). Effects of red and blue LED light on the growth and photosynthesis of barley (*Hordeum vulgare* L.) seedlings. *Journal of Plant Growth Regulation, 42*, 1804-1820. https://doi.org/10.1007/s00344-022-10661-x

Kopsell, D. A., & Sams, C. E. (2013). Increases in shoot tissue pigments, glucosinolates, and mineral elements in sprouting broccoli after exposure to short-duration blue light from light emitting diodes. *Journal of the American Society for Horticultural Science, 138*(1), 31-37. https://doi.org/10.21273/JASHS.138.1.31

Kumar, S., Abedin, M. M., Singh, A. K., & Das, S. (2020). Role of Phenolic Compounds in Plant-Defensive Mechanisms. In R. Lone, R. Shuab & A. N. Kamili (Eds.), *Plant Phenolics in Sustainable Agriculture* (Vol. 1, pp. 517-532). Singapore, Springer. https://doi.org/10.1007/978-981-15-4890-1_22

Lännenpää, M. (2014). Heterologous expression of *AtMYB12* in kale (*Brassica oleracea* var. *acephala*) leads to high flavonol accumulation. *Plant Cell Reports, 33*, 1377-1388. https://doi.org/10.1007/s00299-014-1623-6

Lee, M. K., Arasu, M. V., Park, S., Byeon, D. H., Chung, S.-O., Park, S. U., Yong, P., & Sun, J. (2016). LED lights enhance metabolites and antioxidants in Chinese cabbage and Kale. *Brazilian Archives of Biology and Technology, 59*, e16150546. https://doi.org/10.1590/1678-4324-2016150546

Lee, S. Y., Kwon, H., Kim, J. K., Park, C. H., Sathasivam, R., & Park, S. U. (2023). Comparative analysis of glucosinolate and phenolic compounds in green and red Kimchi cabbage (*Brassica rapa* L. ssp. *pekinensis*) hairy roots after exposure to light and dark conditions.

Horticulturae, 9(4), 466. https://doi.org/10.3390/horticulturae9040466

Li, H., Tang, C., Xu, Z., Liu, X., & Han, X. (2012). Effects of different light sources on the growth of non-heading Chinese cabbage (*Brassica campestris* L.). *Journal of Agricultural Science, 4*(4), 262. https://doi.org/10.5539/jas.v4n4p262

Liang, M.-H., Zhu, J., & Jiang, J.-G. (2018). Carotenoids biosynthesis and cleavage related genes from bacteria to plants. *Critical Reviews in Food Science and Nutrition, 58*(14), 2314-2333. https://doi.org/10.1080/10408398.2017.1322552

Life, G. (2024). *Kale production*. Retrieved from https://www.greenlife.co.ke/kale-production

Lin, L.-Z., & Harnly, J. M. (2010). Phenolic component profiles of mustard greens, yu choy, and 15 other brassica vegetables. *Journal of Agricultural and Food Chemistry, 58*(11), 6850-6857. https://doi.org/10.1021/jf1004786

Liu, Z., Shi, J., Wan, J., Pham, Q., Zhang, Z., Sun, J., Yu, L., Luo, Y., Wang, T. T. Y., & Chen, P. (2022). Profiling of polyphenols and glucosinolates in kale and broccoli microgreens grown under chamber and windowsill conditions by ultrahigh-performance liquid chromatography high-resolution mass spectrometry. *ACS Food Science and Technology, 2*(1), 101-113. https://doi.org/10.1021/acsfoodscitech.1c00355

Luang-In, V., Saengha, W., Buranrat, B., Chantiratikul, A., & Ma, N. L. (2020). Cytotoxicity of selenium-enriched Chinese kale (*Brassica oleracea* var. *alboglabra* L.) seedlings against Caco-2, MCF-7 and HepG2 cancer cells. *Pharmacognosy Journal, 12*(4), 674-681. https://doi.org/10.5530/pj.2020.12.99

Manivannan, A., Soundararajan, P., Halimah, N., Ko, C. H., & Jeong, B. R. (2015). Blue LED light enhances growth, phytochemical contents, and antioxidant enzyme activities of *Rehmannia glutinosa* cultured in vitro. *Horticulture, Environment, and Biotechnology, 56*, 105-113. https://doi.org/10.1007/s13580-015-0114-1

Mark, R., Lyu, X., Lee, J. J. L., Parra-Saldívar, R., & Chen, W. N. (2019). Sustainable production of natural phenolics for functional food applications. *Journal of Functional Foods, 57*, 233-254. https://doi.org/10.1016/j.jff.2019.04.008

Ohashi-Kaneko, K., Takase, M., Kon, N., Fujiwara, K., & Kurata, K. (2007). Effect of light quality on growth and vegetable quality in leaf lettuce, spinach and komatsuna. *Environmental Control in Biology, 45*(3), 189-198. https://doi.org/10.2525/ecb.45.189

Olsen, H., Aaby, K., & Borge, G. I. A. (2009). Characterization and quantification of flavonoids and hydroxycinnamic acids in curly kale (*Brassica oleracea* L. Convar. *acephala* Var. *sabellica*) by HPLC-DAD-ESI-MSn. *Journal of Agricultural and Food Chemistry, 57*(7), 2816-2825. https://doi.org/10.1021/jf803693t

Oussaid, S., Chibane, M., Madani, K., Amrouche, T., Achat, S., Dahmoune, F., Houali, K., Rendueles, M., & Diaz, M. (2017). Optimization of the extraction of phenolic compounds from *Scirpus holoschoenus* using a simplex centroid design for antioxidant and antibacterial applications. *LWT – Food Science and Technology, 86*, 635-642. https://doi.org/10.1016/j.lwt.2017.08.064

Panche, A. N., Diwan, A. D., & Chandra, S. (2016). Flavonoids: an overview. *Journal of Nutritional Science, 5*, e47. https://doi.org/10.1017/jns.2016.41

Park, C. H., Kim, N. S., Park, J. S., Lee, S. Y., Lee, J.-W., & Park, S. U. (2019). Effects of light-emitting diodes on the accumulation of glucosinolates and phenolic compounds in sprouting canola (*Brassica napus* L.). *Foods, 8*(2), 76. https://doi.org/10.3390/foods8020076

Park, C. H., Park, Y. E., Yeo, H. J., Kim, J. K., & Park, S. U. (2020a). Effects of light-emitting diodes on the accumulation of phenolic compounds and glucosinolates in *Brassica juncea* sprouts. *Horticulturae, 6*(4), 77. https://doi.org/10.3390/horticulturae6040077

Park, S.-Y., Park, W. T., Park, Y. C., Ju, J. I., Park, S. U., & Kim, J. K. (2012). Metabolomics for the quality assessment of *Lycium chinense* fruits. *Bioscience, Biotechnology, and Biochemistry, 76*(12), 2188-2194. https://doi.org/10.1271/bbb.120453

Park, W. T., Yeo, S. K., Sathasivam, R., Park, J. S., Kim, J. K., & Park, S. U. (2020b). Influence of light-emitting diodes on phenylpropanoid biosynthetic gene expression and phenylpropanoid accumulation in *Agastache rugosa*. *Applied Biological Chemistry, 63*, 25. https://doi.org/10.1186/s13765-020-00510-4

Prieto, M. A., López, C. J., & Simal-Gandara, J. (2019). Glucosinolates: Molecular structure, breakdown, genetic, bioavailability, properties and healthy and adverse effects. *Advances in Food and Nutrition Research, 90*, 305-350. https://doi.org/10.1016/bs.afnr.2019.02.008

Qian, H., Liu, T., Deng, M., Miao, H., Cai, C., Shen, W., & Wang, Q. (2016). Effects of light quality on main health-promoting compounds and antioxidant capacity of Chinese kale sprouts. *Food Chemistry, 196*, 1232-1238. https://doi.org/10.1016/j.foodchem.2015.10.055

Raiola, A., Errico, A., Petruk, G., Monti, D. M., Barone, A., & Rigano, M. M. (2017). Bioactive compounds in Brassicaceae vegetables with a role in the prevention of chronic diseases. *Molecules, 23*(1), 15. https://doi.org/10.3390/molecules23010015

Šamec, D., Urlić, B., & Salopek-Sondi, B. (2019). Kale (*Brassica oleracea* var. *acephala*) as a superfood: Review of the scientific evidence behind the statement. *Critical Reviews in Food Science and Nutrition, 59*(15), 2411-2422. https://doi.org/10.1080/10408398.2018.1454400

Samuolienė, G., Brazaitytė, A., Jankauskienė, J., Viršilė, A., Sirtautas, R., Novičkovas, A., Sakalauskienė, S., Sakalauskaitė, J., & Duchovskis, P. (2013). LED irradiance level affects growth and nutritional quality of Brassica microgreens. *Open Life Sciences*, *8*(12), 1241-1249. https://doi.org/10.2478/s11535-013-0246-1

Sathasivam, R., Park, S. U., Kim, J. K., Park, Y. J., Kim, M. C., Nguyen, B. V., & Lee, S. Y. (2023). Metabolic profiling of primary and secondary metabolites in kohlrabi (*Brassica oleracea* var. *gongylodes*) sprouts exposed to different light-emitting diodes. *Plants, 12*(6), 1296. https://doi.org/10.3390/plants12061296

Sibian, M. S., Saxena, D. C., & Riar, C. S. (2017). Effect of germination on chemical, functional and nutritional characteristics of wheat, brown rice and triticale: a comparative study. *Journal of the Science of Food and Agriculture, 97*(13), 4643-4651. https://doi.org/10.1002/jsfa.8336

Sikora, E., & Bodziarczyk, I. (2013). Influence of diet with kale on lipid peroxides and malondialdehyde levels in blood serum of laboratory rats over intoxication with paraquat. *Acta scientiarum Polonorum Technologia alimentaria, 12*(1), 91-99.

Singh, A. K., Rehal, J., Kaur, A., & Jyot, G. (2015). Enhancement of attributes of cereals by germination and fermentation: a review. *Critical Reviews in Food Science and Nutrition, 55*(11), 1575-1589. https://doi.org/10.1080/10408398.2012.706661

Singh, B., Singh, J. P., Kaur, A., & Singh, N. (2017). Phenolic composition and antioxidant potential of grain legume seeds: A review. *Food Research International, 101*, 1-16. https://doi.org/10.1016/j.foodres.2017.09.026

Song, Y., Qiu, K., Gao, J., & Kuai, B. (2020). Molecular and physiological analyses of the effects of red and blue LED light irradiation on postharvest senescence of pak choi. *Postharvest Biology and Technology, 164*, 111155. https://doi.org/10.1016/j.postharvbio.2020.111155

Sun, T., & Li, L. (2020). Toward the 'golden' era: The status in uncovering the regulatory control of carotenoid accumulation in plants. *Plant Science, 290*, 110331. https://doi.org/10.1016/j.plantsci.2019.110331

Tan, W. K., Goenadie, V., Lee, H. W., Liang, X., Loh, C. S., Ong, C. N., & Tan, H. T. W. (2020). Growth and glucosinolate profiles of a common Asian green leafy vegetable, *Brassica rapa* subsp. *chinensis* var. *parachinensis* (choy sum), under LED lighting. *Scientia Horticulturae, 261*, 108922. https://doi.org/10.1016/j.scienta.2019.108922

Tariq, U., Ali, M., & Abbasi, B. H. (2014). Morphogenic and biochemical variations under different spectral lights in callus cultures of *Artemisia absinthium* L. *Journal of Photochemistry and Photobiology B: Biology, 130*, 264-271. https://doi.org/10.1016/j.jphotobiol.2013.11.026

Thavarajah, D., Thavarajah, P., Abare, A., Basnagala, S., Lacher, C., Smith, P., & Combs, G. F. (2016). Mineral micronutrient and prebiotic carbohydrate profiles of USA-grown kale (Brassica oleracea L. var. acephala). *Journal of Food Composition and Analysis, 52*, 9-15. https://doi.org/10.1016/j.jfca.2016.07.003

Thwe, A. A., Kim, Y. B., Li, X., Seo, J. M., Kim, S.-J., Suzuki, T., Chung, S.-O., & Park, S. U. (2014). Effects of light-emitting diodes on expression of phenylpropanoid biosynthetic genes and accumulation of phenylpropanoids in *Fagopyrum tataricum* sprouts. *Journal of Agricultural and Food Chemistry, 62*(21), 4839-4845. https://doi.org/10.1021/jf501335q

Uarrota, V. G., Stefen, D. L. V., Leolato, L. S., Gindri, D. M., & Nerling, D. (2018). Revisiting carotenoids and their role in plant stress responses: From biosynthesis to plant signaling mechanisms during stress. In D. K. Gupta, J. M. Palma & F. J. Corpas (Eds.), *Antioxidants and Antioxidant Enzymes in Higher Plants* (pp. 207-232). Cham, Switzerland: Springer International Publishing. https://doi.

org/10.1007/978-3-319-75088-0_10

Velmurugan, B. K., Rathinasamy, B., Lohanathan, B. P., Thiyagarajan, V., & Weng, C.-F. (2018). Neuroprotective Role of Phytochemicals. *Molecules, 23*(10), 2485. https://doi.org/10.3390/molecules23102485

Wang, Z., Li, S., Ge, S., & Lin, S. (2020). Review of distribution, extraction methods, and health benefits of bound phenolics in food plants. *Journal of Agricultural and Food Chemistry, 68*(11), 3330-3343. https://doi.org/10.1021/acs.jafc.9b06574

Wani, T. A., Bhat, I. A., Guleria, K., Fayaz, M., Anju, T., Haritha, K., Kumar, A., & Kaloo, Z. A. (2022). Phytochemicals: Diversity, sources and their roles. In M. K. Swamy & A. Kumar (Eds.), *Phytochemical Genomics* (pp. 3-33). Singapore: Springer. https://doi.org/10.1007/978-981-19-5779-6_1

Ware, M. (2020). *What are the health benefits of kale?* Retrieved from https://www.medicalnewstoday.com/articles/270435.php

Yeo, H. J., Park, C. H., Lee, K. B., Kim, J. K., Park, J. S., Lee, J.-W., & Park, S. U. (2018). Metabolic analysis of *Vigna unguiculata* sprouts exposed to different light-emitting diodes. *Natural Product Communications, 13*(10). https://doi.org/10.1177/1934578X1801301029

Zheng, X., Giuliano, G., & Al-Babili, S. (2020). Carotenoid biofortification in crop plants: citius, altius, fortius. *Biochimica et Biophysica Acta (BBA) - Molecular and Cell Biology of Lipids, 1865*(11), 158664. https://doi.org/10.1016/j.bbalip.2020.158664