Heat Shock Increases the Tolerance of Plants to UV-B Radiation: 2. Ethylene and Carbon Dioxide Evolution

T. A. Borisova, S. M. Bugaje, V. Yu. Rakitin, P. V. Vlasov, and Vl. V. Kuznetsov

Timiryazev Institute of Plant Physiology, Russian Academy of Sciences, Botanicheskaya ul. 35, Moscow, 127276 Russia; fax: 7 (095) 977-8018; e-mail: rakit@ippras.ru

Received August 1, 2000

Abstract—The effects of heat shock (HS, 45°C) and UV-B radiation (280–320 nm, 18.3 kJ/(m² h)) and the consecutive action of the combination of these factors on ethylene production, gas exchange, and the growth of intact melon (Melo sativus Sager.) seedlings were investigated. The changes in ethylene production and carbon dioxide exchange were described by a single-peaked curve. In the course of UV-B irradiation, the time of maximum ethylene and CO₂ evolution coincided (the first 5 min) and comprised 0.36 nl/(seedling h) for ethylene and 146.2 μl/(seedling h) for carbon dioxide. After HS, the maximum of ethylene production (0.37 nl/(seedling h)) was reached within 10 min, and that of carbon dioxide production (313 μl/(seedling h)), within 45 min. The rate of ethylene production (0.22 nl/(seedling h)), carbon dioxide production (97.7 μl/(seedling h)), and oxygen consumption (162.5 μl/(seedling h)) in the control seedlings did not change in the course of experiment. Throughout the experiment, the respiratory quotient of seedlings was ca. 0.6 regardless on the nature and duration of the acting factor. Preliminary heating at 45°C for 1 h increased the tolerance of seedlings to the subsequent UV-B radiation for 1 h. The protective effect of HS manifests itself in alleviating the inhibiting action of UV-B radiation on seedling growth and development, and this effect was preceded by an increase in ethylene production and respiration. The possible mechanisms of cross-tolerance of plants to overheating and UV-B radiation are discussed.

Key words: Melo sativus - seedling - heat shock - UV-B radiation - ethylene - respiration

INTRODUCTION

The formation of stress-induced ethylene is one of the most rapid responses of plants to environmental effects [1–3]. Ethylene was shown to be active only in the presence of oxygen [4], it was related to an increase in respiratory gas exchange [5]. The rapid ethylene production and the changes in the rate of respiration seem to indicate a transition of cell metabolism into the stress condition and to the formation of stress-protecting mechanisms.

The production of stress-induced ethylene was observed in various plant species and under the action of various abiotic factors, such as high temperature in cotton [3] and Mesembryanthemum crystallinum [6], as well as UV-B radiation in Arabidopsis plants [7]. Both these factors are particularly important because the global warming and an increase in the UV-B radiation level are directly related to a predicted change in the Earth’s climate [8]. Up to now, most research was focused on the analysis of plant responses to the action of only one of these factors. Many studies were devoted to consecutive or joint action of these factors [3, 8, 9]. Nevertheless, there is no published evidence concerning the participation of ethylene in the formation of general mechanisms of tolerance of plants to HS and UV-B radiation.

With the account of the fact that HS induces the production of ethylene by plants [3] and increases their tolerance to the subsequent UV-B radiation effect [10], our objective was to find out whether stress-induced ethylene participates in the formation of cross-tolerance systems responsible for plant survival under the conditions of overheating and UV-B radiation.

MATERIALS AND METHODS

Three-day-old melon (Melo sativus Sager., cv. Torpeda, Chardjui selection, Uzbekistan) seedlings were used in the experiments. The seeds were germinated on moist filter paper in petri dishes in the dark at 27°C. After seeds germinated for two days, seed coats were removed, and the plantlets were placed in 20-ml flasks (three seedlings per flask) containing 2 ml of distilled water. The flasks were selected using the spectrophotometric analysis (Specord M40, Carl Zeiss, Germany), so that the glass did not transmit light below 280 nm. During the next day, the seedlings were kept in the flasks loosely covered with a PACLAN film (Folien und Haushalts-Produkte GmbH, Germany) at 26–27°C and continuous illumination with LB-100 luminescent lamps (Russia) placed at 50 cm from the plants.

Twenty min prior to the onset of each measurement, water was removed out of flasks. In experiments on HS, the flasks were tightly hermetically sealed with rubber...
stoppers (Septa, Red Rubber, outer diameter of 13 mm, Aldrich, United States). However, rubber turned out to be sensitive to UV-B radiation, and its destruction under these conditions was accompanied by ethylene emission. Therefore, in the experiments on UV-B radiation, the flasks were hermetically sealed with plastic stops equipped with rubber gaskets isolated from UV-B radiation by aluminum foil. To determine the initial level of ethylene and carbon dioxide, the empty flasks were hermetically sealed.

Ethylene production and gas exchange of intact seedlings were determined both during the action of stress agents and after its termination (Figs. 1, 2); the time of treatment is indicated in the figures. Prior to the analysis, the flasks with seedlings were kept in the dark at 27°C using a TCH 100 thermostat (Laboratorni Pristroje, Czech Republic).

The three-day-old seedlings were treated either with HS (45°C, 1 h, a relative humidity of 100%), UV-B radiation (18.3 kJ/(m² h), 5–90 min, a relative humidity of 100%), or with these stress agents consecutively. The HS treatment was performed using a TVZ-25 thermostat (Russia). The seedlings were irradiated using LE-30 luminescence erythema lamps (Russia) in a 280–320 nm spectral range.

Production of ethylene, carbon dioxide, and oxygen exchange were determined from the changes in the gas concentration in the flasks with seedlings using gas-chromatographic methods [11]. A 1-cm³ gas sample taken out of a flask was used for determining carbon dioxide and oxygen content, and the gas remaining in the flask was used for determining the ethylene content. Ethylene and carbon dioxide contents were calculated per fr wt unit and per seedling, and the identical patterns were obtained in both cases. However, the second method of calculation provided more clear-cut differences between the treatments, and these results are shown in the figures.

Six independent experiments were performed, and each treatment was repeated two or more times. The figures represent the means; standard errors in Figs. 2 and 3 did not exceed 10%. In some cases, for the sake of convenience, the results were expressed as the percentage of the control.

RESULTS

Our preceding communication [10] reported the data on the effects of HS, UV-B radiation, and their consecutive action on the growth and development of melon seedlings. Stimulating (weak), retarding (moderate), and lethal (strong) stressor doses were found, and the preliminary HS treatments (45°C, 1 h) were