Thermochimica Acta 394 (2002) 227–231

thermochimica acta

www.elsevier.com/locate/tca

Comparative effects of blue light and red light on the rates of oxygen metabolism and heat production in wheat seedlings stressed by heat shock

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Received 10 September 2001; received in revised form 5 April 2002; accepted 8 April 2002

Abstract

The effect of blue light (BL, bandwidth 420–460 nm) and red light (RL, bandwidth 620–640 nm) on the rates of consumption and evolution of oxygen and rate of heat production of plants after action of high temperature (45 °C during 30 min) was studied. The rate of heat production was used as indicator of plant resistance to the action of unfavourable factors, since this index reflects the. physiological condition. The object of investigation were the seedlings of summer wheat. The blue light compared with red light had favourable effects on the rates of oxygen metabolism. The rate of O_2 evolution of wheat seedlings with blue light was higher by 50% (optimal temperature) and by 60% (after action 45 °C temperature) as seedlings with red light.

The rate of oxygen consumption of seedlings treated by high temperature with blue light was inhibited by 40–45% as control, whereas this index was decreased by 75% in plants after temperature shock with red light. Heat production rate of wheat seedlings grown in blue light was higher than the heat production rate of seedlings grown with red light.

Keywords: Blue and red light; Plant resistance; Heat production; Evolution and consumption oxygen; Microcalorimetry; Seedlings of summer wheat

1. Introduction

Light, being one of the most important factors of the environment, is not only an energetic substrate, but also is a regulator of the physiological processes in plants [1–4].

The literature covers the problems of influence of intensity and quality of light on photosynthesis [1,5–8]. But information about the role of light quality on other energetic and metabolic processes not associated with photosynthesis is lacking.

At present a conception about intercellular polyfunctional action of light as an important regulator of plant activity is developing [4]. It has been shown that the utilization of light energy takes place not only in chloroplast but in the different structures of plant cells. Many photoreceptors and organelles of intracellular membrane energy system participate in this process [4,8–10].

The aim of this work is to study blue and red light influence on the resistance of energetic processes of wheat seedlings to treatment by stress temperature.

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PII: S0040-6031(02)00257-5

The alterations of heat production rate will allow us to obtain the information about plant resistance to stress conditions.

2. Experimental

The subjects of the investigation were the seedlings of the summer wheat (*Triticum vulgare gr.aestivum*). Seeds were disinfected by a 0.5% solution $KMnO_4$ during 20 min, then placed on moist filter paper for determination of germinability. The germinated seeds were put in vessels for growing seedlings. Seedlings were grown in water medium at 25 °C. For the investigation 7-day-old seedlings were used.

Plants were grown in a special box, divided into three light-closed compartments: (1) white light (light source—luminescent lamps LDC-40); (2) blue light (source—luminescent lamps LG-40, bandwidth 420–460 nm); (3) red light (source—luminescent lamps LK-40, bandwidth 620–640 nm). Seedlings were illuminated with photoperiod of light/dark of 12/12 h. The light energy incident upon surface of growth vessels was equal in quanta and in case of the second compartment 2.3 W/m^2, in case of the third compartment 3 W/m^2, the light intensity in the first compartment was 2.6 W/m^2.

To simulate the influence of ecological stress, some seedlings were placed in other vessels with water medium at 45 °C during 30 min. After the action of stress temperature roots were separated from epicotyls (the top parts of seedlings).

The rate of oxygen evolution was measured on the top part of seedlings by the gasometric method (Light Warburg method) [11–13]. The rate of oxygen consumption was measured on excised roots by the dark Warburg gasometric method [11–13]. The data obtained were processed by algorithms described in [11–13].

The rate of heat production of excised roots was measured in a heat conduction calorimeter (Bioactivity Monitor (BAM), Thermometric AB, Jafalla, Sweden) [14]. The excised roots (50 mg) were placed in 3 cm^3 glass vessels with 1 ml water and sealed before thermal equilibration of 15–20 min. So, the measured heat production rate begins at 20 min. Determination of oxygen consumption and evolution rates, and of the rate heat production rate were carried out simultaneously. The data presented in the figures are the average of 5–7 experiments.

3. Results and discussion

As can be seen in Table 1 the oxygen evolution rate of seedlings grown in blue light (BL) was significantly higher than the photosynthesis rate of those grown in white and red light (RL). These data are in good agreement with the literature [1–3,7,15–18]. The analysis of works about the regulatory influence of BL on photosynthetic function shows a broad spectrum of modifications caused by short-wave light in chloroplasts and plants as a whole. The positive influence of BL on photosynthesis is connected to a number of structural and functional modifications of the photosynthetic apparatus under short-wave light [1,7,17]. Illumination by BL of seedlings influences the effective work of electron transfer at the level of photosystems [7,17]. It is known that chloroplasts with blue light possess higher activity of ribulose diphosphate carboxylase in comparison to chloroplasts with red light [19,20]. The influence of quality of light on metabolic pathways of a plant cell was shown. Plants growing on red light contained more carbohydrate, than plants with blue light. Short-wave radiation exhibited specific effects on metabolic pathway of the plants, increasing quantities of proteins and organic acids [16,18]. Recently, works about the regulatory action of light of different spectral composition on hormone complex status of plants have appeared. A considerable accumulation of cytokinins and high activity of PNA-polymerase at plants with blue light was observed [6,9,21]. In a number of works it has been shown that BL is more effective for opening the leaf stoma than RL [9].

Table 1
Effects of the different spectral composition on oxygen evolution of epicotyls of wheat seedlings after temperature stress

Variant	Oxygen evolution rate ($\times 10^{-4}$ mol h^{-1} g^{-1} of wet weight)	
	Control (25 °C)	After action of temperature 45 °C during 30 min
White light	28.6 ± 1	22.5 ± 0.8
Blue light	43.1 ± 15	38.3 ± 1
Red light	27 ± 15	25.1 ± 1

Table 2
Action of blue and red light on oxygen consumption of excised roots of wheat seedlings after high temperature treatment

Variant	Oxygen consumption rate ($\times 10^{-5}$ mol h^{-1} g^{-1} of wet weight)	
	Control (25 °C)	After action of temperature 45 °C during 30 min
White light	35.2 ± 0.5	15.5 ± 0.8
Blue light	34 ± 1	17.5 ± 2
Red light	39.4 ± 1.8	9 ± 1.7

The data on the influence of light quality and thermostability of O_2 evolution rate of wheat seedlings are also given in Table 1. The decrease in oxygen evolution rate after heat treatment was approximately the same independent of spectral composition of light. But the photosynthesis intensity in plants with blue light was almost two times higher than in wheat seedlings grown with red light. So structural and functional alteration of chloroplast and plants as a whole under the influence of blue light resulted in an increase of photosynthesis rate and maintenance of this process at a significant level under the stress of high temperature.

Respiration plays an important role in adaptation of plants to the varying conditions of environment [4,22,23]. According to the data presented in Table 2, the respiration rate of excised roots from plants grown with red light was slightly greater than that of roots from seedlings grown in blue and white light under optimal temperature. The respiration rate of roots treated at 45 °C during 30 min decreased in all plants. However, in roots from plants grown in white light, the respiration rate was inhibited by 50%, in roots from plants grown with red light the inhibition was up to 75%, whereas in roots from plants grown with blue light respiration was inhibited by only 40–45%. This may point to greater stability toward high temperature of plants grown in blue light.

It was somewhat surprising that the rate of oxygen uptake of roots depended on spectral composition. One possible explanation is that the plant tissues are light-conductive and may cause light to be incident on photo-sensing sites of seedlings [24]. The smaller suppression of the oxygen uptake rate of the roots from seedlings grown with BL may be connected with the fact that blue light takes part in regulation of electron transport and in activation of enzymes of respiratory metabolism and stabilization of membranes [4,22].

A great difference in heat production rate was observed in excised roots of wheat seedlings depending on light quality (Fig. 1). Heat production in roots from plants grown on red light was 50% lower in

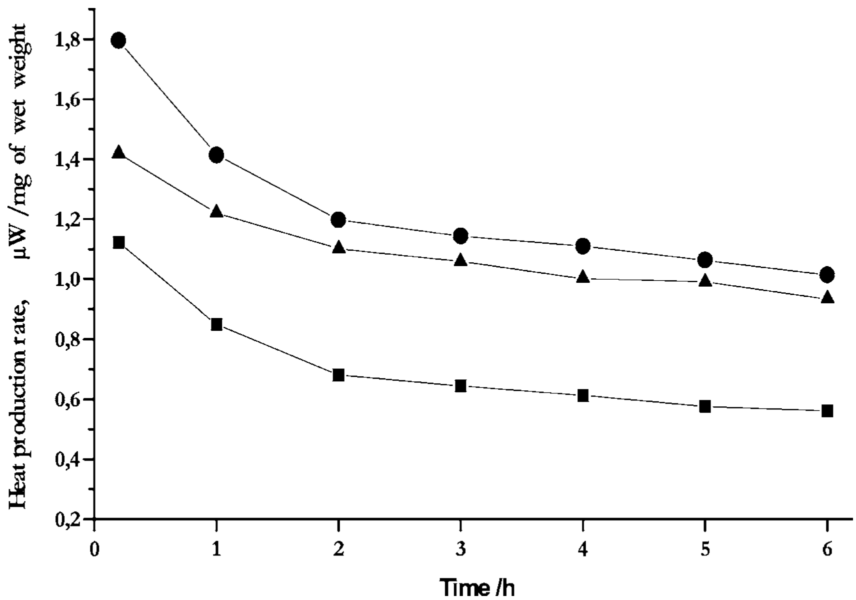

Fig. 1. Action of the light different spectral composition on heat production rate of seedlings: (●) blue light; (■) red light and (▲) white light.

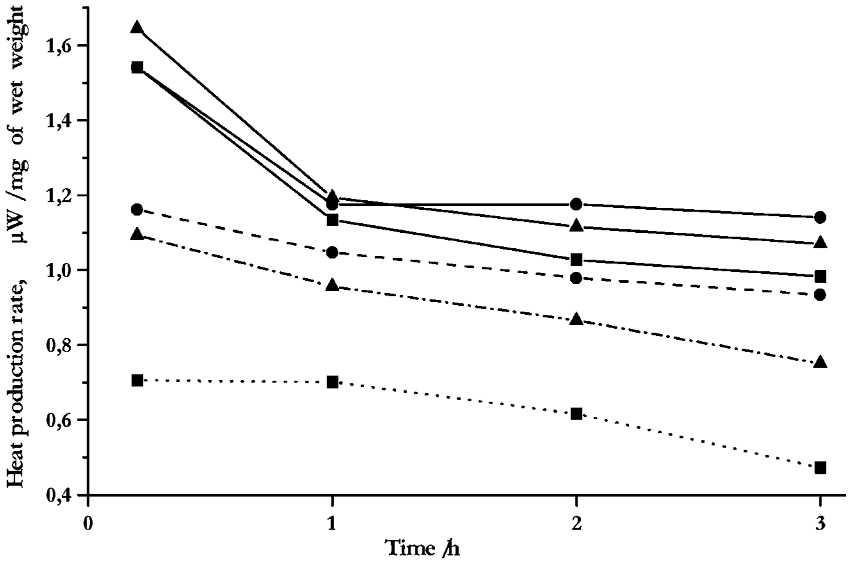

Fig. 2. Action of the light of different quality and temperature on heat production rate of wheat seedlings: (—●—) blue light control; (–●–) blue light + high temperature; (—▲—) white light control; (– - ▲ - –) white light + high temperature; (—■—) red light control; (- ■ -) red light + high temperature.

comparison with heat production in roots from plants grown with blue light. As is seen from the experimental data, the spectral composition of light exerts a regulatory influence on the energy transformation in wheat seedlings under optimal conditions of growth.

The question about the effect of light quality on heat production rate of plants under stress remains. As seen in Fig. 2 the effect of spectral composition of light is clearly observed after the action of the extreme temperature on wheat seedlings. Blue light exerts a positive influence on adaptation of physiological processes in roots treated by high temperature. The heat production rate was almost the same as control values in excised roots from seedlings grown with blue light. In roots from seedlings grown in red light, a sharp decrease of heat production rate was observed. This phenomenon is in good agreement with depression of respiration rate by seedlings grown on red light and treated by high temperature (Table 2).

4. Conclusion

It can be concluded that blue light has a positive effect on resistance of wheat seedlings to high temperature. The increases in the rate of oxygen evolution and oxygen uptake play an important role in resistance of plants to unfavourable conditions, since plants are known to require the addition of metabolic energy expenditure under ecological stress.

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