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Dynamic change of wheat eco-physiology and implications for establishing high-efficient stable agro-ecosystems under Hg stress

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ABSTRACT

Heavy metal-poisoning exerts the serious influence on crops growth, yield and quality. This research has focused on the impacts of $HgCl_2$ with different concentrations on the dynamic trends of photosynthesis, transpiration and water use efficiency (WUE) by using different wheat varieties as materials. The results showed that under 100 μM $HgCl_2$ treatment, wheat leaf photosynthetic rate (Pn) and transpiration rate (Tr) exhibited significant changes, but photosynthetic characteristics presented no obvious regularity, and this kind of impact exerted the critical effects on different Hg^{2+} concentrations. Similar changes sometimes appeared under low concentration and concentrations. WUE changed more regularly, and WUE of each wheat variety tended to drop after Hg^{2+} treatments, except the individual concentration treatment. This change indicated that $HgCl_2$ treatment changed normal transpiration and photosynthesis, which led to the changes in leaf water use efficiency and related wheat eco-physiological parameters. All these results provide valuable information for establishing high-efficient stable agro-ecosystems in abiotic-stress area.

1. Introduction

Throughout their life cycle, the growth and development of agricultural crops can be affected by a myriad of adverse stress, such as drought stress (Pei et al., 2010), salt stress (Wang and Wang, 2012) and heavy metal stress (Feng et al., 2002; Ko et al., 2013; Song et al., 2013). With the rapid development of modern industrial and agricultural production and increasing population, a growing number of heavy metal pollutants enter into ecological systems (Stom et al., 1991; Ye et al., 2013; Yanez-Arancibia et al., 2014). Environmental effects and biological consequences that could occur due to possible changes in water chemistry, would lead to deterioration of water quality and reduction of its biological productivity and destruction of ecosystem functions (Hao et al., 2013; Zhang et al., 2009; Weinstein and Day, 2014). Moreover, heavy metal in water would pollute the agricultural lands in the immediate vicinity of the river or lake (Zimmer et al., 2011; Spasovski et al., 2012; Zheng et al., 2013; Palmera and Davies, 2014). Among all the heavy metal ions polluting the ecosystems, mercury ion (Hg^{2+}) holds the highest toxicity (Comino et al., 2009; Zhang and Shao, 2013; Zuo et al., 2013; Salem et al., 2014). As one of the essential factors for optimum crop growth, soil can rapidly absorb and fix over 95% of Hg^{2+} (Jing et al., 2006; Liu et al., 2012). Some researchers showed that after entering into crop fields, mercury ions mainly deposit in the surface layers of soils, further influencing agro-ecosystems (Sparke et al., 2011; Mitsch, 2013); and because of their small mobility, most mercury ions entering soil in the form of $HgCl_2$ can be absorbed and adhered by organic matters and clay minerals (Zuo et al., 2013; Shang et al., 2000; Duong and Han, 2011), thus bringing about lasting toxicity in crops. The toxicity exerted by mercury ions on plants leads to the inhibition of cell division and plant growth, and the stimulation and suppression of some enzymatic activities (Yang et al., 2002; Anna et al., 2013; Gupta et al., 2012; Muddarisna et al., 2013; Wu et al., 2012). In addition, mercury ions can also affect chlorophyll content, activities of root systems, and free proline content in crops (Liu et al., 2004; Deng et al., 2013; Debeljak et al., 2013; Górska-Czekaj and Borucki, 2013; Verbruggen et al., 2009). Plants have evolved

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diverse-defensing mechanisms to cope with heavy metals, such as extrusion, chelation, vacuolar sequestration and regulation of distribution (Verbruggen et al., 2009; Singh et al., 2010; Demim et al., 2013; Huang et al., 2000). Other researches also indicated that mercury ions can bring about severe effects on water transportation in individual plants and plant organs through influencing water channel proteins from a molecular perspective (Daniels et al., 1996; Agre et al., 1998; Zhang et al., 2012); and under the existence of sub-mM levels' $HgCl_2$ concentrations, water conductance in plant root systems can be 60–90% lower than that of controlled group (Martre et al., 2001; Quiñones et al., 2013). The above-mentioned researches revealed to a certain extent that mercury ions affect the physiological characteristics of various types of crops, such as wheat (Li et al., 2013;), *Medicago truncatula* (García de la Torre et al., 2013), and maize (Gupta et al., 2012; Muddarisna et al., 2013; Liu et al., 2004). However, only a few researches concern on the effects of mercury ions on crop WUE and its relevant physiological process, especially that such issue as the performances of photosynthetic rates, transpiration rates and water use efficiencies of different types of drought-tolerant wheat varieties under different concentrations of mercury stress still remains unrevealed.

In this research, different wheat varieties were selected as experimental materials, hydroponics experiments were conducted under different concentrations of $HgCl_2$ through simulating the effects of different Hg^{2+} concentrations on photosynthetic rates, transpiration rates and water use efficiencies of wheat varieties, and the effects of these indices on seedling growth and physiological characteristics were analyzed so as to lay a solid foundation for relevant further study concerning the physiological, toxicological and molecular mechanisms of Hg effects for establishing a high-stable agro-ecosystem.

2. Materials and methods

2.1. Experimental materials

Four typically representative winter wheat varieties, namely Shi4185 (S4), Jinmai47 (JM), Shijiazhuang8 (S8) and Xifeng20 (XF) were selected as experimental materials, and measurements of relevant physiological indexes were conducted. Varieties S4 and S8 represent water land varieties, which possess such quality characteristics as half-winter, middle-ripped, seedlings with half-creeping stems and strong tillering abilities. Variety S4 generates relatively high yields under the conditions of high water and fertilizer supply with low a planting density, while variety S8 possesses excellent resistance, comprehensive disease-resistance, and widespread adaptations, constituting a combined-typed variety. Varieties XF and JM belong to drought-resistance varieties, holding such characteristics as creeping seedlings, compact plant types and strong tillering, drought-resistance, cold-resistance and lodging-resistance, and adapting to sowing in dry lands.

2.2. Methods for wheat cultivation

Wheat seeds were selected, were soaked in 0.1% $HgC1_2$, were sterilized under 25 °C, absorbed water for 16 h, and then were placed in incubators for 2-day germination. The germinated seeds were placed into vermiculite-filled white plastic boxes for soil culture. After growing into the two-leaf stage, seedlings with consistent growing conditions, seedling weight and stem and leaf length were selected and placed into triangular flasks. The bases of the seedlings were sponge-bound or cotton-bound, a small hole was left for seedling leaves to pass through, and the outside of each triangular flask was bound by black plastic bags for light avoidance. The seedlings were cultured through applying 1/2 Hoagland nutrient solution, which was replaced every 3d. Then, the seedlings were cultured in artificial climatic chambers (26 °C day/22 °C night, with an illuminating time of 14-h/d) with an illumination intensity of 400 mmol m^{-2} s^{-1}. When the seedlings grew into the three-leaf stage, experiments for Hg treatment were conducted.

2.3. Experiments for Hg treatment

Six treatments were set in this experiment: CK (Hoagland nutrient solution), 25-$HgCl_2$ (Hoagland nutrient solution +25 μM $HgCl_2$), 50-$HgCl_2$ (Hoagland nutrient solution +50 μM $HgCl_2$), 100-$HgCl_2$ (Hoagland nutrient solution +100 μM $HgCl_2$), 300-$HgCl_2$ (Hoagland nutrient solution +300 μM $HgCl_2$), and 500-$HgCl_2$ (Hoagland nutrient solution +500 μM $HgCl_2$). Five seedlings were remained in every triangular flask and every treatment had 6 replications. The experiments were conducted in 9:00 in the morning, each triangular flask was added with prepared solution, the seedlings were placed into the triangular flasks and the triangular flasks were cultured in artificial climatic chambers.

2.4. Methods for the calculation of Pn, Tr and WUE in seedling leaves

Wheat seedlings were treated under different $HgCl_2$ concentrations at different times (0, 15, 30, 45 and 60 min), and the measurements of such indexes as photosynthetic rate (Pn, μmol/m^2 s) and transpiration rate (Tr, mmol/m^2 s) were implemented in flag leaves through utilization of Li-6400 Portable Photosynthetic System manufactured by LI-COR 6400, Largo Vista Group Ltd, USA. For each measurement, 3 seedlings were randomly chosen and 3 replications were conducted under the following conditions: gas flow amount: 500 μmol/s, CO_2 concentration: 385 ± 5 mm^3/dm^3, and room temperature: 26 ± 2 °C. An internal light source (with an illumination intensity of 500 μmol/m^{-2} s^{-1}) was set for the measurements, and the instant leaf WUE (WUE, μmol/mmol) was calculated according to the following formula:

$$\mathrm{WUE} = \frac{\mathrm{Pn}}{\mathrm{Tr}} \quad (1)$$

3. Results

3.1. Changes in Pn for different varieties with concentrations of $HgCl_2$ treatments

Pn (photosynthetic rate) values of varieties S4, S8, JM and XF were measured under different concentrations of $HgCl_2$ treatment at different times, and the results for the measurements were shown in Fig. 1. According to Fig. 1, under different concentrations for treatment at different times, Pn values were different, but these values generally fluctuated around Pn value of CK (Pn_{ck}).

As for variety S4, within 15 min after $HgCl_2$ treatments, compared with such values of CK (Pn_0), Pn_{25} (Pn value under 25 μM $HgCl_2$ treatment), Pn_{50} (Pn value under 50 μM $HgCl_2$ treatment) and Pn_{500} (Pn value under 500 μM $HgCl_2$ treatment) of this variety declined significantly, while Pn_{100} (Pn value under 100 μM $HgCl_2$ treatment) and Pn_{300} (Pn value under 300 μM $HgCl_2$ treatment) of this variety enhanced significantly. From 15 to 30 min after $HgCl_2$ treatments, Pn_{50} and Pn_{500} started to increase, while Pn_{100} and Pn_{300} started to decrease until the end of 60 min measurement, and 30 min after $HgCl_2$ treatments, Pn_{500} basically remained increase, while Pn_{25} and Pn_{50} increased until 45 min