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Characterization of photosynthesis of flag leaves in a wheat hybrid and its parents grown under field conditions

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Summary

Two wheat cultivars, one with high yield and the other with a high tolerance against oxidative stress, were compared with a hybrid of these two cultivars by investigating their photosynthetic characteristics of flag leaves. From the beginning of flowering to the 17th day, CO_2 assimilation rate (P_{max}) was maintained and there were no appreciable differences between the hybrid and its parents. P_{max} showed no decrease at noon compared to that in the morning. From the 20th to the 30th day of flowering, P_{max} decreased significantly, and this decrease was significantly less in the hybrid than in its parents. The actual photosystem II (PSII) efficiency (Φ_{PSII}) and the maximal efficiency of PSII photochemistry (F_v/F_m) showed a significant decrease only on the 30th day after anthesis; this decline was much less marked in the hybrid relative to its parents, both in the morning and at noon. A decrease occurred in Φ_{PSII} and F_v/F_m at noon when compared to that in the morning, but this decrease was less marked in the hybrid than in its parents. Rubisco activity decreased significantly from the 13th day of flowering and was higher in the morning than at noon both in the hybrid and its parents. However, the hybrid always showed a higher value of Rubisco activity. The activities of posphoenolpyruvate carboxylase and pyruvate phosphate dikinase showed similar changes to those in Rubisco activity, particularly from the 20th to 30th day. The results of this study suggest that the higher

Abbreviations: Chl, chlorophyll; F_v/F_m, maximal efficiency of PSII photochemistry; Φ_{PSII}, actual PSII efficiency; P_{max}, light-saturated CO_2 assimilation rate; PEPcase, phosphoenolpyruvate carboxylase; PSII, photosystem II; PPDK, pyruvate phosphate dikinase; Rubisco, Ribulose-1, 5-bisphosphate carboxylase/oxygenase

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photosynthetic capacity of the flag leaf in the hybrid can help to accumulate more dry material, and may be the physiological basis for higher yield over its parents.

Introduction

During the last several decades, the canopy structure of wheat has been greatly improved and the leaf area index is relatively high. In addition, the ratio of economic yield to above-ground crop biomass, i.e. the harvest index, is also relatively high. Thus, in order to achieve further increase in wheat yield potential, the rate of biomass production must be improved (Reynolds et al., 2000, Richards, 2000). Although there are many factors that affect biomass production, the efficiency with which solar radiant is transformed into biomass, and the amount of solar radiation available, are the most important (Russell et al., 1989). In general, it has been recognized that the photosynthetic performance of agricultural crops must be improved in order to increase the rate of biomass production and the yield potential (Horton, 2000; Reynolds et al., 2000; Richards, 2000).

Indeed, recent studies have shown that there is an association between wheat yield progress and higher photosynthetic rate (Blum, 1990; Reynolds et al., 1994; Watanabe et al., 1994; Fischer et al., 1998). Because the flag leaf assimilates are the most important contributor to the dry weight accumulation in grains (Evans et al., 1969; Austin et al., 1977; Makunga et al., 1978), improving photosynthetic capacity of flag leaf in order to increase crop yield has been the subject of many studies. It has been proposed that selection for higher photosynthetic capacity than those of recombinant parents among their progeny may increase crop productivity (Nelson, 1988). Recent research has further supported this proposal. It has been shown that there is a genetic gain in yield in response to selection for flag-leaf photosynthetic rate in F_5 sister lines, and that there is also a linear percentage increase between photosynthetic rate and yield and biomass (Gutierrez-Rodríguez et al., 2000). This study suggests that selection for superior photosynthesis as a trait would possibly increase wheat yield, at least when yield is mainly assimilate-limited. Reynolds et al. (2000) proposed that, by selecting parents with superior photosynthetic traits and other high yielding agronomical characteristics, as well as by promoting large numbers of progeny in the breeding process, there is a chance of identifying phenotypes with higher radiation use efficiency and higher yield potential.

Wheat is a particularly important agricultural crop in northern China. However, wheat production in northern China suffers from a continental hot, dry wind, usually in the end of the growing season (from late May to early June). Since such weather coincides with the grain-filling process and hot, dry wind combines with high sun light during a sunny day, photo-oxidative damage often occurs to photosynthetic apparatus and leaves, resulting in a significant adverse effect on grain-filling process and a decrease in wheat yield. Therefore, a cultivar which has not only superior photosynthetic traits and high yield, but also high resistance to photo-oxidative stress is potentially very important to wheat production in northern China.

Several years ago, we initiated a wheat breeding project. The overall objective was to obtain new wheat varieties with high yielding characteristics in northern China. To this end, we selected two cultivars as parents for hybridizing. One is Jing-411, a cultivar with high yield and superior photosynthetic traits under favorable environmental conditions, but lacking high resistance to photo-oxidative stress. The other is Xiaoyan-54, a cultivar with high photo-oxidative resistance but a normal yield (Wang et al., 2000). We have successfully selected a hybrid (1–12) from the progeny (F_3) by crossing Xiaoyan-54 (maternal parent) and Jing-411 (paternal parent). Plot experiments in the field have shown that this hybrid is a potential wheat variety, since it has higher yield than its parents when grown in Beijing in northern China.

The objective of this study was to investigate the physiological basis of the high yield of the hybrid, as this physiological basis would be of significance for wheat breeding as a possible selection indicator. Thus, we examined the changes in photosynthetic rate, stomatal conductance, photosystem II (PSII) photochemistry, and the activities of several key enzymes involved in the CO_2 fixation process in the flag leaves of the hybrid and its parents grown under field conditions.

Material and methods

Plant materials

The winter wheat (*Triticum aestivum* L.) hybrid 1–12 was selected from the F_3 progeny of a crossing