INTRODUCTION

It is known that plant growth and morphogenesis are greatly affected by various surrounding environmental factors. Temperature and light are two of the factors that affect stem elongation and capitulum formation. Techniques that regulate plant growth by controlling temperature and light condition have been examined as potential techniques to reduce the stem elongation and capitulum formation in lettuce. Red and yellow fluorescent lamp were used as light sources in this experiment. Lettuce seeds were sown on May 9, 2013. Seedlings were exposed to low temperature during the night from May 23 to June 6, and sequentially exposed to end of day lighting from June 7 to July 4, 2013. The stem elongation was inhibited by night chilling treatment and was inhibited by end of day lighting treatment remarkably. The capitulum formation was inhibited in the night chilling treatment. These results suggest that end of day lighting after night chilling treatment is effective in suppressing stem elongation and floral stage of lettuce plant.

Keywords: capitulum formation, growth control technique, morphogenesis, red light, stem elongation, yellow light

MATERIALS AND METHODS

Lettuce cultivars ‘Manoa’ and ‘Gokuwase-Cisco’ (Takii Co., Ltd., Japan) were used in the present experiment. On May 5, 2013, seeds of these cultivars were sown in cell trays and cultivated under natural day length in a glass house. The seedlings were moved under natural day
length in a plastic house when the cotyledons completely opened. Night chilling treatment was conducted from May 23 to June 6, 2013 (2 weeks). Subsequently, end-of-day lighting treatment was conducted from June 7 to July 4, 2013 (4 weeks). Treatment factors were prepared night chilling without lighting treatment and night chilling after end of day lighting treatment by using red (EOD-RL) or yellow light (EOD-YL). At last, non-treatment (without night chilling and lighting treatment) was set up as a control. The temperature condition of night chilling treatment was maintained at 15°C and dark condition was achieved by placing seedlings in storage under low temperature from 4:00 PM to 8:00 AM of the next morning. End-of-day lighting treatment was achieved using red and yellow fluorescent lamps (National Co., FL20S R-F and FL20S Y-F). Photon flux density was adjusted at 1–2 μmol m⁻² s⁻¹ and was initiated 5 min before sunset and lasted for 1 h.

The lettuce seedlings were investigated for growth parameters 14 d (first sampling) after night chilling treatment was initiated. After the first sampling, seedlings were transplanted from cell trays to plastic pots (9 cm in diameter), and the second sampling was conducted 42 d after night chilling treatment was initiated. As growth parameters, number of leaves, stem length and diameter were measured. In addition to that, the terminal shoot apex was separated and stabilized using FAA (Formalin-Acetic acid-Alcohol). Finally, the number of nodes, flowering node order, floral stage, and terminal shoot apex were determined using a stereomicroscope (SZ-Tr, OLYMPUS, Japan) and microscopic camera (Moticam2000, SHIMADZU, Japan). Based on the classification of the floral stage by Okuda et al. (2001), there were 9 floral stages.

Fig. 1 Stem length (A), number of leaves (B) and terminal shoot apex diameter (C) of ‘Manoa’ 14 d after night chilling. Different letters indicate a significant (5%) difference using Tukey’s test. Each bar includes the standard error.

Fig. 2 Stem length (A), number of leaves (B) and terminal shoot apex diameter (C) of ‘Gokuwase-Cisco’ 14 d after night chilling. Different letters indicate a significant (5%) difference using Tukey’s test. Each bar includes the standard error.
RESULTS AND DISCUSSION

The present study was examined some growth control techniques to effectively suppress stem elongation in lettuce plant under high temperature conditions. The day lengths during the cultivation of seedlings and the treatment period were changed from 13 h 47 min to 13 h 57 min and 13 h 59 min to 14 h 28 min, respectively.

At 14 d after night chilling, night chilling treated the plants showed shorter stem lengths and fewer number of leaves (Figs. 1 and 2). The floral stage was undifferentiated in all treatments (Fig. 3A). Stem lengths of both cultivars at 42 d after night chilling were shortened in night chilling treatment, and were markedly shortened with end of day lighting after night chilling treatment (Figs. 4A and 5A). The number of leaves of ‘Manoa’ that was cultivated under end of day lighting after night chilling treatment reduced (Fig. 4B). The number of leaves of ‘Gokuwase-Cisco’, reduced the most under end of day yellow lighting after night chilling treatment (Fig. 5B). Inflorescence diameter reduced in night chilling treatment compared with those of the control (Figs. 4C and 5C). The floral stage of ‘Manoa’ was suppressed by night chilling treatment, whereas ‘Gokuwase-Cisco’ was more effectively suppressed by EOD-RL or EOD-YL after night chilling (Fig. 3B). The number of nodes and flowering node order of ‘Manoa’ 42 d after night chilling increased in night chilling treatment (Fig. 6).

In the present experiment, a difference in growth parameters between the cultivars was observed, with the stem length and floral stage of ‘Manoa’ being higher than that of ‘Gokuwase-Cisco’. This result suggests that ‘Manoa’ is more sensitive and reactive to temperature and light than ‘Gokuwase-Cisco’.

In conclusion, night chilling treatment suppressed stem elongation and capitulum formation. Moreover, stronger suppressing effects were obtained using EOD-RL or EOD-YL after night chilling treatment. This tendency was found to be amplified by serially implementing night chilling after end of day lighting. Previous studies of the growth control in lettuce cultivation reported that night chilling (Okuda et al., 2013) as well as EOD-RL or EOD-YL (Okuda et al., 2004; 2005) inhibited stem elongation and floral stage. The present study found the same results; however, stem length under EOD-YL was shorter than those under EOD-RL (Fig. 4A). Plants are able to sense differences in light wavelengths and show a reversible
morphosis reaction (Borthwick et al., 1952). This reaction is similar in the lettuce plant, which shows various morphosis reactions in response to quality of light (Mori et al., 2003). Therefore, the various morphosis reactions by lettuce are considered to be due to differences in suppressing effects caused by varying light quality. In the present study, methods to regulate growth in lettuce by controlling various environmental factors such as temperature and light were studied, and a possible new technique for regulating growth in lettuce has been developed. However, whether these growth control techniques influence the reaction mechanism of the plant, thereby consequently regulating morphosis, remains to be elucidated.

Fig. 5 Stem length (A), number of leaves (B) and inflorescence diameter (C) of ‘Gokuwase-Cisco’ 42 d after night chilling. Different letters indicate a significant (5%) difference using Tukey’s test. Each bar includes the standard error.

The internal water and hormones of the plant are known to influence morphosis. Among these factors, the control of morphosis reactions by environmental control is closely associated with endogenous gibberellins. In an experiment with chrysanthemum, EOD-far red (end of day far red) lighting treatment increased stem elongation and endogenous gibberellins (Hisamatsu et al., 2008). Therefore, the results of morphosis reactions achieved in the present study may have been influenced by gibberellins. It guesses the stem elongation of lettuce is caused by increase of endogenous gibberellins.

This growth control technique has the merit as reduction of work force and environmental conservation. For the purpose of decreasing the running cost, the present study investigated that environmental control technique can obtain more effectively suppressing effects without simultaneously treating during all growth periods. From these results, it is suggested that a short day and night chilling after end of day treatment provides a useful new growth control technique for lettuce using environmental control.

REFERENCES
Borthwick, H. A., Hendricks, S. B., Parker, M. W., Toole, E. H., Toole, V. K. 1952. A reversible photoreaction controlling seed germination. Proc. Natl. Acad. U.S.A. 38: 662–666.
Hiraoka, T. 1967a. Ecological studies on the salad crops. I. Effects of temperature, photoperiod and gibberellins spray on bolting, budding and flowering time of head lettuce (Lactuca sativa L. cultivar, Wayahead, Edogawa strain). J. Jpn. Soc. Hortic. Sci. 36: 70–78.
Hiraoka, T. 1967b. Ecological studies on the salad crops. II. Effect of photoperiods on flower bud differentiation, bolting and heading in lettuce, with special reference to the difference...
of photoperiodic sensibility between varieties on various growing stages. J. Jpn. Soc. Hortic. Sci. 36: 411–420.

Hiraoka, T. 1969. Ecological studies on the salad crops. III. Effects of combination of temperature treatments on flower bud differentiation, bolting, budding and flowering time, of head lettuce (Lactuca sativa L. cultivar. Wayahead, Edogawa strain). J. Jpn. Soc. Hortic. Sci. 38: 42–51.

Hisamatsu, T., Sumitomo, K., Shimizu, H. 2008. End-of-day far-red treatment enhances responsiveness to gibberellins and promotes stem extension in chrysanthemum. J. Hortic. Sci. Biotechnol. 83: 695–700.

Kato, T. 1964a. Physiological studies on the bolting of lettuce plants. I. Relationships between various constituents and flower bud formation. J. Jpn. Soc. Hortic. Sci. 33: 125–132.

Kato, T. 1964b. Physiological studies on the bolting of lettuce plants. II. Relation between the stem elongation and auxin metabolism. J. Jpn. Soc. Hortic. Sci. 33: 243–250.

Mori, Y., Takatsuji, M., Yasuoka, T. 2003. Effects of red and blue LD lights on the growth of lettuce. J. Soc. High Technol. Agric. 15: 43–47.

Okuda, N., Yanagi, T., Fujime, Y. 2001. Studies on capitulum formation and internode elongation of lettuce: 1. Capitulum formation of extremely early variety under controlled temperatures. J. Jpn. Soc. Hortic. Sci. 70 (Suppl. 1): 255.

Okuda, N., Yanagi, T., Fujime, Y. 2004. Studies on capitulum formation and internode elongation of lettuce: 4. Effects of lighting in the end of day on growth and development. J. Jpn. Soc. Hortic. Sci. 73 (Suppl. 2): 188.

Okuda, N., Kudo, R., Otsuda, S., Wada, N., Saito, K. 2005. Studies on capitulum formation and internode elongation of lettuce: 5. Effects of lighting with yellow and far-red fluorescent lamp at the end of day on growth and development. J. Jpn. Soc. Hortic. Sci. 74 (Suppl. 2): 188.

Okuda, N., Toriyama, K., Miya, Y., Daikoku, K., Yanagi, T. 2013. Studies on capitulum formation and internode elongation of lettuce: 11. Effects of short day and night chilling treatment. Japanese Society for Agricultural, Biological and Environmental Engineers and Scientists (JSABEES) Annual Meeting 2013, September, Takamatsu, 212–213.

Okuda, N., Toriyama, K., Miya, Y., Yanagi, T., Yamaguchi, K., Tanaka, M. 2014. Effect of end-of-day light irradiation using LED light sources on the growth of lettuce under a high temperature. Environ. Control Biol. 52: 61–65.

Shibutani, S., Kinoshita, K. 1968. Studies on the ecological adaptation of lettuce. 3. The ecological adaptation of Great Lakes 54 in the growth cabinet in which the temperature is controlled. Sci. Rep. Fac. Agric. Okayama Univ. 32: 25–34.