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Development of Speaking Plant Approach Technique for Intelligent Greenhouse

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Abstract

The Research Center for High-technology Greenhouse Plant Production of Ehime University provides a seamless technology development to establish INTELLIGENT GREENHOUSE SYSTEMS (IGS). The core concept as the basis of IGS is 'Speaking plant approach (SPA)', which was originally proposed by Udink ten Cate et al. and Hashimoto who is a professor emeritus at Ehime University. The SPA concept defines that optimal crop cultivation conditions should be based on the physiological status of the plants. The first step of the SPA is to obtain physiological information from a living plant. As a successful example, a chlorophyll fluorescence imaging robot, which can be used to grasp the heterogeneous distribution of photosynthetic activity of tomato plants in a greenhouse, is introduced. The primary feature of this robot is the feasible design, automated simple operation and low-cost, for implementation in commercial tomato production greenhouses. In addition, it is also focusing on the development of postharvest management techniques to improve the fruit quality. Here, a study to investigate the effects of storage temperature on the color of tomato fruit would be briefly introduced.

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Keywords: automation; environmental control; intelligent greenhouse systems; photosynthesis; plant diagnosis

1. Introduction

The Research Center for High-technology Greenhouse Plant Production of Ehime University was established in 2010. The research center consists of two divisions. Division for intelligent greenhouse systems supported by

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Ministry of Economy, Trade and Industry of Japan, is conducting fundamental researches such as development of harvesting robot, plant diagnosis robot and IT for greenhouse plant production with several highly sophisticated experimental greenhouses. Division for verification, demonstration and on-the-job training supported by Ministry of Agriculture, Forestry and Fisheries of Japan is located at about 100 km from Ehime University and focusing on verification of new technologies in commercial greenhouses (total cultivation area is 6800 m^2). These two divisions provide a seamless technology development to establish INTELLIGENT GREENHOUSE SYSTEMS (IGS). The core concept as the basis of IGS is 'Speaking plant approach (SPA)', which was originally proposed by Udink ten Cate et al. (1978) and Hashimoto (1989) who is a professor emeritus at Ehime University. The SPA concept defines that optimal crop cultivation conditions should be based on the physiological status of the plants. The first step of the SPA is to obtain physiological information from a living plant. As a successful example, a chlorophyll fluorescence imaging robot, which can be used to grasp the heterogeneous distribution of photosynthetic activity of tomato plants in a greenhouse, is introduced. The primary feature of this robot is the feasible design, automated simple operation and low-cost, for implementation in commercial tomato production greenhouses. In addition, we also focus on the development of postharvest management techniques to improve the fruit quality. Here, a study to investigate the effects of storage temperature on the color of tomato fruit would be briefly introduced. Tomato fruit color change after storage was estimated with variables of tomato fruit color before storage, storage temperatures and duration using a multiple regression analysis.

2. Daily Measurement of Tomato Plant's Biological Information with a Chlorophyll Fluorescence Imaging Robot

Chlorophyll fluorescence is the emission of red light from chlorophyll *a* pigments (Govindjee, 1995). So, the chlorophyll fluorescence imaging provides information on photosynthetic functions without touching the living plant. The imaging technique of chlorophyll fluorescence was originally developed by Omasa *et al*. (1987). The subjects of chlorophyll fluorescence imaging have been scaled up to the levels of a whole plant (Takayama *et al*., 2010), a tree canopy (Nichol *et al*., 2012), and tomato crops cultivated in a large-scale greenhouse (Takayama *et al*., 2011abc, 2014). A chlorophyll fluorescence imaging robot by modifying the chlorophyll fluorescence imaging system was developed in our previous studies (Takayama *et al*., 2011abc, 2014). The primary feature of this robot is the feasible design, automated simple operation and low-cost, for implementation in commercial tomato production greenhouse. The developed chlorophyll fluorescence imaging robot was applied to grasp a spatial distribution of photosynthetic function of hydroponically-cultivated tomato plants in a semi-commercial greenhouse.

2.1. Materials and Methods

2.1.1 Chlorophyll fluorescence emission and induction phenomenon

Plant leaves cannot use all the absorbed light energy only for photosynthetic reactions. The residual light energy not used for photosynthetic reactions is dissipated as heat or re-emitted as red light. So, accurate measurement of chlorophyll fluorescence emission thus allows the evaluation of photosynthetic functions. By illuminating a dark-adapted leaf with a stable intensity excitation light, dynamic changes in chlorophyll fluorescence intensity are observed. This is called the "chlorophyll fluorescence induction phenomenon" (Govindjee, 1995; Omasa and Takayama, 2002). Figure 1(a) shows a typical chlorophyll fluorescence induction curve (Takayama and Nishina, 2009) showing a time course of chlorophyll fluorescence intensity during the induction phenomenon. To evaluate the shape of induction curve, the P/S, which is the ratio of chlorophyll fluorescence intensities at the inflection points of P and S, was defined (Takayama *et al*., 2014). The P/S can be used as an index of ability of photosynthetic electron transport (Takayama *et al*., 2012).

2.1.2 Chlorophyll fluorescence imaging robot

Figure 1(b) shows photo and schematic of the chlorophyll fluorescence imaging robot. A blue LED panel ($\lambda <$ 600 nm) illuminates a 1.8 m (H) x 1.0 m (W) area at a distance of 0.6 m from the panel at PPFD of less than 5-30

μmol m^{-2} s^{-1}. The chlorophyll fluorescence emission from the plants was captured by a CCD camera equipped with a long-pass filter (λ > 640 nm). Captured images were analysed using Visual Basic 6.0 software we developed in-house.

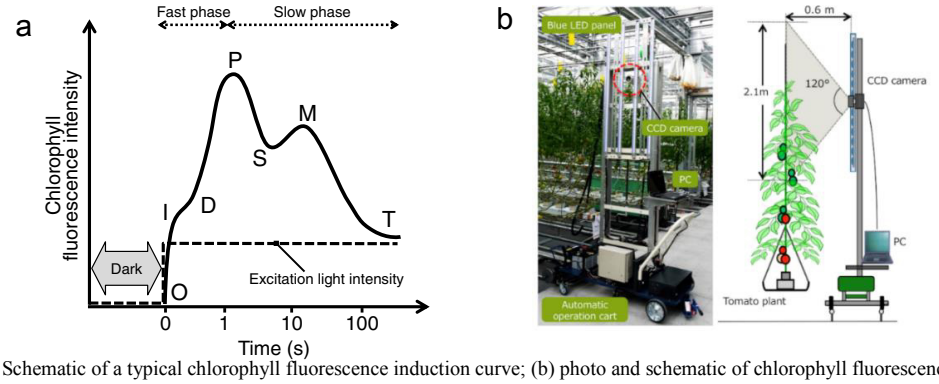

Fig. 1. (a) Schematic of a typical chlorophyll fluorescence induction curve; (b) photo and schematic of chlorophyll fluorescence imaging robot.

2.1.3 Plant material and chlorophyll fluorescence imaging

About forty seven-month-old tomato plants (*Solanum lycopersicum* L., 'Taian Kichijitsu') grown on a cultivation gutter in a semi-commercial greenhouse in Ehime University were measured by the chlorophyll fluorescence imaging robot. All the imaging was performed under dark conditions at night from 5th to 20th February 2014.

2.2 Results and Discussion

Figure 2 shows a map of the imaging points and distributions of chlorophyll fluorescence parameter P/S. A particular area on the south side of the greenhouse, which is surrounded by a circle, showed high P/S values and the area at the northeast corner of the greenhouse showed relatively low P/S values. The P/S represents the initial photosynthetic electron transport activity, the electron transport from Q_A to the secondary electron acceptors such as PQ or others (Takayama et al., 2012). So, this result suggests that the initial electron transport activity of the plants in the area surrounded by the circle is high and that on the northeast of the greenhouse is low.

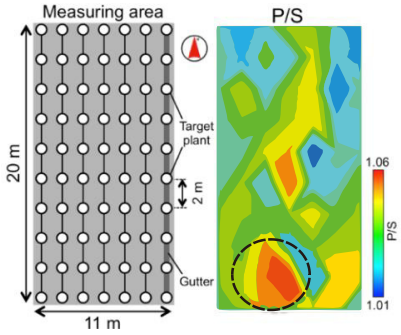

Fig. 2. A map of the points (○) of chlorophyll fluorescence imaging (Left) and the distributions of chlorophyll fluorescence parameters P/S (Right) in the greenhouse.

3. Estimation of Tomato Fruit Color Change with Different Storage Temperatures at Different Maturity Stages

For tomato production in greenhouse, tomato color is the most important marketing factor that is often used for the purchase decision of customer. Since tomato color is varied with the harvesting time and the ripening in tomato is affected by storage temperature (Takahashi and Nakayama, 1962), it is difficult to achieve an even tomato color at the shipping time. Therefore, storage temperature control depended on the maturity stage is essential for stable tomato production in high technology greenhouse. However, it is unknown that the relationship between tomato color change with different maturity stages and storage duration and temperatures. Tomato fruit color change after storage was estimated with variables of tomato fruit color before storage, storage temperatures and duration using a multiple regression analysis.

3.1 Materials and Methods

Tomato (*Solanum lycopersicum* L., 'Taian Kichijitsu') were grown hydroponically in high technology greenhouse in Faculty of Agriculture, Ehime University. Tomato seeds were sown on June 18 and transplanted on July 26 in 2012. The harvesting time was from September 18 to November 10 in 2012. Each harvesting time, different maturity stages of tomato fruit with green, pink, and red colors were obtained. Six tomato fruit were stored in cool incubator for 48 h and the storage temperature was adjusted at 10, 15, 20, 25, and 30 °C, respectively. Tomato fruit color and quality measurements were conducted at the harvesting time (0 h) and 24 h, and 48 h after storage.

Tomato fruit image was captured with Digital Camera (SX5-WKIT, Canon Inc.). The measurement distance was 115 mm from the top of the tomato fruit. The camera condition was adjusted with F value, shutter speed, and ISO for 5.0, 1/30, and 200, respectively. A ring-shaped white LED was used for light source. The light intensity was adjusted for 2500 lx at the top of the tomato fruit. The polarizing filter and film were equipped with camera and light source to reduce halation from surface reflectance of tomato fruit. After capturing image, the image was processed with application which was programmed with Visual basic (Microsoft Visual Studio 2010).

The fruit area was extracted automatically using a discriminant analysis method. Threshold value was determined with luminance histogram. RGB values were obtained from the fruit image and the color characteristics were calculated according to Kurita et al. (2006).

3.2 Results and Discussion

Tomato fruit color change at different maturity stages after storage was estimated using a multiple regression analysis. In this study, equation (3) was obtained for estimation of tomato fruit color after storage:

$$y = 23.31 + 0.68C + 0.57T + 0.31t + 0.01Tt \tag{3}$$

where y is chromaticity of tomato fruit after storage, C is chromaticity of tomato fruit before storage, T is storage temperature (°C), and t is storage duration (h). Tomato fruit color after storage was estimated using equation (3) except for the data which was used to get the equation (3). The coefficient of determination between estimated chromaticity and observed chromaticity of tomato fruit after storage was 0.88 (Fig. 3).

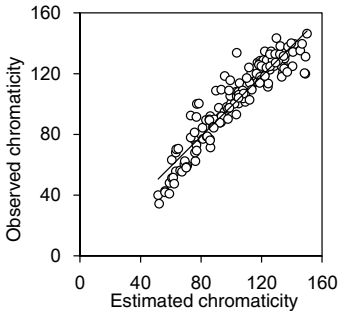

Fig. 3. Relationship between estimated chromaticity and observed chromaticity of tomato fruit after storage using a multiple regression (R^2=0.88, n=150).

4. Conclusions

In this study, a chlorophyll fluorescence imaging robot was developed to monitor the health conditions of tomato crops in semi-commercial greenhouse by measuring the induction curves. The imaging robot proved that there was an apparent heterogeneous distribution of photosynthetic functions across the 20 m x 11 m cultivation area. The developed chlorophyll fluorescence imaging robot is expected to be implemented in commercial tomato production greenhouse in the near future.

Tomato fruit color change after storage was estimated with variables of tomato fruit color before storage, storage temperatures and duration using a multiple regression analysis. Our results suggested that tomato fruit color estimation technique can be contributed to control the tomato fruit color with storage.

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