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Light effects on growth and essential oil quantity and constituents in some Apiaceae plants

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The Apiaceae family known for vegetable crops rich in essential oils, includes numerous genera of high medicinal and economic value. This study investigates the effects of red and far-red light treatments through the dark period (night-break), on the growth characteristics, essential oil quantity and composition, in *Coriandrum sativum* L., *Anethum graveolens* L., and *Petroselinum crispum*. Treatments began 20 days after sowing, with exposure to red or far-red light for 4 h, nightly, from 10 pm to 2 am. Control plants had no treatment. The plants shoots were harvested after 30 days of treatment. The fresh and dry weight, height, petiole length, internode length, leaf number, leaf area, and total chlorophyll of plant samples were measured. Essential oils were evaluated and then analyzed using gas chromatography–mass spectrometry. The results showed that the red and far-red light led to non-significant increase in fresh and dry weight, plant height, petiole length, leaf number, leaf area, essential oil content, and concentration of individual oil components, while the internode length and total chlorophyll showed a significant increase in all treated plants. Therefore, the controlled use of red light and far-red light may be useful for initiating a response in plants, and enhancing their nutritional value.

Key words: Apiaceae, light, night-break, essential oil constituents.

INTRODUCTION

The Apiaceae family contains vegetable crops that are rich in secondary metabolites and essential oils. The family includes numerous genera of high medicinal and economic value (Margaris et al., 1982). The family has a wide global distribution consisting of about 300 genera and 3000 species, mostly of temperate herbs (Hassan and Elhassan, 2017). Dill (*Anethum graveolens* L.) is a member of the Apiaceae family and is an aromatic herb used as a seasoning in different foods such as seafood,

sauces, soups, and salads (Huopalahti and Linko, 1983). Parsley (*Petroselinum crispum* (Mill.) Fuss) and cilantro (*Coriandrum sativum* L.) are two herbs used to enhance the flavor of many cuisines, including in South America, China, India, Mexico, and South East Asia (Wong and Kitts, 2006).

The light spectrum plays an important role in regulating the growth processes, morphology and photosynthesis activities in planta or *in vitro* (Wang et al., 2016). Most

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plant species can modify and develop their anatomical structure, morphology, physiology and biochemical makeup in response to light (Gonçalves et al., 2005). Furthermore, most plant species can develop acclimation systems to cope with different light regimes (Zhang et al., 2003), including adjusting their essential oil content, which could be one of the ways in which plants respond to stress (Mench and Martin, 1991). Increasing oil content in plants can increase their economic value (Hälvä et al., 1992b), consequently, plant survival, growth, and adaptation.

Studies have indicated that exposure to red light (RL) and far-red light (FRL) during the middle of the night (night-break; NB) has effects on multiple morphological and physiological parameters in plants. Vince-Prue (1977) showed that treatment by RL and FRL at NB led to a non-significant increase in stem and internode elongation of *Fuchsia hybrid*. Furthermore, FRL fluorescent and low red to far-red ratio (R:FR ratio) at NB promoted internode elongation in the stems of *Eustoma grandiflorum* (Yamada et al., 2008, 2011), and *Chrysanthemum morifolium* (Liao et al., 2014). NB treatment every 4 h with RL for 8 weeks led to a non-significant increase in plant height and total dry weight in *Solanum lycopersicum* L. (Cao et al., 2016). Chia and Kubota (2010) reported that a low RL:FRL ratio, or FRL at end-of-day, led to a significant increase in stem elongation, with no significant effects on leaf area in tomato plants (*S. lycopersicum*). A low RL/FRL ratio has also been found to increase the growth and internodes elongation in rosemary (*Rosmarinus officinalis* L.) (Mulas et al., 2006). An end-of-day RL and FRL treatment increased internode elongation in dill plants (Hälvä et al., 1992b), and *Populus tremula* × *tremuloides* (Olsen and Junttila, 2002). RL and FRL led to fast growth, elongation of stem, and an increase in the petiole length in silver birch (*Betula pendula* Roth) seedlings (Tegelberg et al., 2004), and increased the internode and petiole length in chrysanthemum (*C. morifolium* Ramat.) (Dierck et al., 2017).

RL, in normal conditions has a greater effect than FRL on plant growth because it is a major energy source for photosynthesis in plants. Under normal conditions, RL enhances shoot and root biomass of *Lactuca sativa* L. (Son and Oh, 2013), promotes shoot elongation in rice (*Oryza sativa* L.) (Chen et al., 2014), and shoot and root length, biomass, and leaf number of artichoke (*Cynara cardunculus*) seedlings (Rabara et al., 2017). RL caused a significant increase in fresh and dry weight, leaf number, petiole length, and leaf area of strawberry *Fragaria* × *ananassa* (cv. Queen Elisa) plants (Norouzi et al., 2017). RL treatment also increased the fresh weight of peppermint (*Mentha piperita* L.) (Heydarzadeh et al., 2014), and stimulated an increase in the weight and height of *Taraxacum officinale* L. (Ryu et al., 2012), and *Rehmannia glutinosa* Gaertn. (Manivannan et al., 2015). Red shade cloth stimulated stem elongation in

Pittosporum variegatum (Oren-Shamir et al., 2001), and increased shoot fresh weight in sweet basil (*Ocimum basilicum* L.), cilantro (*C. sativum*), and parsley (*P. crispum*) plants (Appling, 2012).

In normal conditions FRL led to increased plant height and stem mass in pepper (*Capsicum annuum* L.) (Brown et al., 1995), increased stem elongation in *R. officinalis* (Whitelam and Halliday, 2008), increased stem elongation in chrysanthemums (Rajapakse et al., 1993), and increased the fresh and dry weight, and stem length in baby lettuce (*L. sativa*) (Li and Kubota, 2009; Kubota et al., 2012). FRL was more effective in maintaining growth in *Picea abies* L. compared to RL (Molmann et al., 2006). FRL:RL ratio has effects on plants, where the shoot size and whole biomass ratio increased in Corn (*Zea mays* L.) seedlings that received a high FRL:RL ratios of reflected from near plants or soil surface (Kasperbauer and Karlen, 1994). Low RL:FRL ratio can induce stem and petiole elongation in *Arabidopsis thaliana* (Wang et al., 2015), and increase plant height in *Chenopodium album* L., *Amaranthus retroflexus* L., and *S. lycopersicum* (Ma and Upadhyaya, 2016). Molmann et al. (2006) reported that FRL was more effective at maintaining growth in *P. abies* compared to RL.

Other studies have reported different results on the effects of RL and FRL. For example, Brown et al. (1995) reported that plant biomass and leaf number was reduced in pepper (*C. annuum*) under RL treatment. Liu (2013) showed that leaf area in *Anoectochilus roxburghii* was not different under a 12 h photoperiod with red LEDs. Su et al. (2014) showed that RL inhibited plant height, leaf area, and fresh weight of cucumber seedlings. Holmes and Smith (1975) showed that a high level of FRL reduces leaf area. Hälvä et al. (1992b) reported that petiole length, and leaf area decreased significantly, but that leaf number decreased non-significantly, in dill grown under R and FR lights for 4 h at end-of-day. Mulas and Craker (2005) reported that leaf number reduced in rosemary (*R. officinalis*) under FRL. The treatment of *Ficus benjamina* with FRL led to a negative effect on biomass production (Werbrouck et al., 2012).

In higher plants, chlorophyll is the most important pigment, it is responsible for capturing light for photosynthesis, and converts light energy into the chemical energy needed for the growth and development of the plant. Chlorophyll content is used to assess plant growth and vigor (Ni et al., 2009). Chlorophyll content and composition changed in plants in response to light quality (Manivannan et al., 2015), which may affect the growth of plants in terms of the accumulation of biomass, chlorophyll, and other plant products of economic importance (Ye et al., 2017).

Several reports have declared that RL and FRL have an effect on chlorophyll pigments in plants. RL is essential for stimulating chlorophyll synthesis, but this stimulating effect is cancelled out by subsequent FRL pulses (Lamparter et al., 1997). RL promotes chlorophyll

synthesis in marigold (*Tagetes erecta* L.) and salvia (*Salvia splendens* F.) seedlings (Heo et al., 2002), kale (*Brassica oleracea* L.) (Lefsrud et al., 2008), *Cattleya loddigesii* Lindley (Galdiano et al., 2012), rice (*O. sativa* L.) (Chen et al., 2014), *R. glutinosa*, *Triticum aestivum* L. (Dong et al., 2014; Manivannan et al., 2015), lettuce (*L. sativa* 'Creipa') (Chen et al., 2016) and artichoke *C. cardunculus* seedlings (Rabara et al., 2017). Other studies have shown that chlorophyll content decreases under RL in some plants, for example in three hybrid grapes; *Vitis riparia*, *V. ficifolia* and *V. vinifera* (Hybrid Franc, Ryuukyuganebu and Kadainou R-1) under pure red-light-emitting diodes (Poudel et al., 2007), and (*Cucumis sativus*) plants under RL (Wang et al., 2010). FRL decreased the concentrations of anthocyanin, carotenoids, and chlorophylls compared with white light alone (Li and Kubota, 2009; Brouwer et al., 2014), but Paradiso et al. (2011) showed that FRL could improve plant photosynthesis in rose plants 'Akito' and Lettuce (*L. sativa* 'Green Towers') (Zhen and van Iersel, 2017).

Plant essential oil content and composition is affected by many factors, including environmental conditions (Fernandes et al., 2013; İzgi et al., 2017), light spectrum (Hälvä et al., 1992a; Li and Kubota, 2009), light period (Hälvä et al., 1992a; Malayeri et al., 2010), and light intensity (Hälvä et al., 1992a; Shafiee-Hajiabad et al., 2016). Hälvä et al. (1992b) showed that essential oil content increased and composition changed in dill plants that were treated with 4 h of RL and FRL at end-of-day light. RL and FRL treatments increased the essential oil content of rosemary (*R. officinalis*) (Mulas et al., 2006). Heydarizadeh et al. (2014) showed that RL increased the essential oil content in peppermint (*M. piperita*) fourfold compared to natural light conditions, and increased it in *M. piperita*, *M. spicata*, and *M. longifolia* compared to blue or white light (Sabzalian et al., 2014). Red, blue, and ultraviolet (UV) lights enhanced the concentration of essential oils in various herbs (Dou et al., 2017). Ivanitskikh and Tarakanov (2014) showed that the essential oil content was highest in *O. basilicum* and *Salvia officinalis* grown under white and red and blue LED light, while it was three times lower when under just RL LEDs. The essential oil composition of plants is very sensitive and can be affected and modified under various conditions of light, nutrition, water, and temperature (Fernandes et al., 2013). Shafiee-Hajiabad et al. (2016) reported that light intensity affected the essential oil composition in *Origanum vulgare* L.

Many studies have shown that environmental factors have plants effects on plants and their essential oil content and composition. However, the role of most of these factors, including the effects of light quality on the synthesis of essential oils, is still not clearly understood; especially the factor of light quality during the dark period. Therefore, the objective of this study is to investigate the effects of light (RL and FRL) in a limited period during the dark period on some growth characteristics, and essential oil quantity and composition in parsley, dill, and cilantro.

MATERIALS AND METHODS

Plant material and treatments

Cilantro (*C. sativum*), dill (*A. graveolens* 'Dura Sv') and parsley (*P. crispum*) were used in this study. Seeds were sown in plastic pots (size 1.5 L) containing a commercial potting mixture, pro Mix BX (peat moss 60: vermiculite 20: perlite 20 parts, by volume; N: P₂O₃: K₂O, 5:10:5; pH 6.0). The plants were thinned after cotyledon emergence to 5 seedlings per pot, and were grown in a glasshouse (Botany and Microbiology Department, College of Science, King Saud University, Riyadh, KSA). Average day and night temperatures were 23 and 19°C, respectively. Plant watering included weekly treatment with 0.2% water soluble fertilizer (Peters Professional, N: P₂O₃: K₂O, 24:8:16).

All plants received full daylight during the experimental period, while at night, all plants were covered with black cloth to prevent light from external sources, and concentrate the treatments. Plant treatments were as follows. Red light (RL): 40 W red fluorescent tubes from General Electric Co. (F 40 R) + Red Filter (Roscolux 19) for 4 h at 1.2 mW/m², RL: FRL 2.08; Far-red light (FRL): 75 W incandescent bulbs + Plastic Filter (Roscolux 358) for 4 h at 1.4 mW/m², RL: FRL 0.7; Control: untreated. Each treatment consisted of 18 pots (6 cilantro, 6 dill, and 6 parsley). Light treatments were started 20 days after sowing with 18 pots treated with either RL, or FRL, or control. Additional light exposure was for 4 h nightly, from 10 pm to 2 am. Control plants were not exposed to any treatment during the night. Experimental duration was 50 days: 20 days' pretreatment, and 30 days of treatment. All plants were harvested 30 days after the start of treatment. The natural day length increased during the experiment from 13 h 20 min, to 13 h 35 min. Light levels were measured every 5 days at canopy height by a digital photometer LI 250 a light meter (Li-Cor Biosciences, Lincoln, Nebraska, USA). The RL: FRL ratio was measured with a cosine corrected sensor (SKR 100 660/730 measuring unit, SKR 110 sensor head, Skye Instruments Ltd., Llandrindod, Wells, UK).

Measurements

The plant samples were harvested at a vegetative stage (prior to flower bud formation) by cutting the vegetative parts above ground. Plant fresh weight, height, petiole length, internode length, leaf number, and leaf area were determined by measuring 10 randomly selected plants from each treatment. An LI-3100 meter (Lambda Instruments Corp., Lincoln, Nebraska, USA) was used to measure leaf area. The plant material was dried to a constant weight in an oven at 55°C to determine dry weight.

Chlorophyll analysis

Chlorophyll was extracted using 80% acetone in the dark at 22-25°C. Chlorophyll concentration was calculated as mg g⁻¹ FW according to the equations described by Porra (2002).

Essential oil isolation

Air-dried plant samples (200 g) were placed in a 0.5 L round-bottom distillation flask and 300 ml of distilled water was added. The essential oils were obtained by steam distillation for approximately 3 h with Clevenger's apparatus, according to the European Pharmacopoeia method (Commission, 2010). The oils were separated, dried over anhydrous sodium sulphate, filtered, and stored in a closed bottle at 4°C until used. The essential oil yield for each treatment was calculated as the ratio of oil to dry vegetative biomass (oil µg/g DW).

GC-MS analysis of essential oil

The essential oils were analyzed by gas chromatography coupled with mass spectrometry (GC-MS) (QP2010 Ultra, Shimadzu, Kyoto, Japan). The sample was dissolved in dichloromethane (1%) and injected at 250°C (injector temperature) into a capillary column type HP-1 (30 m, 0.25 mm i.d, 0.25 µm film thickness, stationary phase (95% diethyl-5% diphenyl poly siloxane)), using helium as a carrier gas at a flow rate of 1.2 ml/min. The injected volume was 1 µl and the injection mode used was split (split ratio 300), the injection temperature was 250°C. The oven temperature was raised from 35°C (hold for 3 min) to 240°C at the rate of 5°C/min, then at the rate of 3°C/min, raised to 280°C, hold for 3 min. Interface temperature was 250°C; the ion source temperature was 200°C. The MS system was operated in electron ionization mode at 70 eV. The mass and scan range was set at m/z 35-800. Identification of the essential oil compounds was based on the comparison of their spectral fragmentation with data reported in NIST 14 (National Institute of Standards and Technologies, Mass Spectra Libraries) (Adams, 2007; NIST, 2017).

Statistical analysis

Each pot was treated as one replicate and all the treatments had 6 replicates. The data were analyzed statistically with SPSS-17 statistical software (SPSS Inc., Chicago, Illinois, USA). Means were statistically compared with Duncan's Multiple Range Test at $p < 0.05$.

RESULTS AND DISCUSSION

Effects of RL and FRL on vegetative traits

The growth and development of cilantro, dill, and parsley plants in response to RL and FRL treatments (Table 1) was similar to that reported for other plants. RL and FRL showed effects on the morphological and physiological parameters under study in the experimental period. The effects of RL and FRL treatments appeared in all species under study, some significant variations were observed in treated plants. Plant species differed in their responses to light quality, the variation in effects was low between RL and FRL. The effect of RL was slightly greater than FRL in some traits. Fresh and dry weight increased non-significantly, compared to the control plants in all species under RL and FRL treatment, and FRL treatment decreased them non-significantly compared with RL plants.

Our results in Table 1A, B, and C show that fresh and dry weight in all plants treated with RL and FRL showed no significant changes, but generally, the traits tended to increase in the RL and FRL treatments compared to control plants. RL showed greater effects compared to FRL. The slightly increased biomass in study plants can be attributed to the short exposure to RL and FRL. Our results are generally in line with previous studies which indicate that treating plants with RL, or RL and FRL, at midnight (Cao et al., 2016), or under normal conditions (Norouzi et al., 2017), leads to an increase in fresh and dry weight. However, the results are contrary to Su et al.

(2014) and Werbrouck et al. (2012) who reported that RL and FRL have negative effects on biomass. The increase in biomass in our study can be attributed to increased carbohydrate content and starch accumulation, due to the increased amount of chlorophyll, thus increasing the frequency of photosynthesis. Photosynthesis is responsible for the accumulation of most, or all, dry matter in plants (Kang and van Iersel, 2004). This explanation is consistent with previous studies, which reported that the concentration of starch increased in seedlings grown under RL (Li et al., 2012).

In all plants treated with RL or FRL, internode length increased significantly, while plant height and petiole length increased non-significantly. The response of plants to the effects of RL and FRL varied depending on the species. In general, plants tended to increase in height compared to control plants (Table 1A, B, and C).

In the present study, the elongation of stems, height of plants and petiole length in plants treated with RL and FRL may be due to changes in indole-3-acetic acid (IAA) and gibberellic acid (GA3) levels. IAA and GA3 may alter plant tissues and cells through conversion of phytochromes (phys) from Pr form to Pfr form, or vice versa. Pr is the biologically inactive form and absorbs RL, whereas the Pfr form is biologically active and absorbs FRL (Smith, 2000). Conversion between the Pr and Pfr forms may be occurring, and therefore leading to plant growth and adaptation to the light environment. In daylight, phys exists mainly in the Pfr form, which may cause inhibition of genes involved in growth and elongation. During the night period, Pfr slowly converts into the inactive Pr form, which may lead to the stimulation of genes involved in growth and elongation (Soy et al., 2012). Phys has a variety of photomorphogenic effects in plants including effect on leaf and stem traits (Nobel, 2009). This explanation is supported by several of reports, which indicate that IAA and GA levels in plants are related to the state of Pr, Pfr and the conversion between them. This may be due to exposure of the plant to RL or FRL, and therefore lead to effects on the growth and development of the plant (Hisamatsu, 2005; Kurepin et al., 2010; Liao et al., 2014).

Generally, our results are consistent with several results of previous studies on plants treated with RL, or FRL, or both. For instance, RL and FRL at NB lead to non-significantly increased stem and internode elongation of *Fuchsia hybrida* (Vince-Prue, 1977), treatment by a low RL:FRL ratio or end-of-day FRL led to a significant increase in stem elongation in tomato (*S. lycopersicum*) (Chia and Kubota, 2010), also, in tomato (*S. lycopersicum*) NB treatment with RL led to a non-significant increase in plant height and total dry weight (Cao et al., 2016), RL led to stimulated an increase in the height of *T. officinale* (Ryu et al., 2012), and *R. glutinosa* (Manivannan et al., 2015). The red shade cloth stimulated stem elongation in *P. variegatum* (Oren-Shamir et al., 2001), sweet basil (*O. basilicum*),

Table 1. Effects of red light (RL) and far-red light (FRL) for a limited time (10 pm - 2 am) during the dark period on the growth and development of cilantro Ci (*C. sativum*), dill Di (*A. graveolens*), and parsley Pa (*P. crispum*).

| Plant | Treat | Weight | | Height (cm) | Length | | Leaf | | Total Chlo (mg g ⁻¹ FW) |
|----------|-------|-------------------|-------------------|--------------------|-------------------|--------------------|--------------------|-------------------------|------------------------------------|
| | | Fresh (g) | Dry (g) | | Internode (mm) | Petiole (cm) | Number per plant | Area (mm ²) | |
| A | | | | | | | | | |
| Ci | Con. | 7.31 ^a | 0.63 ^a | 23.87 ^a | 1.57 ^c | 8.55 ^a | 11.75 ^a | 133.60 ^a | 2.68 ^b |
| | RL | 7.55 ^a | 0.76 ^a | 25.45 ^a | 2.55 ^b | 8.57 ^a | 11.48 ^a | 132.07 ^a | 2.73 ^a |
| | FRL | 7.47 ^a | 0.74 ^a | 25.63 ^a | 3.60 ^a | 8.58 ^a | 11.25 ^a | 131.86 ^a | 2.73 ^a |
| B | | | | | | | | | |
| Di | Con. | 3.98 ^a | 0.49 ^a | 25.67 ^a | 1.23 ^b | 13.93 ^a | 9.53 ^a | 22.29 ^a | 2.44 ^b |
| | RL | 4.30 ^a | 0.57 ^a | 28.42 ^a | 3.33 ^a | 13.95 ^a | 9.42 ^a | 21.22 ^a | 2.48 ^a |
| | FRL | 4.20 ^a | 0.54 ^a | 29.50 ^a | 4.67 ^a | 13.97 ^a | 9.40 ^a | 21.20 ^a | 2.47 ^a |
| C | | | | | | | | | |
| Pa | Con. | 3.22 ^a | 0.33 ^a | 18.60 ^a | 0.95 ^b | 8.88 ^a | 8.72 ^a | 42.08 ^a | 2.72 ^b |
| | RL | 3.48 ^a | 0.44 ^a | 19.92 ^a | 2.00 ^a | 8.90 ^a | 8.47 ^a | 41.43 ^a | 2.77 ^a |
| | FRL | 3.45 ^a | 0.43 ^a | 20.20 ^a | 2.35 ^a | 8.93 ^a | 8.42 ^a | 40.67 ^a | 2.76 ^a |

Different letters in a column represent significance at 0.05 level. Control (Con.) and (Chlo) chlorophylls.

cilantro, and parsley (*P. crispum*) (Appling, 2012).

The results also concur with results of previous studies about effects of the FRL on plant growth, where it has been suggested that FRL increased plant height and stem mass in pepper (*C. annuum*) (Brown et al., 1995), caused increased stem elongation in *R. officinalis* L. (Whitelam and Halliday, 2008), and increased the stem length, in baby lettuce (*L. sativa*) (Li and Kubota, 2009), and FRL was more effective than RL at maintaining growth in *P. abies* (Molmann et al., 2006). Leaf number and leaf area decreased non-significantly in plants treated with RL and FRL, compared to the control (Table 1A, B and C). This may be because the period of exposure to RL or FRL was not enough to cause significant effects. Norouzi et al. (2017) reported that 8 h of RL led to an increase in the number of leaves and leaf area of strawberry plants. Some previous studies reported similar results to the current study. Hälvä et al. (1992b) reported that leaf number and leaf area decreased non-significantly in dill plants that grew under RL or FRL for 4 h at end-of-day. Mulas et al. (2006) reported that leaf number reduced in rosemary (*R. officinalis*) under FRL. Holmes and Smith (1975) showed that a high level of FRL reduced leaf area. Chia and Kubota (2010) and Kurepin et al. (2010) reported that the tomato plants treated with a low RL:FRL ratio, or were treated with end-of-day FRL showed no differences in leaf area. Liu (2013) reported that the leaf area in *A. roxburghii* was not different under a 12 h photoperiod with red LEDs. Su et al. (2014) showed that RL inhibited the expansion of leaf area of cucumber seedlings.

Chlorophyll pigments in plants are important for

capturing light energy and converting it into chemical energy needed for the growth and development of plants. Chlorophyll content is used as an indicator to assess the growth and vigor in plants (Ni et al., 2009). Plants change their chlorophyll content and composition in response to light quality (Manivannan et al., 2015), which may affect the growth of the plant in terms of accumulation of biomass, chlorophyll, and products of economic importance (Ye et al., 2017).

In the current study, light quality had a positive effect on the chlorophyll content in the leaves of all treated plants (Table 1A, B and C). Total chlorophyll content increased significantly in plants treated with RL and FRL. This increase is likely to be because wavelengths of RL are fully proportional to the peak absorption of chlorophyll and phytochromes. In our study, the increase in chlorophyll content was in line with the other trait results, such as increases in biomass, and petiole and internode length. The results of the current study are consistent with previous reports, which declared that RL and FRL have an effect on the chlorophyll pigments in plants. RL is essential for chlorophyll synthesis (Lamparter et al., 1997), and promotes chlorophyll synthesis and its content in plants, such as in marigold and salvia seedlings (Heo et al., 2002), kale (*B. oleracea* L.) (Lefsrud et al., 2008), and *C. loddigesii* (Galdiano et al., 2012). Similar results have also been reported for *R. glutinosa* and *T. aestivum* L. (Manivannan et al., 2015), lettuce (*L. sativa* 'Creipa') (Chen et al., 2016) and artichoke (*C. cardunculus*) (*Rabara et al.*, 2017). FRL can lead to an increase in photosynthetic efficiency through increases in photochemical and photosynthetic efficiency of light

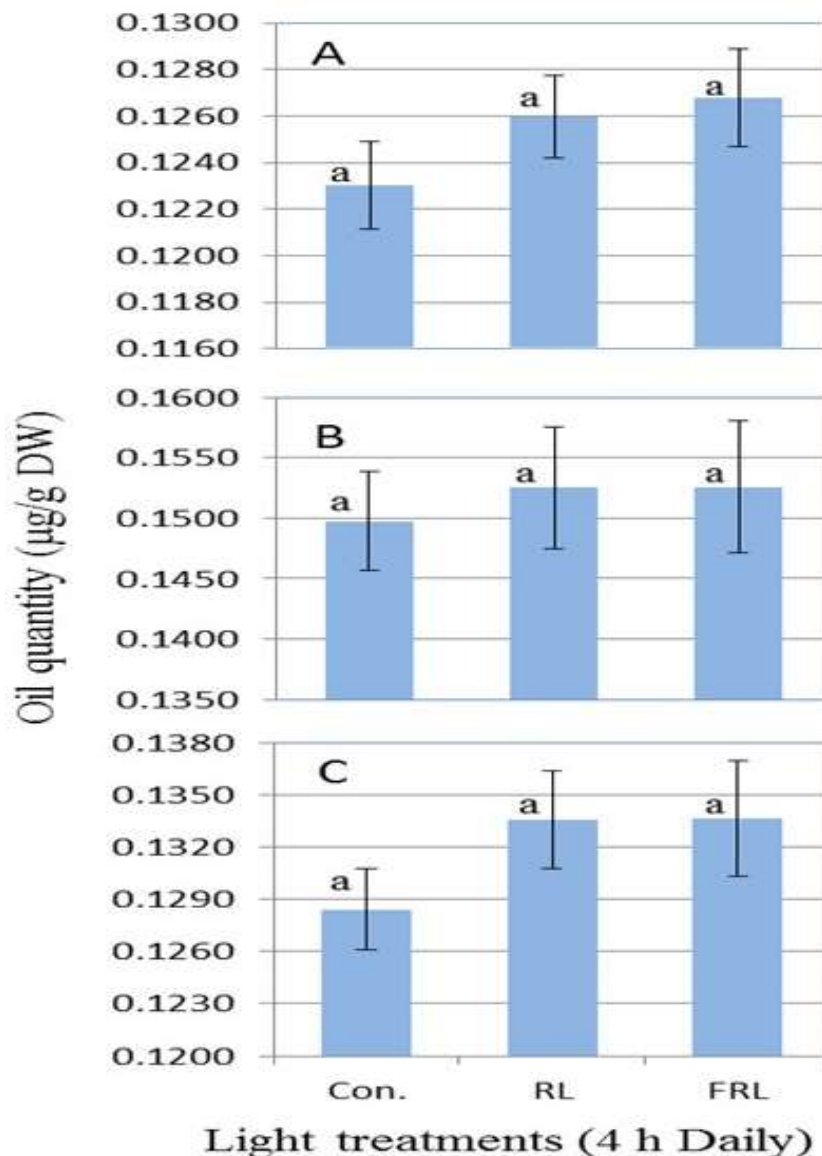


Figure 1. The effects of red light (RL) and far-red light (FRL) for a limited time (10pm-2am) during the dark period on essential oil quality in cilantro (A), dill (B), and parsley (C), control (control).

(Zhen and van Iersel, 2017). However, some studies have indicated contrary results. RL and FRL may decrease the chlorophyll content in some plants, for instance, chlorophyll content decreased in three grape hybrids (Hybrid Franc, Ryuukyuganebu and Kadainou R-1) under pure red-light-emitting diodes (Poudel et al., 2007), and cucumber plants under RL (Wang et al., 2010). FRL decreased the concentrations of anthocyanin, carotenoids, and chlorophylls compared with white light alone (Brouwer et al., 2014), but Paradiso et al. (2011) showed that FRL could improve plant photosynthesis in rose and lettuce (*L. sativa* 'Green Towers') (Zhen and van Iersel, 2017).

Essential oil quantity

The results (Figure 1) show that all species treated with RL and FRL had higher percentages of essential oil content in the dry sample than in control plants. The percentage and difference between light treatments effects, was non-significant statistically, compared to the control plants; this may be due to insufficient exposure to the light treatments. In general, the results tend to indicate that the light spectra used in our study have a positive effect on the essential oil content in the plants under study. The results of the study are in line with the results of a number of previous studies which indicate

Table 2. The effects of red light (RL) and far-red light (FRL) for a limited time (10 pm to 2 am) during the dark period on the composition of essential oil in cilantro Ci (*C. sativum*), dill Di (*A. graveolens*), and parsley Pa (*P. crispum*), and Control (Con.).

| Plant | Light treatment | Name of chemical compounds | | | | | | | |
|-----------|-----------------|----------------------------|--------|----------|----------|------------|---------|------------------|-----------------|
| | | α -Phellandrene | Cymene | Limonene | Linalool | Myristicin | Myrcene | α -Pinene | β -Pinene |
| (µg/g) | | | | | | | | | |
| 2A | | | | | | | | | |
| Ci | Con | 4.4 | 0.26 | 0.31 | 13.97 | - | - | 2.1 | - |
| | RL | 4.77 | 0.28 | 0.32 | 15.3 | - | - | 2.2 | - |
| | FRL | 4.8 | 0.28 | 0.33 | 15.36 | - | - | 2.3 | - |
| 2B | | | | | | | | | |
| Di | Con | 10.58 | 1.5 | 0.64 | 9.8 | 0.37 | 3.71 | 4.24 | 2.62 |
| | RL | 11.63 | 1.59 | 0.67 | 10.2 | 0.38 | 3.88 | 4.39 | 2.8 |
| | FRL | 11.67 | 1.63 | 0.69 | 10.4 | 0.39 | 3.95 | 4.47 | 2.85 |
| 2C | | | | | | | | | |
| Pa | Con | - | 1.63 | 4.85 | 0.46 | 41.4 | 4.36 | 6.26 | 2.44 |
| | RL | - | 1.77 | 5.2 | 0.47 | 44.3 | 4.77 | 6.81 | 2.64 |
| | FRL | - | 1.79 | 5.26 | 0.48 | 44.8 | 4.83 | 6.83 | 2.67 |

that the RL and FRL treatment have effects on the content of essential oil in some plants, where Hålvä et al. (1992b) indicated that the oil content increased in dill (*A. graveolens*) that was treated for 4 h with RL and FRL at end-of-day. Mulas et al. (2006) indicated that RL and FRL treatment led to a significant increase of essential oil in rosemary (*R. officinalis*). RL and other light wavelengths also have an effect on essential oil content in plants. Heydarizadeh et al. (2014) showed that RL increased the content of essential oil fourfold in peppermint (*M. piperita*), compared to that in the field. RL increased essential oil content in *M. piperita*, *M. spicata*, and *M. longifolia* compared to blue or white light (Sabzalian et al., 2014). Red, blue, and UV light enhanced the concentration of essential oils in various herbs (Dou et al., 2017).

In our study, the increase in essential oil contents was consistent with other vegetative characteristics, and the correlation with biomass seems clear. Our results concur with previous studies which indicate that essential oil synthesis and its increased production is associated with the traits of growth, function, and biomass in plants, and influenced by several factors (El-Zaedi et al., 2016), including environmental conditions (İzgi et al., 2017). Essential oils are one of the most important compounds in plants. Researchers have reported that light can have a direct or indirect effect on the production and accumulation of essential oils through the increase of plant biomass; for example, in chamomile (*Matricaria recutita* L.) Verzar-Petri et al. (1978), sage (*S. officinalis*), thyme (*Thymus vulgaris*) (Li et al., 1996), *M. piperita* (Pegoraro et al., 2010), *Ocimum gratissimum* L.

(Fernandes et al., 2013), and cell cultures of *Melastoma malabathricum* (Chan et al., 2010).

Essential oil constituents

After essential oil isolation from cilantro, dill, and parsley shoots, eight compounds were identified to investigate the essential oil components using GC-MS (Table 2). All eight compounds were observed in the essential oils of the plants under study, except for α -phellandrene in parsley, and Myrcene, Myristicin and β -Pinene in cilantro. The eight compounds were found in different amounts in the three species, this may be due to the differences in plant species. Table 2 shows slight differences in the quantities of essential oils in the study species.

In cilantro (Table 2), the essential oil constituents included α -phellandrene, cymene, limonene, linalool, and α -pinene. Our results revealed there to be various effects on the essential oil components in plants under RL and FRL treatments compared to control plants. With the exception of linalool, the light treatments had little effect on other essential oil components, including α -phellandrene, cymene, limonene, and α -pinene. The highest concentration of linalool was observed in plant tissue that was treated with RL and FRL, while the lowest concentration was cymene. The highest essential oil percentage increase was observed in linalool, whereas the lowest was observed in limonene.

The essential oil components of dill included α -phellandrene, cymene, limonene, linalool, myristicin, myrcene, α -pinene, β -pinene (Table 2). The four major

components were α -phellandrene, linalool, myrcene, and α -pinene. The effects of the treatments on the concentrations of essential oil constituents was to increase them slightly but non-significantly.

Finally, the essential oil components of parsley were cymene, limonene, linalool, myristicin, myrcene, α -pinene, and β -pinene (Table 2). The three major components were myristicin, limonene, and myrcene. Our results showed no differences in the proportions of essential oils, but quantities tended to increase.

In general, the effects of RL and FRL treatments on concentrations of essential oil constituents increased, but not significantly. This may be because the period of plant exposure to the treatments was insufficient to cause a significant increase. The eight compounds tended to be in higher concentrations in plants treated with FRL, then RL, then control. The increase in the total oil content in plant tissues and the effect on its components may be due to the effects of RL and FRL on the pathways of building these components. The RL and FRL may also have an effect on the enzymes induced to build the compounds. The biosynthesis of aromatic compounds occurs through two complex chemical pathways, involving different enzymatic reactions which depend on a large group of enzymes known as terpene synthases (Rehman et al., 2015). Ivanitskikh and Tarakanov (2014) reported that light spectrum variations can be used for the biosynthesis of substances in plants including essential oils. Light intensity can also affect essential oil production through the stimulation of photosensitive enzymes involved in the mevalonic acid pathway (Gobbo-Neto and Lopes, 2007). Thus, irradiance can directly influence the production of essential oils, or indirectly, through the increase of plant biomass (Pegoraro et al., 2010). Plant essential oil composition is very sensitive and can be affected and modified under various conditions of light, nutrition, water, and temperature (Simões and Spitzer, 2000; Lima et al., 2003; Fernandes et al., 2013). Shafiee-Hajiabad et al. (2016) reported that light intensity affected the essential oil composition in *O. vulgare*. Based on our study, there seems to be consistency between our results and the results of previous studies on essential oil components.

Conclusion

The present study shows the effect of RL was slightly greater than FRL in traits, fresh and dry weight that increased non-significantly, compared to the control plants in all species under RL and FRL treatment; and they increased the essential oil content and dry matter of all three species. In our study, the increase in chlorophyll content was in line with the other trait results, such as increases in biomass, and petiole and internode length. The concentrations of individually volatile compounds in cilantro, dill, and parsley essential oils were slightly affected by the different light spectra. Light spectrum that

used in present study increased the essential oils content may be due to the effects of RL and FRL on the pathways of building these components. The RL and FRL may also have an effect on the enzymes induced to build the compounds. In general, most of studied traits in the study species subjected to RL and FRL tended to increase slightly. Therefore, the use of light spectra may be useful for inducing plant responses, and for enhancing the nutritional value of plants.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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