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Title of Thesis: Optimization of LED lighting and root-zone temperature for enhancing secondary metabolite accumulation and production of coriander in plant factory

植物工場におけるコリアンダーの 2 次代謝産物の蓄積と収量を高めるための LED 光条件と根域温度の最適化

ABSTRACT OF THE THESIS

The demand for high-quality and freshly consumed vegetables has been growing rapidly in large cities (e.g. Tokyo). A plant factory with artificial light is a facility that enables food production inside cities with high productivity. It can satisfy specific demands for qualities in plant growth and secondary metabolite accumulation by controlling the environmental factors. Among the vegetables that have potential for efficient cultivation in plant factory, coriander has been gaining a lot of attention due to its various uses. Coriander (*Coriandrum sativum* L.) is an annual herbaceous plant, and its fresh leaves are widely used in food flavouring in daily cuisines. All parts of this herb are used as traditional remedies for the treatment of different disorders in the folk medicine systems of different civilizations. Coriander leaves are rich in minerals and vitamins, such as vitamin C up to 1.35 mg g^{-1}, vitamin B_2 of 0.6 mg g^{-1}, calcium up to 12.5 mg g^{-1}, potassium up to 44.7 mg g^{-1}, and zinc up to 0.047 mg g^{-1}. They are also well known for their antioxidant properties, such as volatile components, flavonoids, chlorogenic acid, rutin, β-carotene, and phenolic compounds. The concentrations of those secondary metabolic compounds in herbs are important indexes for their quality assessment.

This study is proposed in an attempt to provide better understanding of the effects of light source and root-zone temperature on plant growth and secondary metabolite

accumulation in coriander. Then, finding an optimal combination of these two factors for coriander plant cultivation would benefit both fundamental research and commercial application. The thesis is composed of seven chapters and the contents of each chapter are as follows.

In chapter 1, a general introduction including the overview of coriander, plant factory, light source and root-zone temperature factors, and the objective of the study are provided.

In chapter 2, the effects of monochromatic (red (R), blue (B), green (G)) and mixed (red:blue (RB) and red:blue:far-red (RBFr)) lights on plant growth, mineral contents, and secondary metabolite accumulation of coriander under environmental controlled conditions were investigated comparatively. Five different light qualities, R, B, G, RB (ratio of 87:13), and RBFr (ratio of 81.5: 12.5: 6) were applied. Results showed that biomass, chlorophyll index, and ascorbic acid content of coriander plants were significantly higher in RB or RBFr treatments than in other light treatments. The antioxidant capacity and total phenolic content were highest under B light. The total phenolic content per plant was highest under RBFr light due to its high growth rate and biomass production. Besides, tipburn occurrence in coriander was not affected by total Ca content in the shoot. RBFr was found to be the optimal light spectrum for producing coriander with high yield and contents of ascorbic acid, total phenolics, Ca, and P in a plant factory.

In chapter 3, five types of white LEDs with different ratios of blue, green, red and far-red (Fr) lights and a R:B LED as the control were applied to identify the suitable light spectrum for enhancing the growth and bioactive metabolite accumulation of coriander plants grown in plant factory. The results showed that both plant growth and bioactive compound production were affected by combining ratio of monochromatic lights in white LED. Blue and far-red light proportions play important roles in regulating morphological characteristics and biomass accumulation in coriander plants. Plant biomass was highest under white LED with a B:G:R:Fr ratio of 8:29:53:10, and contents of bioactive metabolites including ascorbic acid and total phenolic contents in white LED treatments decreased slightly in comparison with those in control. However, the ascorbic acid (ASA) content and the total phenolic content (TPC) per plant were higher under white LED with a B:G:R:Fr ratio of 8:29:53:10 because of the higher biomass accumulation compared with those under control treatment. These results demonstrated that white LED light can be used to produce coriander plants with high yield and good quality in plant factory.

In chapter 4, the responses of coriander plants to photosynthetic photon flux density (PPFD) and root-zone temperature (RZT) were investigated to achieve the desirable plant growth and quality. Nine different combinations of three PPFDs—100, 200, and 300 µmol m^{-2} s^{-1}—and three RZTs—20, 25, and 30 °C—were applied on coriander plants grown hydroponically in a plant factory to identify the optimal environment for enhancing growth and accumulations of principal secondary metabolites (SMs). Plant biomass was highest under RZT at 25 °C and increased with increases in PPFD. However, contents of SMs, including *trans*-2-decenal, rutin (QR), chlorogenic acid (CA) and total phenolic content, were lowest at RZT of 25 °C regardless of PPFD. The highest SM contents were achieved under the highest RZT (30 °C) with PPFD of 300 µmol m^{-2} s^{-1} in correlation with a decrease in biomass.

In chapter 5, the combination of a mid-RZT (25 °C) pre-treatment with low (15 °C, 20 °C) or high (30 °C, 35 °C) RZT stress for short period (3 or 6 days) during cultivation before harvesting was applied to find a suitable cultivation condition for enhancing both biomass and secondary metabolite accumulation of coriander plant. The results showed that secondary metabolite production were strongly influenced by the interaction of RZT and short-term stress period. The growth of coriander plant was lightly reduced under stress condition. In contrast, secondary metabolites including ASA, total carotenoid, TPC, QR, and CA concentrations as well as the antioxidant capacity of coriander plant were enhanced with a combination of the lowest or the highest RZT (15 or 35 °C) and longer stress period (6 days). Shoot FW and DW of coriander grown under RZT of 30 °C for 6 days slightly decreased in comparison with control treatment but TPC and CA content per plant were higher than control treatment. Therefore growing coriander under RZT of 30 °C for 6 days can produce coriander with high amount of bioactive compounds. While growing coriander at RZT of 15 °C for 6 days can produce coriander with high dry biomass and secondary metabolite contents.

Chapter 6 would like to determine a suitable cultivation condition (light quality, PPFD and RZT) based on economic aspect to archive maximum cost performance and profit. The profitability was particularly highest when white LED with a B:G:R:Fr ratio of 8:29:53:10 was used. In addition, the highest yield performance was attained when coriander plants were grown under RZT of 25 °C. Under the price structure prevailing in Japan at the time of our study, the profit-maximizing level of electricity consumption was, in terms of PPFD, 350 µmol m^{-2} s^{-1}.

In chapter 7, the results of the study in meeting the objectives of the research are summarized and assessed. Recommendations for future work to fully understand coriander plant response on cultivation environment and enhance the effectiveness of coriander production in controlled environment condition were provided.