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The beneficial effects of exogenous melatonin on tomato fruit properties

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As a highly conserved molecule evolutionarily, melatonin displays an exceptional multiplicity of actions in plants. Our study objective was to analyze how long-term applications of exogenous melatonin influence the quality and yield of fruit from 'ZheFen No. 701′ tomato (*Solanum lycopersicum*). Plants that grew from seeds that had been soaked with melatonin prior to germination had much higher yields as well as more ascorbic acid, lycopene and the content of Ca element, while the content of N, Mg, Cu, Zn, Fe, and Mn element decrease. By contrast, plants irrigated weekly with melatonin-supplemented nutrient solutions showed significant improvements in their contents of soluble solids, ascorbic acid, lycopene, citric acid, and P element when compared with control plants that received only a standard solution. These results are the first to provide evidence for the role that melatonin has in increasing both fruit yield and quality in tomato.

1. Introduction

Tomato (*Solanum lycopersicum*) is one of the most popular and extensively consumed vegetable crops worldwide (Song et al., 2015). This fruit is associated with lowered risks of developing certain types of cancer, cardiovascular diseases, and age-related macular degeneration (Dorais et al., 2008). In addition to its economic importance, this species can serve as an experimental model for the study of fruit development (Mueller et al., 2005). Both genetic factors and growing conditions influence its productivity and quality. Fruit yields can be improved if plants are treated with humic acid (Yildirim, 2007), ethylene (Alexander and Grierson, 2002), gibberellic acid (Zang et al., 2016), vermicompost (Azarmi et al., 2008), calcium (Paiva et al., 1998), seaweed sap (Zodape et al., 2011), or arbuscular mycorrhizal fungi (Zodape et al., 2011).

Melatonin, which was first detected in tomato in 1995, accumulates in the fruits as they mature (Dubbels et al., 1995; Hattori et al., 1995). High levels of melatonin in foods are not only beneficial to consumer health, but might also prolong shelf life (Tan et al., 2012). Many edible fruits, e.g., cherry, banana, apple, strawberry, pineapple, tomato, and grape, are natural sources of melatonin, a trait that is increasingly drawing attention from scientists and consumers (Arnao and Finlayson, 2014). This molecule is highly conserved evolutionarily, and present in almost all organisms, both plant and animal, where it has numerous functions (Hardeland et al., 2011; Kolár and Macháckov, 2005). In plants, its physiological roles can include protection against chlorophyll degradation (Arnao and Hernández-Ruiz, 2009) and oxidative damage (Meng et al., 2014), delayed floral induction (Byeon and Back, 2014), and the regeneration of adventitious and lateral roots (Arnao and Hernández-Ruiz, 2007). Melatonin can also guard against damage caused by biotic and abiotic stresses such as drought, salinity, chilling, heavy metals, ultraviolet radiation, pathogens, and herbicides (Arnao and Hernández-Ruiz, 2014; Liu et al., 2015; Zhang et al., 2014a, b).

Various experiments have been conducted to investigate the effects of exogenous melatonin on plant development. When seeds of *Phacelia tanacetifolia* were soaked with melatonin, germination was promoted under light and high-temperature stresses (Tiryaki and Keles, 2012). Likewise, germination rate was enhanced for melatonin-treated seeds of cucumber (*Cucumis sativus*) that were then exposed to high salinity (Zhang et al., 2014a, b) while cucumber seedlings cultured with a melatonin solution showed greater tolerance to water stress (Zhang et al., 2013). Finally, when apple tree roots were irrigated with a melatonin-supplemented solution over the long term, leaf senescence normally associated with drought was delayed (Wang et al., 2013). Despite these reports, however, it is still unclear which method of melatonin application is the most effective for inducing the desired response.

Here, we explored two types of exogenous melatonin treatment for tomato: seed-soaking and root irrigation. Our objective was to

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determine how those approaches influence fruit quality and yield by measuring the soluble solids content and levels of organic acids, ascorbic acid, lycopene, and mineral elements.

2. Materials and methods

2.1. Plant materials and treatments

The 'Zhefen No. 701′ tomato (*Solanum lycopersicum*) is widely cultivated in China. All experiments were conducted at the Northwest A & F University, Yangling, China (34°20′N, 108°24′E).

This experiment was carried out in greenhouse, and the temperature was controlled in 28–35 °C. Seeds were soaked for 5 h in solutions containing 0.0 or 0.1 mM melatonin. After germination, the seedlings were placed in plastic pots (38 cm × 28 cm) filled with 12 kg soil. Seedlings that had developed from seeds pre-treated with 0.1 mM melatonin were grown according to standard practices. Plants that developed from seeds not exposed to melatonin pretreatment (0.0 mM) were assigned to one of two groups: 1) normal management, without any melatonin added to the irrigation solution (Control) or 2) weekly applications with 500 mL of 0.1 mM melatonin-supplemented solutions that began with expansion of the first fruit cluster. Plants irrigated with a melatonin solution was designated as I-MT group (I-MT) and plants growing from soaking seed with a melatonin solution was designated as S-MT group (S-MT). Each treatment group comprised three replicates of 25 plants each. Plants were watered daily, at 5:00 pm, and they also received 500 mL of Hoagland's nutrient solution every two weeks during the experimental period (Hoagland and Arnon, 1950). Plants retained five layer fruit. Healthy and uniformly red-ripened fruits were harvested and weighed. Afterward, samples from each treatment type were rapidly frozen in liquid nitrogen and stored at −50 °C.

2.2. Analysis of soluble solids content and soluble sugars

The soluble solids content (SSC) was determined at 25 °C with a portable system (Pocket REFRACTOMETER PAL-1, ATAGO, Japan). Metabolite profiling was performed via gas chromatography-mass spectrometry, using an Agilent 7890A GC/5975C MS (Agilent Technology, Palo Alto, CA, USA) and an electron ionization source. Three tomato fruits were randomly selected from each treatment. The flesh (0.1 g) was extracted in 1.4 mL of 75% methanol, with ribitol added as an internal standard. Measurements were made as described by Zhang et al. (Zhang et al., 2010).

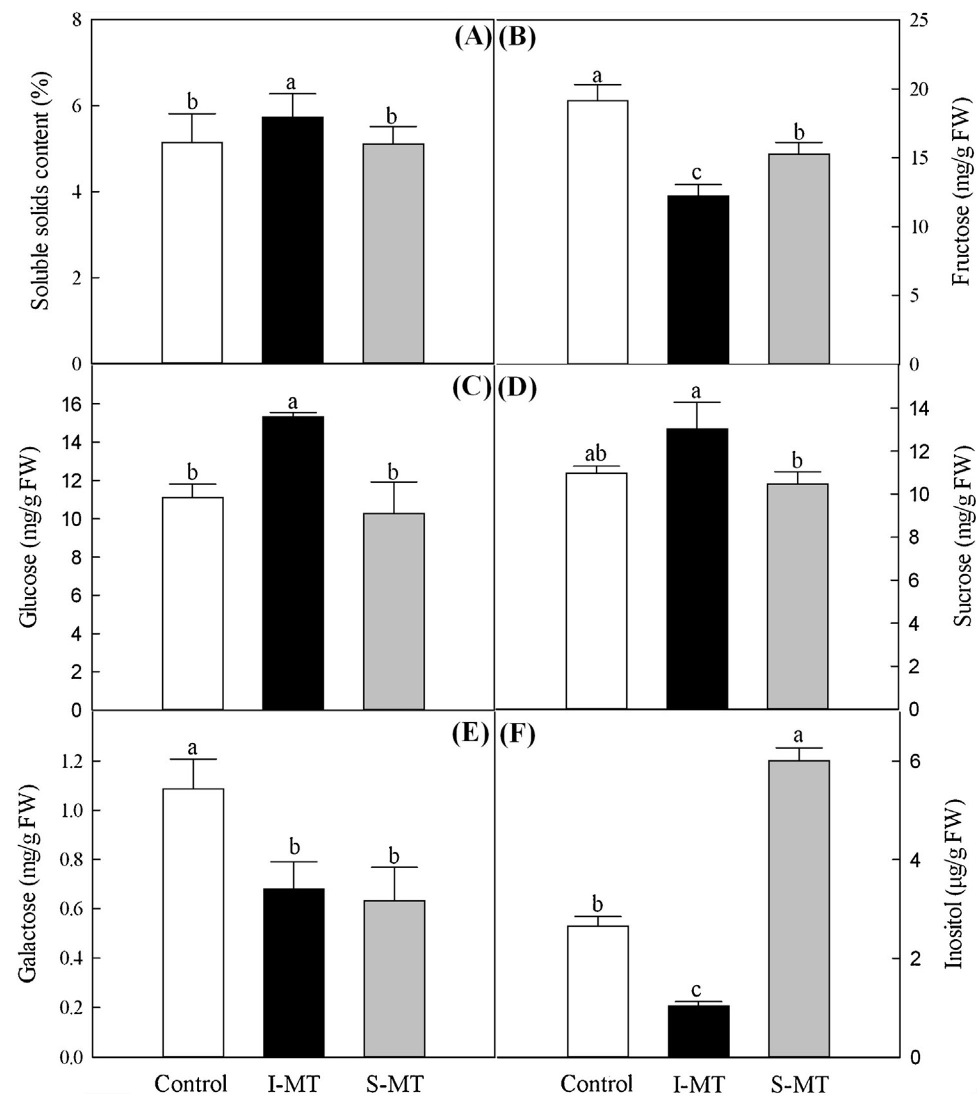

Fig. 1. Effects of exogenous melatonin on contents of soluble solids (A), fructose (B), glucose (C), sucrose (D), galactose (E), and inositol (F). Data represent means ± SD of 15 replicate samples for soluble solids and 3 replicate samples for others. Different letters within a panel indicate significant differences among treatments according to LSD multiple-range tests (P <0.05).