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Light modulation of volatile organic compounds from petunia flowers and select fruits

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ABSTRACT

Light intensity, duration, direction, and wavelength are informative to plants. The biochemical circuits that connect specific light wavelengths to expression of specific genes and the metabolic networks they govern have been well defined. However, little emphasis has been placed on how discrete wavelengths of light, alone or in combination, may be applied to manipulate postharvest qualities of high-value horticultural crops. Using narrow-bandwidth LED light we test the hypothesis that discrete light wavelengths can affect the accumulation of volatile compounds known to affect aroma or taste in select flower and fruit products. Volatile benzenoid/phenylpropanoid emission from petunia flowers could be altered with light application. Levels of a key floral volatile, 2-phenylethanol, increased with a red and far-red light treatment. Similar experiments demonstrated that fruit volatile profiles of tomato, strawberry, and blueberry can be manipulated with specific light treatments. These results suggest that compounds affecting sensory qualities of flowers and fruits can be modified by adjustment of ambient light conditions. These findings open new areas of inquiry about how the fragrance and flavor of flowers and fruits may be improved with simple changes in postharvest light conditions.

1. Introduction

Plant growth and development is a product of the genetic potential of the plant and how it responds to stimuli from the ambient environment. An element of this interaction is facilitated by a suite of plant photosensory receptor proteins, each adapted to sense and relay information about the incident light spectrum. In the case of horticultural crops, light quantity, quality, and duration inform the plant of current conditions that ultimately contribute to plant productivity and product quality.

Light signaling pathways are well understood in the model system *Arabidopsis thaliana*. Light signals are transduced through well-described pathways that influence many aspects of plant growth and development (Chen et al., 2004b). These pathways have been translated to a large number of crop species, where genetic and photophysiological analyses demonstrate the effects of various wavelengths of light on plant productivity (Barrero et al., 2012; Frantz et al., 2004; Li and Ma, 2012; Preuss et al., 2012; Reynolds et al., 2012; Singh et al., 2011). Although yield is often affected, qualities such as ripening, color and nutraceutical content are also affected by the light environment. In practice, light is a passive entity, driving plant processes based on light quantity and quality from a natural or artificial environment. However, light may also be used to control growth and development by manipulating the light spectrum itself. A change in the ambient spectrum can alter plant behavior or potentially affect quality of plant products (Folta and Childers, 2008).

There is great interest in understanding plant–human interaction with regard to plant produced volatile organic compounds (Du et al., 2011; Dudareva and Pichersky, 2008; Miyazaki et al., 2012; Tieman et al., 2012). Specific combinations and concentrations of volatile organic compounds can impart distinct fragrances and flavors to flowers and fruits (Klee, 2010; Tieman et al., 2012; Underwood et al., 2005; Vogel et al., 2010) during gustation (retronasal), and fragrance during inhalation (ortho-nasal), adding value for product quality and ultimately a consumer's sensory experience (Goff and Klee, 2006; Small et al., 2004).

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The literature shows evidence of environmental factors influencing the production of these volatile molecules *in planta* (Oyama-Okubo et al., 2005; Watson et al., 2002). Numerous aspects of plant organic compound metabolism are influenced by light conditions, e.g. the cellular redox state, cyclic nucleotide metabolism in bean, phenylpropanoid production in *Arabidopsis* (Brown et al., 1989; Dietz and Pfannschmidt, 2011; Jin et al., 2000). Additionally, plant volatile production can be influenced by light quantity over the course of fruit development in strawberry (Watson et al., 2002). Terpenoids have been shown to be modulated by the phytochrome photosensors (Peer and Langenheim, 1998; Tanaka et al., 1998). It was demonstrated that when sweet basil plants were grown on colored mulches, the volatile compounds emitted from fresh leaves varied with the color of mulch used (Loughrin and Kasperbauer, 2003).

The central hypothesis of this work is that plant volatile emission could be reproducibly manipulated by variation in light quality. To directly test this hypothesis, we exploited the capacity to control discrete spectral quality using a narrow-bandwidth LED based light platform (Zhang et al., 2011) to expose flowers and fruits to specific wavelengths of light. Five lighting conditions were employed: white, blue, red, far-red, and dark (Fig. 1).

Harvested petunia flowers, tomato, strawberry, and blueberry fruits were analyzed for the emission of key volatile compounds subsequent to treatments with different wavelengths of light. Results show that the emissions of discrete volatiles important to plant product quality are influenced by light quality. These results have created a foundation for future identification of light regimes that may alter plant product post-harvest quality for consumers.

2. Materials and methods

2.1. Narrow-bandwidth LED light platform

The light treatments were generated using a light emitting diode (LED) platform (Zhang et al., 2011). A dark treatment and four light treatments were tested: white, blue, red, and far-red (Fig. 1). In all cases, light treatments were 50 μmol m^{-2} s^{-1} in separate illumination chambers within an environmentally controlled and actively ventilated area (22 ± 1.5 °C). The control treatment (white light) was generated by cool white fluorescent bulbs, while the dark treatments were performed in an identical light-tight enclosure under the same ambient conditions. The light treatments were generated using the Flora Lamp LED arrays (Light Emitting Computers, Victoria, BC). The spectra used in these experiments are shown in Fig. 1. Fruits and flowers were treated without photoperiod. Spectroradiometer readings were obtained with a StellarNet device and visualized on SpectraWiz software (Stellar Net, Tampa, FL).

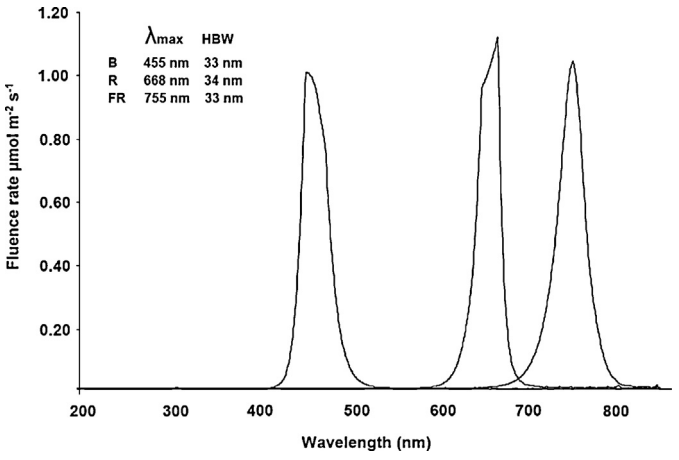

Fig. 1. Spectroradiometer readings of the light qualities used in this study. All treatments represent the waveform generated at a fluence rate of 50 μmol m^{-2} s^{-1}. B = blue, R = red, FR = far-red, HBW = half-bandwidth.

2.2. Petunia

In all cases of petunia experimentation, *Petunia* × *hybrida* cv. 'Mitchell Diploid' (MD) plants (Mitchell et al., 1980) were grown in a glass greenhouse to reproductive maturity, from seed. Developing MD flowers were tagged at stage 6 and allowed to grow to stage 8 (Colquhoun et al., 2010). The morning of what would be a stage 8 open flower; tagged flowers were excised at the petiole, and placed in a 4 mL glass vial with 2 mL of tap water.

In the initial experiment (Fig. 2), the prepared MD flowers were placed in each of five light environments: white, blue, red, far-red, and dark. Six flowers were exposed to each light condition for 8 h and removed at 18:00 h. The corollas were then removed from the receptacle and two corollas were each inserted into a single glass tube for volatile collection, totaling three biological replicates per experiment. Multiple replications of this experiment were performed with similar results observed.

To determine the length of time required to obtain a light-induced volatile response, a time course was conducted. Samples of eight flowers were exposed to a far-red light environment for 0, 2, 4, 6, or 8 h. Flowers were kept under white light (control) conditions until entering the far-red light treatment (Fig. S1). A dark environment control was also included. At 18:00 h, all flowers were removed from their respective light treatments. The receptacle was detached, and two flowers were each inserted into a single glass tube for volatile collection, totaling four biological replicates per experiment. Multiple replications of this experiment were performed with similar results observed.

2.3. Tomato

Field-grown tomatoes (*Solanum lycopersicum*, M82) were harvested at breaker stage and allowed to ripen under five different light conditions: white, blue, red, far-red, and dark. After 10 d, multiple fruits per treatment were diced, pooled, and 100 g samples were loaded into glass tubes in triplicate per experiment (n = 3) for volatile collection (Schmelz et al., 2001; Tieman et al., 2006). Multiple replications of this experiment were performed with similar results observed.

2.4. Strawberry

Field-grown mature *Fragaria* × *ananassa* 'Strawberry Festival' fruit were harvested in the morning and chilled at 4 °C overnight in dark conditions. Seven berries were selected based on uniformity of appearance per treatment, and were placed into clear plastic containers the next morning, followed by the treatment conditions for 8 h. Light environments tested were white, blue, red, far-red, and dark. After 8 h, light-treated fruit samples from each treatment were pooled, homogenized in a blender, and 20 g of homogenate was loaded in triplicate (n = 3) into glass tubes for volatile collection. Multiple replications of this experiment were performed with similar results observed.

2.5. Blueberry

Field-grown *Vaccinium corymbosum* 'Scintilla' fruit were harvested 1 d prior to light treatments. Mature blueberry fruits were harvested in the morning and chilled at 4 °C overnight in dark conditions. The next morning selected uniform fruit were spread in a single layer and placed in white, blue, red, far-red, and dark conditions for a 8 h treatment. After the