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Ethylene production as an indicator of stress conditions in hydroponically-grown strawberries

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Abstract

As a soilless system, hydroponics eliminates competing weeds and soil-born pests while conserving water and providing conditions that can be quickly altered to suit specific crops. However, stress-induced physiological conditions may arise within the system from factors such as mechanical injury, pests, or inconsistent nutrient flow rates that result in some plants receiving too much or too little water. Most abiotic stress conditions result in increased production of the plant hormone ethylene. High levels of ethylene inhibit growth, cause premature ripening, and induce the onset of senescence, potentially reducing the productivity of hydroponically-grown crops. In this study, we demonstrate that assessing ethylene levels from leaves of hydroponically-grown strawberry plants can be used as an early indicator of stress conditions. Our results demonstrate that there is no significant correlation between ethylene production and temperatures ranging from 15 to 37 °C or with light intensities ranging from 63 to 1500 μmol m^{-2} s^{-1}. However, an increase in ethylene production tended to be positively correlated with sampling time; levels were higher during midday compared to early morning or later afternoon. The daily ethylene fluctuations under greenhouse conditions due to sampling time, light intensity, or temperature changes were not significantly high enough to indicate stress conditions. Overall, three system analyses showed altered ethylene production in plants farthest from the pump supplying the nutrient solution. This effect was interpreted to be caused by excess accumulation of nutrient solution around the plant roots, causing increased ethylene production in the leaves. Our results indicate that different watering patterns, manifested as pump pressure or drainage control, was the more difficult component to control in the design of these hydroponic systems. For example, in one system, an increase in ethylene production was measured for the position farthest from the pump, and resulted in those plants having a lower number of flowers and significantly reduced overall plant radii relative to the system average. In a separate experiment, plants from trays that had been flooded for 24 h showed a significant decrease in the plant radii and number of leaves and flowers 1 month after the flooding treatment. We conclude that system-wide ethylene measurements can be used to identify stressed plants within hydroponic systems. This type of analysis would be especially useful as an indicator of general stress conditions no matter the cause, identifying locations that may result in lower plant productivity.

Keywords: Ethylene; Hydroponic; Strawberry; Stress; Hypoxia

1. Introduction

With the worldwide phaseout of methyl bromide as a soil fumigate, the use of hydroponic systems has rapidly increased as an economic alternative for the growth of many horticulturally-important crops (Environmental Protection Agency, 1997; Carpenter et al., 2000; VanSickle et al., 2000; Federal Register, 2004). As a soilless system, hydroponics eliminates competing weeds and soil-born pests, thus reducing the need for pesticides and avoiding toxic residues that may accumulate on plants. In addition, hydroponic cultivation conserves water and provides conditions that can be quickly altered to suit specific crops. However, stress-induced physiological conditions may arise within the system if nutrient flow is inconsistent, resulting in some plants receiving too much or too little water. For example, flooding of root systems causes oxygen deficiency and interferes with nutrient uptake (Urrestarazu and Mazuela, 2005). Therefore, careful management of hydroponic systems becomes an important consideration for reducing stress conditions that negatively impact yield, in order to increase market profitability by decreasing cultivation costs.

Many abiotic stress conditions, including chilling and freezing, high temperature, flooding, drought, chemical damage, radiation, and mechanical perturbation, stimulate

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ethylene production. High levels of ethylene inhibit growth, cause premature ripening, and induce the onset of senescence, potentially reducing plant productivity (Abeles et al., 1992; Druege, 2006). Stress-induced ethylene is regulated by the production of the ethylene precursor, ACC (1-aminocyclopropane-1-carboxylic acid) (see reviews by Abeles et al., 1992; Druege, 2006). For example, during flooding, oxygen deficiency in plant roots results in increased production of ethylene (Jackson, 2002). Anaerobic conditions in plant roots inhibit the oxygen-requiring enzyme, ACC oxidase, which catalyzes ethylene production from its immediate precursor, ACC. As a result, ACC accumulates in the roots and is then transported by the vascular system to the stems and leaves where it is rapidly converted to ethylene. Anaerobic conditions also stimulate the production of ACC synthesis in the roots, contributing more ACC to be transported to the leaves. Consequently, higher levels of ethylene in leaves can stimulate ACC oxidase synthesis and activity, further increasing ethylene production there. In addition to the effects of flooding on ethylene production, Saltveit and Dilley (1978) report that wound-induced ethylene production increases after a time lag of 16–26 min and proceeds to peak production within 60 min after wounding in etiolated tissue. Peak production varied from 1.6 to 24 times basal level in dark-grown seedlings. Non-etiolated woody tissue showed greater variation in the kinetics of wound-induced ethylene production, often had a longer lag (up to 55 min), and displayed peak ethylene production times of 100–133 min. Based on these examples of the effect of stress on ethylene levels, ethylene measurement may be a useful tool for identifying conditions that impact plant growth.

Hydroponic systems provide an economical and viable alternative for the cultivation of strawberry, a crop that has been particularly dependent upon methyl bromide fumigation (Stanley, 1998). In this study, we demonstrate that assessing ethylene levels from leaves of hydroponically-grown strawberry plants is useful as an early indicator of stress conditions within the system. This method can be used to determine inconsistencies within a hydroponic system that may cause plant stress and affect subsequent plant growth and fruit production.

2. Materials and methods

2.1. Hydroponics

The strawberry growth conditions and hydroponic system design were developed in consultation with Dr. Fumiomi Takeda (USDA-ARS Appalachian Fruit Research Station, Kearneysville, West Virginia, USA) and adapted from the procedures described in Takeda (1999). Chandler strawberries (*Fragaria* × *ananassa*), a short-day (SD) cultivar, were purchased as plants (Davon Crest Farm, Maryland, USA) or grown from runners (Strawberry Tyme Farms, Ontario, Canada). Prior to planting in the hydroponic systems, runners and plants received a cold treatment of 4 °C in a refrigerator for 6 weeks to stimulate flowering. Runners were rooted under a misting bench. Rooted runners or plants were planted in commercial peat-based soilless planting mixture (Premier Horticulture Inc., Red Hill, Pennsylvania, USA) within 15.24 cm circular net pots. Pots were placed in Hydroware™ trays (1.06 m length × 0.203 m width × 0.102 m depth; Sea of Green, Tempe, Arizona, USA), lined with plastic screening, and surrounded by sifted perlite. White-on-black plastic mulch (Garden Indoors, Columbus, Ohio, USA) was placed over the perlite and around the plants to control evaporation and algal growth. A nutrient solution of 5N–11P–26K fertilizer (Scotts HydroSol Water Soluble Fertilizer) supplemented with 0.18 g l^{-1} Epson salts ($MgSO_4$), 0.64 g l^{-1} $CaNO_3$, and 0.015 g l^{-1} $FeCl_3$ at pH 6.2 was changed every 7–10 days to maintain nutrient concentrations, regulate pH, and minimize salt accumulation.

Each hydroponic system consisted of 10 trays containing three plants each (30 plants total), connected to a central nutrient delivery pipe (Fig. 1). A submersible fountain pump was located in a 55 l container, and the nutrient solution was circulated through a central pipe that was attached to 1.3 m of irrigation drip tape per tray with 10 cm emitter spacing (RO-DRIP, Roberts Irrigation Products, San Marcos, CA). The drip tape lay over the perlite and pots and under the plastic mulch of each tray. Pressure in the central delivery pipe and the attached drip tape was controlled by a valve adjacent to the tray farthest from the pump so that the drip tape was completely expanded over all trays to deliver 5 l h^{-1} m^{-1}. Troughs were inclined to approximately a 15° angle to aid drainage, with the higher end located at the central delivery pipe. Excess solution from the central delivery pipe and from each tray was returned by gravity back to the main 55 l reservoir. No pesticides were used.

Plants were allowed to acclimate to the hydroponic systems for a minimum of 2 weeks prior to experimentation. Experiments were conducted under natural SD photoperiod, supplemented by high-pressure sodium lights. During daylight hours, light intensity ranged from 63 to 1500 μmol m^{-2} s^{-1} photosynthetic active radiation (PAR). Greenhouse temperatures ranged between 15 and 37 °C during these experiments.

2.2. Ethylene measurements

The kinetics of wound-induced ethylene production were determined in excised strawberry leaflets in order to establish the basal and peak wound-induced ethylene levels for this tissue. To evaluate wound-induced ethylene production, excised leaflets (0.25–0.5 g fresh weight each) were wounded (cut into sections), placed in 2 ml vials, and capped. Headspace around leaflets in vials was sampled at 20 min intervals; vials were aired for 0.5 min before they were re-capped for the next sampling interval. A 1.0 ml headspace sample was injected onto an alumina F1 column (0.635 cm × 0.91 m) in a gas chromatograph (Varian 3700, Varian Instrument Division, Walnut Creek, California, USA) equipped with a flame ionization detector according to the procedure described by Harrison (1997). The nitrogen carrier gas flow rate was 40 ml min^{-1} and the oven temperature was maintained at 100 °C. Hydrogen and air flow rates to the detector were 40 and 300–400 ml min^{-1}, respectively, and the detector temperature