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RESEARCH PAPER

Characteristics of Photosynthesis in Wheat Cultivars with Different Sensitivities to Ozone Under O_3-Free Air Concentration Enrichment Conditions

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Abstract: With the help of the Chinese Ozone-Free Air Concentration Enrichment (O_3FACE) platform, the responses of photosynthsis characteristics to elevated O_3 concentration were investigated using winter wheat (*Tritcium aestivum* L.) cultivars Yannong 19 and Yangmai 16, which differ in sensitivities to O_3. Under O_3 treatment for 75 d, the net photosynthetic rate (P_n), stomtal conductance (G_s), and transpiration rate (T_r) decreased significantly in both cultivars, whereas the intercellular CO_2 concentration (C_i) changed slightly. The O_3-sensitive cultivar Yannong 19 had larger reductions in P_n (61.1%), G_s (68.0%), and T_r (57.4%) than Yangmai 16 (27.9%, 37.5%, and 27.9%, respectively). This indicated that the reduction of P_n mostly resulted from the nonstomatal factors in cooperation with stomal factors. In the chlorophyll fluorescence parameters, the maximal photochemical efficiency of PSII in the dark (F_v/F_m), the potential activity of PSII (F_v/F_o), the photochemical quenching (q_P), and the rate of photochemical reaction (P_{rate}) decreased in the O_3 treatment, but the nonphotochemical quenching (NPQ) and the rate of thermal dissipation (D_{rate}) showed a upward tendency. The change tendency of total soluble protein content and the amount of Rubisco was similar to that of chlorophyll fluorescence parameters and P_n. The results implied that the major nonstomal factors responsible for the P_n decrease under elevated O_3 concentration were the Ribulose-1,5-bisphosphate (RuBP) carboxylation limitation and the damage of PSII. The change extents of all the parameters were larger in Yannong 19 than in Yangmai 16. The high T_r value and slow reduction of Rubisco amount in Yangmai 16 are probably crucial reasons for its high photosynthetic rate.

Keywords: Ozone; Wheat; Photosynthesis; Chlorophyll fluorescence; Soluble protein; Rubisco

The tropospheric ozone (O_3) concentration is rising at a rate of 0.5–2.5% per year due to anthropogenic activities, and it will exceed 60 nL L^{-1} at the mid-twenty-first century. Especially in eastern China, O_3 concentration is predicted to increase by 50% by 2030 [1–3]. Ozone has been recognized as a secondary phytotoxic pollutant that is gained wide concern in agriculture due to its effects on physiology, growth, and yield of crops [4–7]. Therefore, it is crucial to understand the effects of chronic O_3 exposure on plant growth, development, photosynthesis, and yield.

Photosynthesis is one of the most important physiological processes affected in sensitive crops by excess O_3 [8]. Numerous studies have been conducted to investigate the effects of elevated O_3 concentration on photosynthesis. Calatayud et al. [9] found that elevated O_3 concentration could inhibit photosynthesis and reduce net photosynthetic rate (P_n) of plants after a long-term exposure. Guo et al. [10] reported that the reduction in photosynthetic capability resulted from the limitation of CO_2 and H_2O entering cells due to the decrease in stomatal conductance. Besides, Farage and Long [11] suggested that the decline of Rubisco activity in wheat (*Triticum aestivum* L.) is the main reason for the photo-

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inhibition of leaves under O_3-Free Air Concentration Enrichment (O_3FACE). However, in lettuce (*Lactuca sativa* L.), the limitation of stomatal conductance and the decrease of mesophyllic CO_2-fixation ability were responsible for the decline of CO_2 assimilation when the lettuce plants were exposed to elevated O_3 [12]. Yao et al. [13] also revealed that the reduction of P_n is related to both stomatal and nonstomal limitations with open-top chamber (OTC) platform. Although the effects of elevated O_3 concentration on plant photosynthesis have been widely studied with environment-controlled chambers, the conclusions are not ascertained due to the difference between free-air field and environment-controlled chambers. Compared to the environment-controlled facilities, O_3FACE can provide undisturbed field conditions and more reliable measurements. Therefore, the O_3FACE platform is in favor of predicting the real responses of plants to elevated O_3 concentration.

Wheat is one of the staple food crops in the world. Unfortunately, it is believed to be very sensitive to O_3 [14]. The response of wheat to O_3 varies among cultivars with different sensitivities to O_3 [15]. In this study, 2 winter wheat cultivars, Yannong 19 and Yangmai 16, were used to investigate the responses of photosynthsis characteristics to elevated O_3 concentration with the Chinese O_3FACE platform. The objectives of this study were to gain further insights into the mechanism of the O_3-tolerent cultivars.

1 Materials and methods

1.1 Experimental site and experiment design

The O_3FACE facilities in the rotation system of rice (*Oryza sativa* L.) and wheat are located at Maling Village (32°35′5″N, 119°42′0″E) of Jiangdu City, Jiangsu Province, China. The experimental site is an example of a subtropical marine climate with the mean annual precipitation of 980 mm, mean annual evaporation no less than 1100 mm, mean annual average temperature of 14.9°C, the total annual sunshine time more than 2100 h, and the frostless period of 220 d.

To minimize the O_3 contamination between treatments, the O_3FACE was set 90 m away from the ambient air rings. For the O_3FACE rings of 14.5 m in diameter, pure O_3 was released towards the center of each ring from a large number of portholes (0.5 × 0.9 mm) evenly distributed along the octahedral vent pipes. The octahedral vent pipes were horizontally surrounded the experimental area and approximately 50–60 cm above plant canopy.

The O_3FACE system had 3 O_3FACE rings and 3 similar ambient rings. The O_3 concentration in the center of the O_3FACE plots was controlled as 1.5 times, with 10% error, of the ambient air by a computer system. The ambient air rings were in normal atmosphere as nature. The O_3 treatment duration, from March 5 to May 27, 2008 except for April 29 because of pipe failure, is approximately 83 d. The O_3 concentration dynamics in O_3FACE and ambient air are shown in Fig. 1.

The O_3-sensitive wheat cultivar, Yannong 19, and the O_3-tolerant cultivar, Yangmai 16, were sown on November 13, 2007 at a density of 2.25 million seedlings per hectare with row space of 25 cm. The photosynthetic parameters were measured at 9:00–11:00 of the 55th (April 28, 2008), 65th (May 9, 2008), and 75th day (May 19, 2008) after O_3 treatment. The same leaves were sampled for the measurements of physiological parameters.

1.2 Methods for measurements

1.2.1 Gas exchange parameters In each cultivar, net photosynthetic rate (P_n), stomatal conductance (G_s), transpiration rate (T_r), and intercellular CO_2 concentration (C_i) were measured with 5 uppermost fully expanded leaves per ring using a LI-6400 portable photosynthesis system (Li-Cor, Lincoln, NE, USA). Measurements were taken at the air CO_2 concentration under photosynthetic photon flux density of 1200 μmol s^{-1} m^{-2} when the ambient temperature was 25°C and the air relative humidity was 45%.

1.2.2 Chlorophyll fluorescence parameters Using the identical leaves for the measurements of gas exchange parameters, the readings of FMS-2 portable fluorometer (Hansatech, UK) were obtained in the subsequence of a 20-minute predarkness, including minimal fluorescence (F_o), maximal fluorescence (F_m), maximal fluorescence in the light (F_m'), fluorescence in the stable state (F_s), efficiency of light energy transformation of PSII (F_v/F_m), potential activities of PSII (F_v/F_o), photo chemical quenching (q_P), and nonphotochemical quenching (NPQ). The relative limit of photosynthesis (L_{PFD}), photochemical reaction rate (P_{rate}), and thermal dissipation rate (D_{rate}) [16] were calculated from the chlorophyll fluorescence parameters measured, using the following equations: $L_{PFD} = 1 - [q_P \times (F_m' - F_s) / F_m'] / 0.83$, $P_{rate} = (F_m' - F_s) / F_m' \times q_P \times PFD$, $D_{rate} = [1 - (F_m' - F_s) / F_m'] \times PFD$, where *PFD* is the photo flux density. Each value of the parameter is the average of 5 replicates.

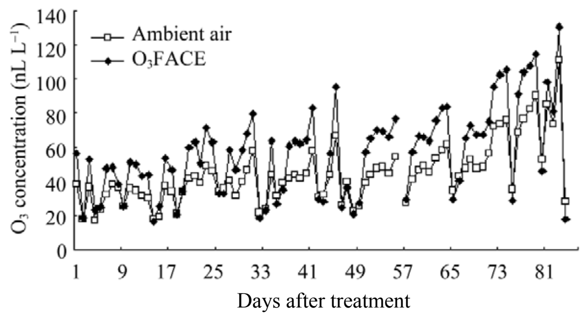

Fig. 1 Changes of O_3 concentration under O_3FACE and ambient air conditions during the experiment

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