

# IMPROVING CAROTENOID PHYTOCHEMICAL CONCENTRATIONS IN VEGETABLE CROPS

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Phytochemicals are broadly defined as food components that elicit profound effects on health maintenance and disease prevention. In the human body, oxidants produced during normal metabolism and immune defense against infectious and chemical agents are responsible for damage to DNA, proteins, and cellular tissues. This harmful oxidative damage is considered the major cause of aging and degenerative diseases such as cancer, cardiovascular disease, immune-system decline, and cataract (Kopsell and Kopsell, 2009). Compounds such as ascorbate,  $\alpha$ -tocopherol, and carotenoids are examples of antioxidants that have the ability to quench reactive oxygen species. In fact, carotenoids are some of the most potent biological quenchers of reactive oxygen species.

Changing environmental factors can impose stress on plants (Kopsell et al., 2009). Organic phytochemicals are assumed to be utilized by plants to combat stress conditions. The topics discussed in this manuscript were designed to measure the influence of several environmental growing conditions on the production of carotenoid phytochemicals in leafy and other vegetable crops. Our overall goal was to investigate the potential of manipulating environmental growing conditions to increase the availability of functional components that may provide long-term health consequences.

## ***Carotenoids in Plant Metabolism***

Carotenoids are lipid soluble yellow, orange, and red pigments that are uniquely synthesized in plants, algae, fungi, and bacteria. In photosynthesis, carotenoids function to help harvest light and dissipate excess energy before damage occurs. In their main role, carotenoid pigments protect photosynthetic structures by quenching reactive oxygen species (ROS) to inhibit oxidative damage.

## ***Carotenoids and Human Health***

Carotenoids are lipid soluble which possess reported health benefits of reducing cancers (lycopene), cardiovascular (lycopene), and aging eye diseases [lutein (L) and zeaxanthin(Zea)] when regularly consumed in the diet. One of the most important physiological functions of carotenoids in human nutrition is as vitamin A precursors [ $\beta$ -carotene (BC)]. Humans cannot synthesize carotenoids; therefore, fruits and vegetables are primary sources of carotenoids in human diets world-wide.

## **Growing Air Temperature can Influence Carotenoid Accumulation**

Environmental factors such as light, water and growing air temperatures can have significant influences on plant growth and development. Rapid fluctuations in growing air temperature can limit plant growth at both low and high temperature extremes. Plants can adapt to air temperature changes in the growing environment and usually easily adjust to conditions slightly above and below optimum air temperature ranges. Our goal was to investigate the influences of different air temperatures on the accumulation of carotenoid pigments in kale and spinach. ‘Winterbor’ kale and ‘Melody’ spinach were grown in environmental chambers that provided plants with set point air temperature treatments of 15, 20, 25, or 30 °C for the kale, and 10, 15, 20, or 25 °C for the spinach (Lefsrud et al., 2005). Carotenoid concentrations in the leaves of kale increased as the air temperatures increased from 15 to 30 °C, while the carotenoid concentrations decreased in spinach as the air temperature increased from 10 to 25 °C. Results from our study demonstrated that changes in growing air temperatures can influence the production of carotenoid pigments in the leaves of kale and spinach. Air temperatures in field conditions can be modified by growing kale and spinach at different times of the year.

### **Light Intensity can Influence Carotenoid Accumulation**

As light strikes the surface of plant leaves, photons are absorbed by antenna pigments which funnel this energy to the photosynthetic reaction center. Carotenoids are bound to pigment-protein complexes within the thylakoid membranes and are utilized as antenna pigments. At high light levels, excess energy must be removed from the photosynthetic system to prevent damage. Our goal was to investigate the effects of different irradiance levels on plant biomass and accumulation of carotenoid pigments in kale and spinach. ‘Winterbor’ kale and ‘Melody’ spinach were grown in environmental chambers that provided plants with average irradiance treatment levels of photosynthetically active radiation (PAR) of 125, 200, 335, 460, and 620  $\mu\text{mol m}^{-2} \text{sec}^{-1}$ . The daily photoperiod was 16 h, with irradiance treatment daily integrals of 7.2, 11.5, 19.3, 26.5, and 35.7  $\text{mol m}^{-2}$ , for the increasing PAR treatments (Lefsrud et al., 2006a). Kale leaf tissue L accumulation ranged from 9.1  $\text{mg } 100 \text{ g}^{-1}$  at 125  $\mu\text{mol m}^{-2} \text{sec}^{-1}$ , to as high as 15.1  $\text{mg } 100 \text{ g}^{-1}$  at 335  $\mu\text{mol m}^{-2} \text{sec}^{-1}$ . Similarly, BC accumulation in the kale leaf tissues responded significantly to irradiance treatments and ranged from 5.7  $\text{mg } 100 \text{ g}^{-1}$  at 125  $\mu\text{mol m}^{-2} \text{sec}^{-1}$ , to as high as 11.1  $\text{mg } 100 \text{ g}^{-1}$  at 335  $\mu\text{mol m}^{-2} \text{sec}^{-1}$ . The largest accumulation of carotenoid pigments in spinach leaf tissues occurred at the irradiance level of 200  $\mu\text{mol m}^{-2} \text{sec}^{-1}$ , with L levels at 11.1  $\text{mg } 100 \text{ g}^{-1}$ , BC levels at 9.2  $\text{mg } 100 \text{ g}^{-1}$ . However, spinach leaf tissue carotenoid concentrations were not affected by irradiance treatments. Average field irradiance levels can vary dependent on location, time of year, shading, and atmospheric conditions.

### **Light Photoperiod can Influence Carotenoid Accumulation**

The length of the photoperiod will influence a number of plant physiological factors including biomass production, bud formation, flowering, germination, leaf elongation, leaf emergence, and changes in secondary compounds. Proper photoperiod is critical for plant growth and development, and the length of the photoperiod can easily be controlled by growers using artificial growing environments or shading/lighting techniques. Our goal was to determine the influences of four different irradiance photoperiods on plant biomass and accumulation patterns of carotenoid pigments in the leaf tissues of kale. ‘Winterbor’ kale was grown in environmental chambers under irradiance photoperiods of 6, 12, 16, or 24 h. The plants were grown for 3 weeks under the photoperiod treatments (Lefsrud et al., 2006b). Maximum L accumulation (13.5  $\text{mg } 100 \text{ g}^{-1}$ ) occurred under the 24-h photoperiod treatment, whereas the

lowest L concentrations ( $8.8 \text{ mg } 100 \text{ g}^{-1}$ ) occurred at the 6-h photoperiod. Maximum BC accumulation was  $10.4 \text{ mg } 100 \text{ g}^{-1}$  for the 24-h photoperiod treatment, whereas the lowest BC accumulation ( $6.3 \text{ mg } 100 \text{ g}^{-1}$ ) occurred during the 6-h photoperiod treatment. Both L and BC concentrations significantly increased in response to increasing photoperiods. Photoperiod conditions can be easily manipulated in plant production systems to maximize plant biomass production and concentrations of plant secondary compounds, such as carotenoids.

## Conclusions

Changing environmental growing conditions will impose stress on crop plants. Research conducted by our group demonstrates the influence of environmental growing conditions such as air temperature, light intensity, photoperiod, and other directed stress factors on plant biomass and the production of carotenoid phytochemicals in leafy vegetable crops. In many parts of the U.S., cool-season crops, such as kale and spinach, can be planted in both the spring and fall, two seasons having very different environmental conditions. Therefore, producers must recognize that, even though overall crop yield may differ little when crops are produced in different seasons of the year, there may be considerable variation in crop phytochemical concentrations among different seasonal production schemes.

## Literature Cited in Text

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