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出版情報：BIOTRONICS. 29, pp.23-31, 2000-12. Biotron Institute, Kyushu University
バージョン：
権利関係：

BIOTRONICS **29**, 23–31, 2000

EFFECT OF ADDITIONAL LOW INTENSITY LUMINESCENCE RADIATION 625 nm ON PLANT GROWTH AND PHOTOSYNTHESIS

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(Received March 12, 2000; accepted April 6, 2000)

KOSOBRYUHOV, A. A., KRESLAVSKI, V. D., KHRAMOV, R. N., BRATKOVA, L. R., and SHCHELOKOV, R. N. *Effect of additional low intensity luminescence radiation 625 nm on plant growth and photosynthesis.* BIOTRONICS 29, 23–31, 2000. Tomato (*Licopersicon esculentum Mill.*) and cabbage (*Brassica oleracea L. var. Cymosa*) plants were grown in a glass greenhouse under natural radiation in summer. A half of pots with plants were placed under an ordinary (control) and the other part under the "Redlight" (experimental variant) polyethylene films, both 100 μm thick. The Redlight film had the same transmittance but transformed 3.5% of ultraviolet light falling on a plant into fluorescent radiation with a main maximum of 625 nm. Plants grown under modified solar radiation exhibited high intensity of photosynthesis at light saturation, a shift of saturation region to the higher level of radiation, as well as high efficiency of photosynthesis under low light intensity. An appreciable increase in the CO_2 assimilation rate and biological productivity under modified light irradiation of plants allows recommending the method of additional plant irradiation under controlled conditions. Under natural irradiation of plants this can be achieved by the use of Redlight film.

Key words: light–transforming film; solar radiation; controlled environment; photosynthetic activity; biological productivity

INTRODUCTION

Light quality is an important factor in the regulation of physiological processes in plants resulting in significant changes in growth and photosynthesis (*15, 3*). Investigations show that even small amounts of low intensity red or far –red light can play considerable role in physiological processes. For example, an increase in the amount of far–red light at the same background irradiance of

white light caused a decrease in the leaf size and the stem lengthening of *Chenopodium album* (*14*). Absorption of far-red radiation by the far-red-absorbing film caused an increase in the leaf size and stem shortening of *Antirrhinums* plants (*7*). Low intensity red light influences the formation of photosynthetic apparatus, synthesis of chlorophyll and other physiological responses (*2, 10*). Increasing irradiation in the 450–800 nm range upon simultaneous lowering of ultraviolet radiation led to an increase in the leaf surface area and accumulation of dry mass by cucumber plants (*6*).

An increase in productivity up to 100% under additional irradiation of plants with red light with maxima at 615 nm (*12*) and 625 nm (*1*) using narrower spectral zones was shown. For this purpose, a film with a fluorescent additive that transformed part of the ultraviolet solar light absorbed by the film into fluorescent radiation in the red spectral range was used.

Under controlled light conditions (the level of PAR=115 Wm^{-2}) the higher rate of CO_2 assimilation was revealed in the case of the lamps with maxima at 620 and 670 nm in red spectral range in comparison with the lamps giving maximum irradiation at 670 nm (*16*). These data also confirm the significance of the spectral range around 620 nm for the growth and development of plants. At the same time physiological mechanisms, ensuring positive effects of additional irradiation at 620 nm on the growth and development of plants, remain unknown.

The principal objective of this study was to understand the peculiarities of CO_2 exchange, efficiency of primary photosynthetic responses, pigment accumulation and growth processes in plants grown under additional luminescent red light with a maximum at 625 nm.

MATERIALS AND METHODS

The Broccoly cabbage (*Brassica oleracea* L. *var. Cymosa,* cv. Tonus), and tomatoes (*Licopersicon esculentum* Mill, cv Beliy Naliv) plants were grown for 32 days in a fixed glass greenhouse at the Institute of Basic Biological Problems. Several cycles of plant cultivation were carried out under natural radiation in summer. The light intensity in the greenhouse in the middle of the day made up 1,000±200 μmol m^{-2} s^{-1} the temperature varied within 25–35℃ in the afternoon and 20–25℃ at night. The plants were grown in 0.5 L pots (one plant per pot) filled with the substrate: peat/sand 1 : 1. Once a week, the plants were watered with the Knope nutrient solution supplemented with microelements. The pots with plants were placed under an ordinary (control) and fluorescent additive-containing (experimental variant) polyethylene films, both 100 μm thick. Red fluorescence in the experimental Redlight film was emitted by small amounts of a rare earth's compound that transformed about 3.5% of ultraviolet radiation, falling on the plants, into the fluorescent radiation with main 625 nm maximum (*12*). Fig. 1 shows the fluorescence spectrum of the Redlight film.

Fluorescence induction curves were recorded by one-ray method (*8*) in the installation consisting of monochromator (±1 nm), photomultiplier, storage oscilloscope (Tektronix, USA) and an Endim 322.01 M recorder (FRG). The leaf

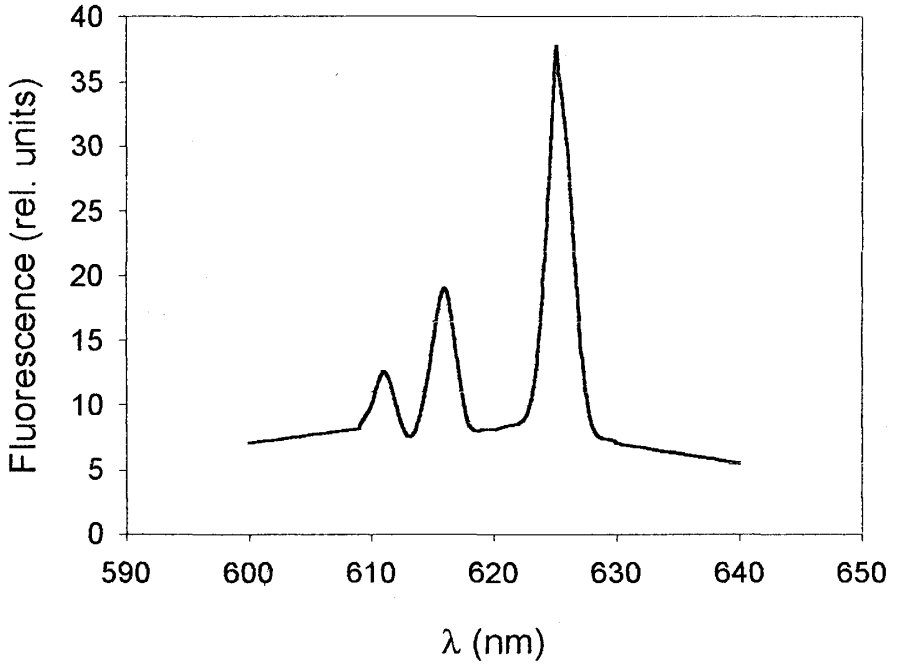

Fig. 1. Fluorescence emission spectrum of Redlight film. The fluorescence was excited at the wavelength 340 nm.

surface was irradiated with blue excitation light (λ_m=480 nm; I=125 μM m^{-2} S^{-1}). The top-third part of the leaf was used. Standard nomenclature of fluorescence parameters was followed Van Kooten and Snel Jan (*18*). Calculated fluorescence parameters included the variable fluorescence yield (F_v), determined as $F_v=F_P-F_o$, the half-rise time $F_v/2$, and the F_v/F_p ratio. The size of plastoquinone pool was determined by estimating the working integral which was defined as a square above the kinetic curve during its rise, normalized to the initial fluorescent level. The leaves of all plants were dark-adapted for 15 min. The light intensity was measured by an RTN 20 radiometer (Optical-Mechanical Association, t. S.-Petersburg, Russia) with a spectral sensitivity range of 180-5,500 nm.

The intensity of CO_2 exchange in the leaves was measured with the help of an infrared ges analytical installation (Ciras-2) or a system with an Infralit-4 gas analyser [*4*]. The content of pigments was determined using a Specord M-40 spectrophotometer (Karl Zeis Jena, FRG) in 80% acetone and calculated by relevant formulas [*9*]. The area of leaves and the weight of the leaves and stems were determined. All experiments were done in 4-6 repeats. The average values were calculated. The differences between the variants wewe estimated at the level 0.95 by the student's t-test. The experimental results were processed using the Excel, Statmost 3^2, and Photosyn Assistant programs [*11*].

RESULTS

The photosynthetic capacity was monitored by measuring the chlorophyll

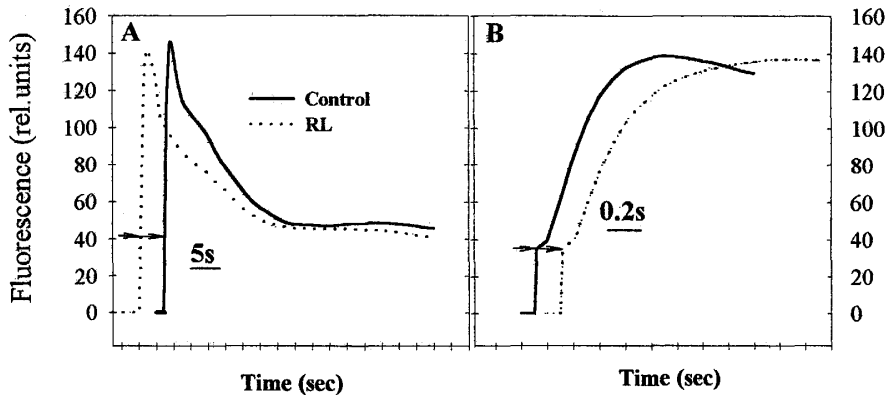

Fig. 2. The chlorophyll fluorescence inductions of completely developed cabbage leaves grown under control and Redlight films. A–slow part; B–fast part. The wavelength of excitation −480 nm and intensity −125 μ mol m^{-2} s^{-1}.

fluorescence induction kinetics (Fig. 2). The fluorescence induction had the typical S–like form and the F_vF_p ratio about 0.74±0.03 that characterized normal occurrence of primary photosynthetic reactions in the control and test plants. The size of the plastoquinone pool was greater in the variant with the Redlight film and was equal to 1.80±0.05 and 1.65±0.04 (rel. units) in the experiment and control respectively. The half–rise time was 1.4±0.2 s in the control and 1.7±0.15 s in the experiment.

The value of the F_p/F_{st} ratio reflecting mainly the efficiency of the processes of dark carboxylation, was also slightly higher in the experiment than in the control and the difference was reliable. These processes in the plants grown under the Redlight film seem to be more effective. At the same time, the difference observed in the PS II activity in both variants, registrated as the F_v/F_p ratio, was insignificant.

The data obtained from slow fluorescence inductions are supported by the results of analysis of light and CO_2 curves of gas exchange in plants. Fig. 3 and Table 1 (calculated by the Photosyn Assistant program) present the results describing the light curves of CO_2 exchange in plants. The plants grown under the conditions of modified solar irradiation are characterized by the high intensity of photosynthesis at light saturation, shift of saturation area to the higher levels of irradiation, as well as high efficiency of photosynthesis in the field of low light intensities. At light saturation, photosynthesis in cabbage made up 12.0±0.2 and 16.8±0.3 μmol CO_2 m^{-2} s^{-1} in tomatoes 5.84±0.1 and 12.9 ±0.3 μmol CO_2 m^{-2} s^{-1} in the control and experiment respectively (under the same conditions). The activity of Rubisco, calculated from the CO_2 curves (Fig. 4, Table 2), was 86.1±2.6 against 72.0±2.2 μmol CO_2 m^{-2} s^{-1} in the test and control variants of cabbage, respectively. In tomato plants, the difference in the activity of Rubisco for both variants was insignificant. The insignificant rise of the Rubisco activity in cabbage leaves could not explain the significant rise of CO_2 assimilation by plants, grown under the light–transforming film. The effective utilization of light by plants in experiment can be explained in many

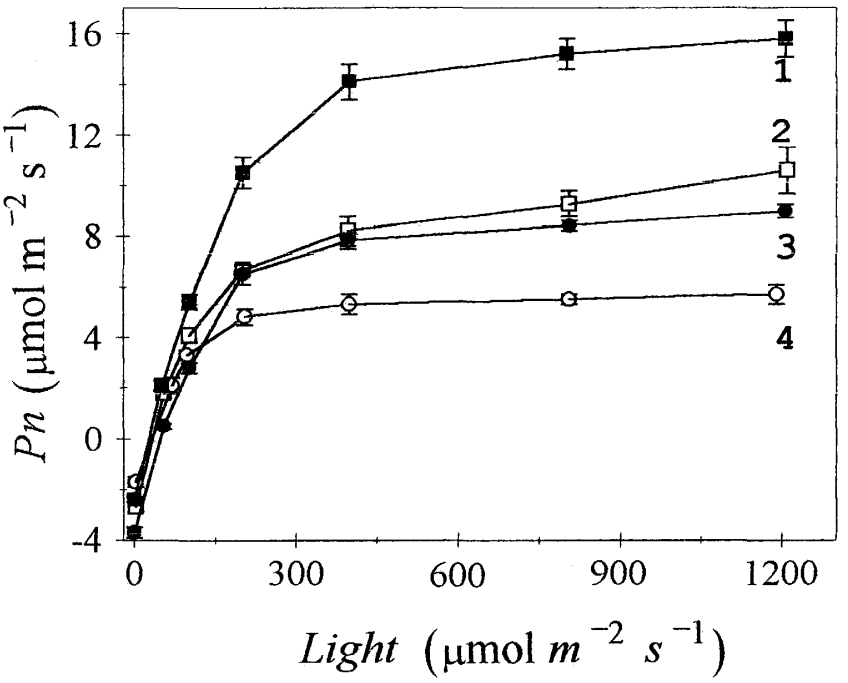

Fig. 3. Light curves of CO_2 assimilation of cabbage (1, 2) and tomato (3, 4) leaves. Plants were grown under changed solar irradiation (1, 3) and under control conditions (2, 4) at intensity of light 1,000±200 μmol m^{-2} s^{-1}.

Table 1. Light curve parameters of plant leaves grown under ordinary polyethelen film and "Redlight" film. Each value is the mean of four-five determination. Asterisks indicate 95% confidence limits.

Parameters	Cabbage		Tomato	
	Control	"Redlight"	Control	"Redlight"
Dark respiration rate, μmol CO_2 m^{-2} s^{-1}	−3.08±0.21	−1.62±0.18*	−1.09±0.15	−2.33±0.12*
Photosynthetic efficiency μmol (Co_2) μmol (photon)	0.0602±0.0022	0.0644±0.0012	0.0429±0.0011	0.0835±0.0014*
Photosynthetic capacity at light saturation μmol CO_2 m^{-2} s^{-1}	12.0±0.2	16.8±0.3*	5.84±0.1	12.9±0.3*
Light compensation point μmol (photon) m^{-2} s^{-1}	51.2±3.2	25.2±2.1*	25.4±1.5	27.9±1.2
Light saturation point μmol (photon) m^{-2} s^{-1}	250±5.4	285±6.2	162±6.6	183±7.2

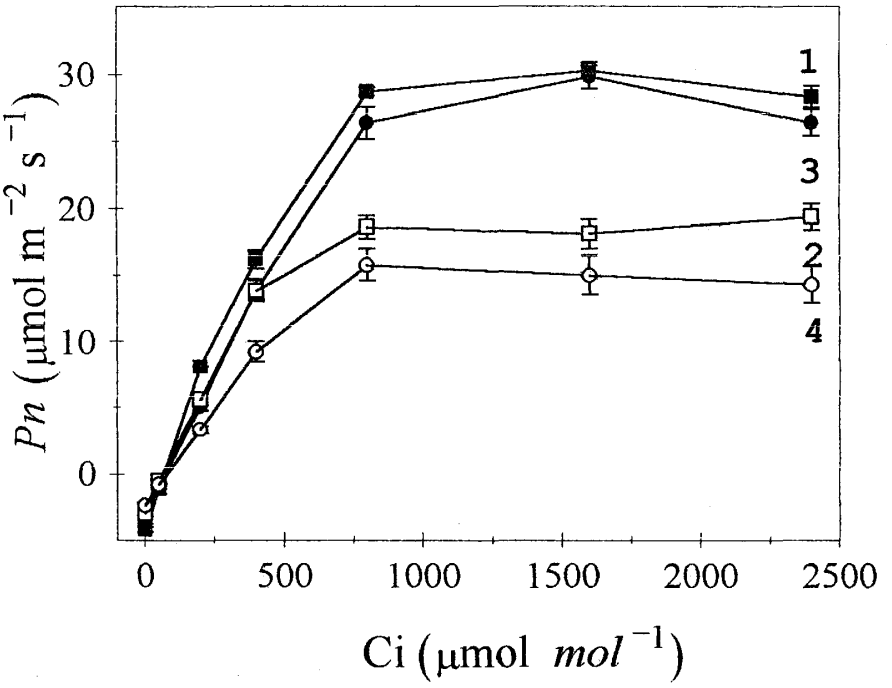

Fig. 4. Carbon dioxide curves of CO_2 assimilation of cabbage (1, 2) and tomato (3, 4), leaves. Plants were grown under changed solar irradiation (1, 3) and under control conditions (2, 4) at intensity 1,000±200 μmol $m^{-2} s^{-1}$.

respects by changes in the structural organization of photosynthetic apparatus under additional red light. The long-term plant cultivation under conditions of additional luminescent irradiation resulted in the increased content of chlorophylls ($a+b$) and in the higher chlorophyll a/b ratio in the cabbage leaves. The cabbage plants accumulated 5.05±0.12 mg dm^{-2} chlorophyll ($a+b$) in comparison with 3.32±0.10 mg dm^{-2} in the control. At additional radiation the chl a/chl b ratio increased from 2.20±0.15 to 2.76±0.2.

Along with the increased content of pigments in plant leaves, a twofold rise of stomatal conductivity was observed in experimental plants in comparison to the control. Hence, the high rate of CO_2 assimilation under conditions of additional irradiation of plants by light with λ_m=625 nm can be connected with a greater accessibility of carbonic acid due to the increased stomatal conductivity.

A positive effect of additional irradiation was observed in the whole plants. Thus, the area of the leaf surface in cabbage made up 0.85±0.14 and 2.22±0.16 dm^2 and in tomatoes −3.12±0.14 and 1.87±10 dm^2 in experiment and control, respectively. The relative area and the specific surface density of leaves varied insignificantly in the experiment and control. Therefore, an increase in biological productivity of plants was due to the bigger fresh mass of leaves and stem in the experiment in comparison with the control.

Table 2. A/Ci curve parameters of plant leaves grown under ordinary polyethelen film and "Redlight" film. Each value is the mean of four–five determination. Asterisks indicate 95% confidence limits.

Parameters	Cabbage		Tomato	
	Control	"Redlight"	Control	"Redlight"
Dark respiration rate μmol CO_2 m^{-2} s^{-1}	2.42±0.21	5.04±0.31*	2.54±0.23	0.91±0.30*
Carboxylation efficiency μmol CO_2 m^{-2} s^{-1}	4.32±0.01	3.25±0.01	6.01±0.26	3.28±0.21*
Maximum rate of carboxylation by Rubisko mol m^{-2} s^{-1}	72.0±2.2	86.1±2.6*	68.4±1.1	67.1±1.2
PAR saturated rate of electron transport μmol m^{-2} s^{-1}	167.0±3.2	196.0±4.5*	103.2±2.4	98.5±3.2
Rate of triosophosphate utilisation μmol CO_2 m^{-2} s^{-1}	9.54±0.22	10.8±0.12	5.23±0.08	6.11±0.12
Photosynthetic capacity at light saturation μmol CO_2 m^{-2} s^{-1}	49.9±1.8	50.55±2.3	33.7±1.2	32.3±2.1
CO_2 compensation point μmol mol^{-1}	6.92±0.25	8.60±0.27	6.92±0.23	5.82±0.12

DISCUSSION

The changes observed in the growth rates took place under conditions of high natural irradiation of plants. The insignificant lowering of ultraviolet radiation under the Redlight film (by 3.5%) could not explain the substantial accumulation of dry mass in plants. Experimental data show that UV–A that mainly passes through the greenhouse glass (1–0.5 cm) and film (1–100 μm) reduces insignificantly the growth of plants and sometimes stimulates it, at least at a high level of PAR (*19*). Hence, the stimulatory effects of the Redlight are likely to be connected with the long–term action of the light with λ_m=625 nm. The regulatory effect of the red light in artificial–light culture with the resonance radiation lines of the lamps at 620 nm and 640 nm was also demonstrated in other studies [*16, 20*]. The red light was shown to cause changes in the plant respiration and CO_2 assimilation activity as well as photochemical activity of chloroplasts [*16*].

The regulatory effect of the red light on plants is often associated with the change in the ratio of two phytochrome forms (*13*). In particular, in the range of 620–640 nm, both forms of phytochrome have high absorption coefficient(*20*). Therefore, upon changes in activity of a number of processes induced by red

light, variations in stomatal conductivity may take place (*13*). The effect of monochromatic irradiation at 600 nm on the synthesis of matrix RNA of heat shock proteins was observed (*7*). The authors suggest the presence of a specific photoreceptor, operating only in response to red light irradiation with the wavelength about 600 nm.

The results obtained point to significant change in physiological parameters due to the stimulating effect of low intensity luminescence (λ_m=625 nm), with a long-term action on plants. In this connection, it is possible to present a scheme of the photoregulation of metabolic processes and plant morphogenesis through the effect of light with λ_m 625 nm on the plant genome.

An essential increase in the CO_2 assimilation rate and biological productivity under conditions of modified light irradiation of plants allows us to use the method of additional plant irradiation under the controlled conditions. Upon natural irradiation of plants, this can be achieved by the use of the Redlight film or the glass with a luminescent additive emitting red light. Under conditions of artificial light culture, the use of the lamps with the resonance line of plant irradiation in the range close to 625 nm may be effective.

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