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GROWTH OF LETTUCE PLANTS (*LACTUCA SATIVA* L.) UNDER VARIABLE-VALUE CONTROL OF AIR TEMPERATURE BY USING NATURAL LIGHT INTENSITY AS FEEDBACK SIGNAL

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EGUCHI, H., YOSHIDA, S., TOH, K., HAMAKOGA, M. and KITANO, M. *Growth of lettuce plants* (Lactuca sativa *L.*) *under variable-value control of air temperature by using natural light intensity as feedback signal.* BIOTRONICS **26**, 13–20. 1997. Lettuce plants (*Lactuca sativa* L.) were grown under different regimes of variable-value control of air temperature, where the set values of air temperature increased quadratically with the natural light intensity in the different dynamic ranges. Under the regime of lower night temperature and larger dynamic range of air temperature, succulent growth was prevented, and leaf fresh and dry weights per unit leaf area became larger because of leaf thickening with well developed spongy layer. The results suggest that the variable-value control of air temperature by using the natural light intensity as a feedback signal can improve plant growth under controlled environment.

Key words: lettuce plant; *Lactuca sativa* L.; air temperature; growth analysis; natural light intensity; variable-value control.

INTRODUCTION

Air temperature is one of the important environmental factors affecting plant growth, and different manners of air temperature control have been applied to systems for plant environment control (*2, 9, 12*). When plants are exposed to lower night temperatures, plant production is improved through carbon balance between photosynthesis and respiration (*5, 7, 10, 11*). It is known that the carbon balance is the light- and temperature-dependent process in plants (*1, 4, 6*). Therefore, under the fluctuating natural light, the air temperature control according to changes in light intensity can be considered to improve the plant growth through the carbon balance. In the previous study (*3*), a system for variable-value control of air temperature by using the natural light intensity as a feedback signal has been newly developed, and it has been found that cucumber plants grown under the variable-value control of air temperature appear healthy, while plant growth under constant air temperature results in succulent growth (i.e. rapid and weak shoot growth). In the present study, different regimes of the variable-value control of air temperature under the natural light were applied to cultivation of lettuce plants (*Lactuca sativa* L.), and air temperature effects on plant growth were analyzed.

MATERIAL AND METHODS

Regimes of variable–value control of air temperature

The system for variable–value control of air temperature in a natural light growth chamber has been developed in the previous paper (*3*). The set values (T_{set}) of air temperature varied with light intensity under a constant relative humidity. An intensity (P) of the natural light incident into the growth chamber was detected by using a PPFD sensor, and the sensor signal was transmitted to a computer. The set value of air temperature was determined in the computer by the following quadratic equation of P.

$$T_{\mathrm{set}}=\frac{T_{\mathrm{i}}-T_{\mathrm{min}}}{P_{\mathrm{i}}^{2}-2P_{\mathrm{max}}P_{\mathrm{i}}}P^{2}-2P_{\mathrm{max}}\frac{T_{\mathrm{i}}-T_{\mathrm{min}}}{P_{\mathrm{i}}^{2}-2P_{\mathrm{max}}P_{\mathrm{i}}}P+T_{\mathrm{min}} \qquad (1)$$

where P_{max} is fixed value of upper limit of P, T_{min} is the value of T_{set} in darkness, and T_{set} is fixed at T_{i} when P is equal to the intermediate value (P_{i}). T_{set} increases quadratically with P. The regime of variable–value control of air temperature depends on the preset values of P_{i}, P_{max}, T_{i} and T_{min} in the computer, and the dependence of T_{set} on P can be altered by changing these preset values. The determination of T_{set} was repeated with an interval of 1 min. The signal of T_{set} in each determination was transmitted to an air temperature controller and held for 1 min. Air temperature in the growth chamber was measured by a thermometer (Pt 100 Ω) and transmitted to the controller for feedback control.

The variable–value control was applied to three natural light growth chambers (Chamber–a, –b and –c) by using different values of T_{min} and P_{i}. In the respective chambers, the values of T_{min} were preset at 18 (a), 16 (b) and 14℃ (c), and the values of P_{i} were preset at 500 (a), 320 (b) and 300 μmol m^{-2} s^{-1} (c). Preset values of $P_{\mathrm{max}}=1500$ μmol m^{-2} s^{-1} and $T_{\mathrm{i}}=20$℃ were common in all the chambers. Figure 1 shows the respective regimes of T_{set} in Chamber–a, –b and –c. T_{set} became higher with increase in P from 0 μmol m^{-2} s^{-1} to P_{max} in temperature regions of 18 to 22℃ (a), 16 to 26℃ (b) and 14 to 32℃ (c). Thus, Chamber–c provided the lowest T_{set} under poor light condition and the highest T_{set} under high light condition. Figure 2 shows time course patterns of the natural light intensity and controlled variables of air temperature on a fair day (December 12, 1996). In darkness, air temperatures in Chamber–a, –b and –c were kept constant at the respective T_{min} of 18, 16 and 14℃. The air temperatures increased after sunrise and reached the maximum values of 19, 22 and 26℃ in chamber–a, –b and –c, respectively. Thus, the lowest night temperature and the largest dynamic range of air temperature were found in Chamber–c.

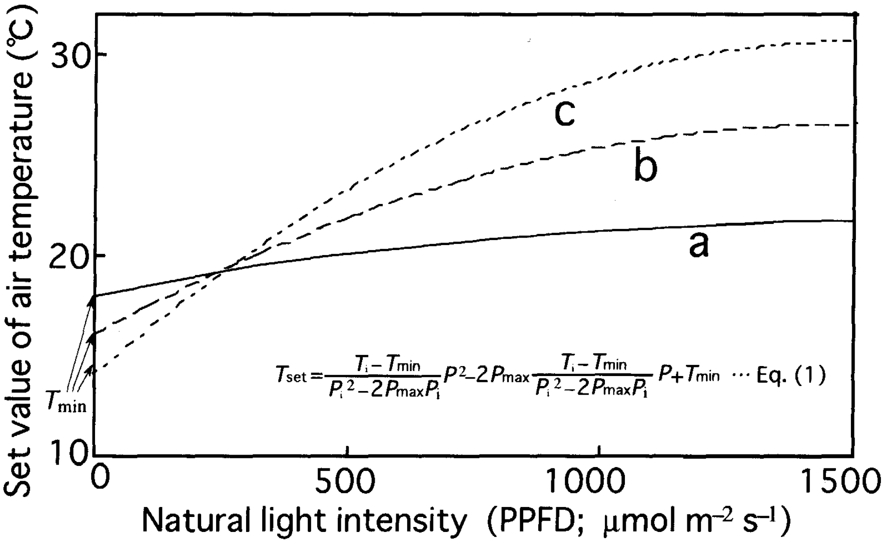

Fig. 1 Set values of air temperature (T_{set}) determined by Eq. (1) under the variable–value controls in the respective growth chambers (a, b and c) : P, measured value of the natural light intensity ; P_i, intermediate value of P; P_{max}, fixed value of upper limit of P; T_i, fixed value of T_{set} at $P=P_i$; T_{min}, T_{set} in darkness.

a : $P_i=500$ μmol m^{-2} s^{-1}, $P_{max}=1500$ μmol m^{-2} s^{-1}, $T_i=20$℃ and $T_{min}=18$℃

b : $P_i=320$ μmol m^{-2} s^{-1}, $P_{max}=1500$ μmol m^{-2} s^{-1}, $T_i=20$℃ and $T_{min}=16$℃

c : $P_i=300$ μmol m^{-2} s^{-1}, $P_{max}=1500$ μmol m^{-2} s^{-1}, $T_i=20$℃ and $T_{min}=14$℃

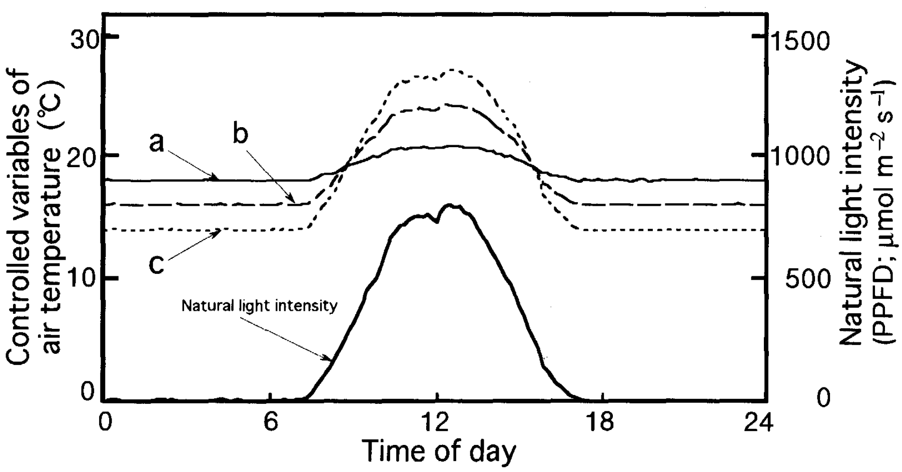

Fig. 2 Time course patterns of the natural light intensity (PPFD) and controlled variables of air temperature on a fair day in the respective growth chambers (a, b and c), where set values of air temperature (T_{set}) were determined by Eq. (1) according to the natural light intensity.

Plant material and growth analysis

Lettuce (*Lactuca sativa* L. cv. Okayama–Saradana) seeds were sown in 14 cm pots with vermiculite on November 8, 1996, and they were germinated at air temperature of 23℃ and relative humidity of 70% in a phytotron glass room. Four cotyledonary plants at 10 days after sowing were transferred into the respective natural light growth chambers, and the plants were grown for 8 weeks under the respective regimes of variable–value control of air temperature at constant relative humidity of 70%. The root medium was moistened enough with a complete nutrient solution (Mg^{2+}, 1.86; Ca^{2+}, 4.10; K^+, 7.63; $H_2PO_4^-$, 1.69; NO_3^-, 15.42; NH_4^+, 1.61 mM with iron–EDTA and micronutrients). Leaf area (LA ; cm^2) of the plants was evaluated at intervals of a week: Length (LL; cm) and width (LW; cm) of each leaf were measured non–destructively, and LA of each leaf was calulated on the basis of the predetemined relationship of $LA = 0.7 \times LL \times LW - 2.4$. After the growing for 8 weeks, leaf fresh and dry weights per plant were measured. Cross section of the matured 15th leaf was made by using a micro slicer (DTK–1500, Dosaka E. M. Co., Ltd., Kyoto), and mesophyll was observed by using an optical microscope (Optiphot–2, Nikon corp., Tokyo).

RESULTS AND DISCUSSION

Figure 3 shows photograph of the lettuce plants grown for 8 weeks in Chamber–a, –b and –c. In general view of the plants, all of the plants appeared healthy. Thus, the temperature regions in all the chambers were estimated to be around the optimum temperature for growth of lettuce plants. Figure 4 shows time course patterns of number of leaves. Differences in number of leaves among Chamber–a, –b and –c were not significant at 5% levels. Thus, leaf emergence was scarcely affected by the regimes of variable–value control of air temperature. Figure 5 shows time course patterns of leaf area. Leaf area

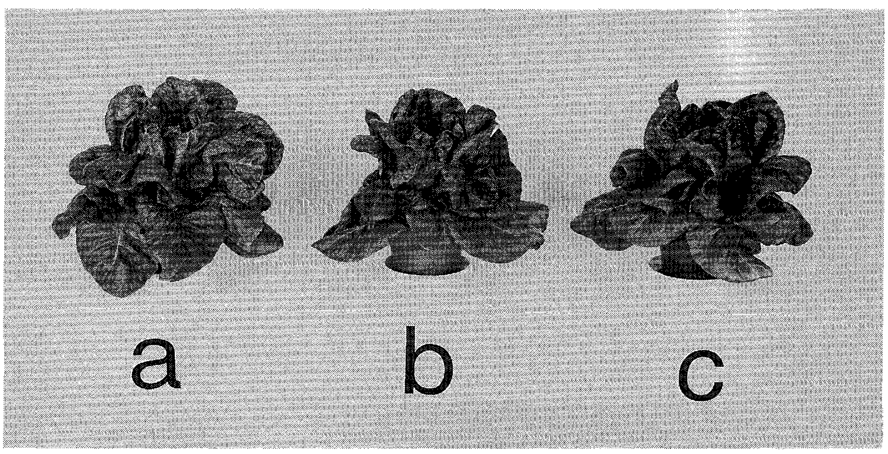

Fig. 3 Photograph of lettuce plants grown for 8 weeks in the respective growth chambers (a, b and c), where set values of air temperature (T_{set}) were determined by Eq. (1) according to the natural light intensity.

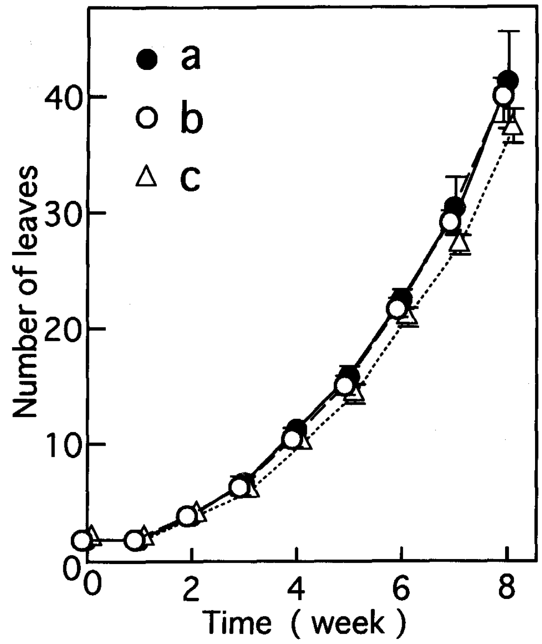

Fig. 4 Time course patterns of number of leaves in the respective growth chambers (a, b and c), where set values of air temperature (T_{set}) were determined by Eq. (1) according to the natural light intensity: The means of measured values in 4 plants were shown with 95% confidence limits.

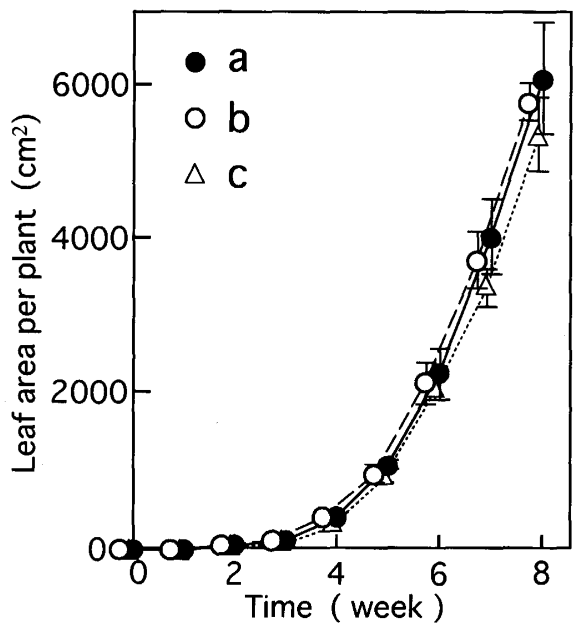

Fig. 5 Time course patterns of leaf area per plant in the respective growth chambers (a, b and c), where set values of air temperature (T_{set}) were determined by Eq. (1) according to the natural light intensity: The means of measured values in 4 plants were shown with 95% confidence limits.

increased rapidly in Chamber–a and –b, and the lower increase rate was found in Chamber–c. The leaf areas at 8 weeks in the respective chambers were 6199 (a), 5882 (b) and 5400 cm^2 (c), and the differences in the leaf area between Chamber –a and –c and between –b and –c were significant at 5% level. Thus, leaf expansion in Chamber–c was slower than those in Chamber–a and –b. Figure 6 shows shoot fresh weight, leaf fresh weight per unit leaf area and dry weight per unit leaf area in the plants at 8 weeks. The shoot fresh weights in the respective chambers became 165 (a), 161 (b) and 158 g (c), and differences among them were not significant at 5% level. The fresh and dry weights per unit leaf area in Chamber–c were larger than those in Chamber–a and –b, and the difference was significant at 5% level. From the results, lower night temperature and larger dynamic range of air temperature as controlled in Chamber–c brought decrease in leaf area and increase in fresh and dry weights per unit leaf area. Consequently, shoot fresh weight in Chamber–c became almost equivalent to those in Chamber–a and –b.

Figure 7 shows thickness of mesophyll in the matured 15th leaf. The leaf grown in Chamber–b and –c became thicker than that in Chamber–a (significant at 5% level). Figure 8 shows micrographs of cross section of mesophyll in typical matured leaves. Thicker spongy layer was found in Chamber–b and –c as compared with Chamber–a, while differences in thickness of palisade layer among Chamber–a, –b and –c were scarcely found. Thus, the well developed spongy layer in Chamber–b and –c brought the leaf thickening, and the leaf

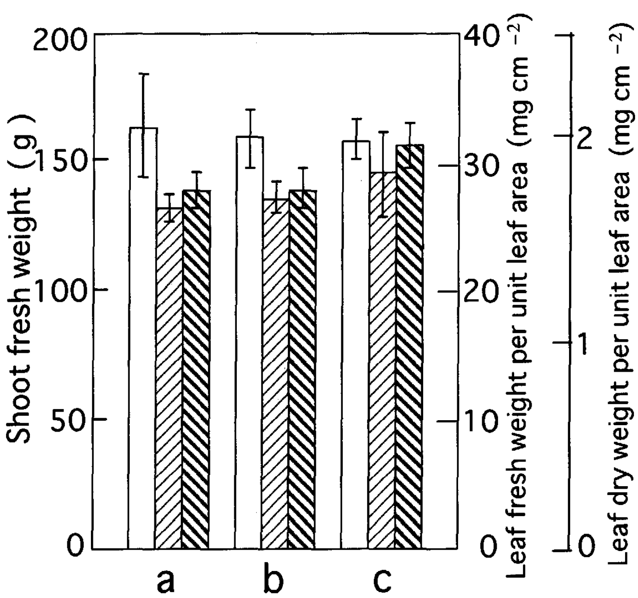

Fig. 6 Shoot fresh weight (□), leaf fresh weight per unit leaf area (▨) and leaf dry weight per unit leaf area (▧) in lettuce plants grown for 8 weeks in the respective growth chambers (a, b and c), where set values of air temperature (T_{set}) were determined by Eq. (1) according to the natural light intensity: The means of measured values in 4 plants were shown with 95% confidence limits.

thickening resulted in the larger fresh and dry weights per unit leaf area.

It is known that respiratory carbon loss in plants depends on air temperature (*5, 10*). Therefore, the excessive carbon loss by respiration can be

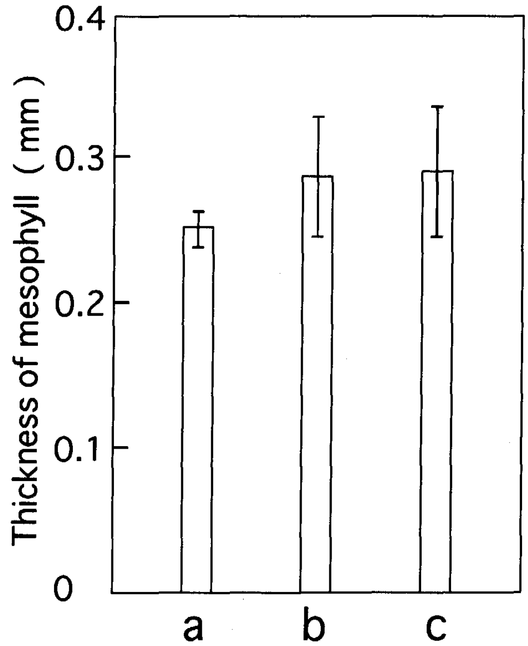

Fig. 7 Thicness of a matured leaf (the 15th leaf) in the lettuce plants grown for 8 weeks in the respective growth chambers (a, b and c), where set values of air temperature (T_{set}) were determined by Eq. (1) according to the natural light intensity: The means of measured values in 3 plants were shown with 95% confidence limits.

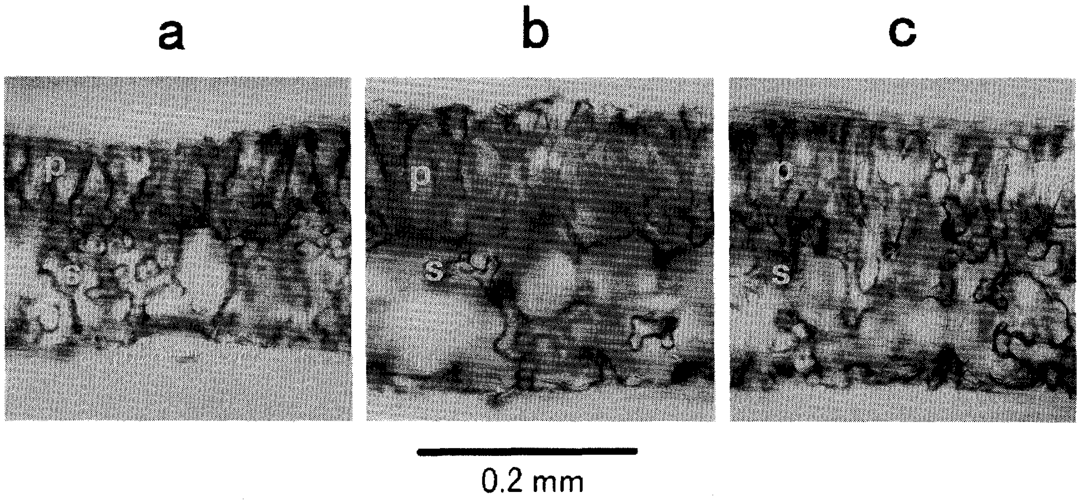

Fig. 8 Micrographs of the cross section of typical matured leaves in the lettuce plants grown for 8 weeks in the respective growth chambers (a, b and c), where set values of air temperature (T_{set}) were determined by Eq. (1) according to the natural light intensity: p, palisade layer; s, spongy layer.

considered to be reduced by lowering air temperature under the condition where photosynthesis is depressed under lower light intensity. In the previous paper (*3*), it has been reported that the variable–value control of air temperature influences on growth of cucumber plants through carbon balance between photosynthesis and respiration. In the present study, it can be estimated that the carbon balance between respiration and photosynthesis in the lettuce plants is improved in the regime of lower night temperature and larger dynamic range of air temperature. In the plants grown in Chamber–c, the leaf thickening with the well developed spongy layer was found, and the fresh and dry weights per unit leaf area became larger. It is known that higher temperatures under poor light conditions induce succulent (tall and weak) tomato plants (*8*), and furthermore it has been found that cucumber plants grown under constant–value control of air temperature become somewhat succulent (*3*). The succulent growth in the lettuce plants was prevented under the regime of lower night temperature and larger dynamic range of air temperature. These facts suggest that the variable–value control of air temperature according to the natural light intensity can improve plant growth under controlled environment.

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