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RESEARCH ARTICLE

Photosynthetic characteristics and nitrogen distribution of large-spike wheat in Northwest China

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Abstract

The leaf photosynthesis and nitrogen (N) translocation in three large-spike lines and control cultivar (Xi'nong 979) of winter wheat (*Triticum aestivum* L.) were studied in 2010–2011 and 2011–2012. The objectives of this study were to investigate the differences in the physiological characteristics of large-spike lines and control cultivar and identify the limiting factors that play a role in improving the yield of breeding materials. The average yield, grain number per spike, kernel weight per spike, and 1 000-kernel weight of the large-spike lines were 16.0, 26.8, 42.6, and 15.4%, respectively, significantly higher than those of control. The average photosynthetic rates (P_n) were not significant between the large-spike lines and control cultivar during the active growth period. The average PSII maximum energy conversion efficiency (F_v/F_m), PSII actual quantum efficiency (Φ_{PSII}), photochemical quenching coefficient (q_P), PSII reaction center activity (F_v'/F_m') and water-use efficiency (WUE) of the large-spike lines were 1.0, 5.1, 3.6, 0.8, and 43.4%, respectively, higher than those of the control during the active growth stages. The N distribution proportions in different tissues were ranked in the order of grains>culms+sheathes>rachis+glumes>flag leaves>penultimate leaves>remain leaves. This study suggested that utilization of the large-spike wheat might be a promising approach to obtain higher grain yield in Northwest China.

Keywords: wheat, nitrogen distribution, large-spike lines, photosynthetic characteristics, yield

1. Introduction

Food demand has increased dramatically due to the increasing population (Rosegrant and Agcaoili 2010). The total yield potential of wheat can be greatly increased by improving the yields of individual plants, which is an important approach to ensure high food yield and quality (Reynolds and Borlaug 2006). Because large-spike wheat was characterized by big large spike, high grains per plant and high yield potentials, its varieties are more attractive and are given more attention in wheat production and breeding practices under the circumstances of everlasting arable land reduction and stable food demand increase (Gaju *et al*. 2014).

Wheat varieties with high yield potentials can be achieved by delaying leaf senescence, enhancing nutrient assimilate accumulation (Maydup *et al*. 2010). There have been contradictory conclusions regarding the function of the rate of photosynthesis in determining the crop yield in many studies (Richards 2000; Ehdaie *et al*. 2008; Sun *et al*. 2014). Wheat can accumulate considerable amounts of carbohydrates and

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nitrogenous compounds in the vegetative organs before anthesis (Plaut *et al*. 2004; Chen *et al*. 2012; Wang *et al*. 2014) and can reallocate the accumulated carbon and nutrients among different tissues during the grain-filling period (Arndt and Wanek 2002; Fernández-García *et al*. 2014). Wilhelm *et al*. (2002) reported that the N concentrations of the culm sheathes and internodes increased with the increasing culm order in contrast to individual culms, but the nitrogen distributions among the different tissues of the large-spike wheat varieties still remain unknown. Qiu *et al*. (2008) revealed that the grain yield, dry matter, photosynthetic characteristics and water-use efficiency (WUE) of winter wheat depend on the soil water in northern China. The optimal agronomic trait compositions of wheat have been reported under some experimental conditions (Peltonen *et al*. 2011; Tian *et al*. 2011); however, the study of photosynthesis, nitrogen translocation and yield formation for large-spike wheat is still far from being completely understood. The objectives of this study were to explore differences in the photosynthetic characteristics and nitrogen distributions of large-spike wheat lines in yield formation and to provide a theoretical basis for further determining the production potential of large-spike wheat lines.

2. Results

2.1. Grain yield

The grain number per spike, kernel weight per spike and 1 000-grain weight of the three large-spike lines were significantly (P<0.05) higher than those of the control cultivar (Table 1). The yields of three large-spike wheat lines were also 16.5, 9.8 and 14.7%, respectively, higher than those of the control cultivar. However, the spike numbers per hectare of the large-spike lines were significantly lower than those of Xi'nong 979. These results indicate that the future yield may be improved by increasing the spike number of the large-spike lines.

2.2. Net photosynthetic rates and WUE

The P_n of wheat tended to first increase and then decrease during the growing period (Fig. 1-A), and the average P_n during heading stage and WUE during five stages of the large-spike lines was higher than that of Xi'nong 979 (Fig. 1). The line 2040 had a higher WUE than that of the other lines during the heading, flowering, pre-ripening, and mid-ripening stages, the differences between large-spike lines and Xi'nong 979 most likely resulted from genetic characters or genotype-environment interactions.

2.3. Chlorophyll fluorescence parameters

The high-energy capture efficiencies in the PSII reaction center (Fig. 2-A) showed that the wheat did not suffer from environment stress during the active growth period. The average F_v/F_m of the large-spike lines was higher than that of the Xi'nong 979, and the average F_v/F_m of the lines and cultivar during active growth stages was ranked in the order of 2040>2038>2037>Xi'nong 979, indicating that the energy-capturing transforming capacities and the quantum efficiencies of the large-spike lines were higher than those of Xi'nong 979. The Φ_{PSII} of wheat tended to first decrease from the jointing to the heading stages, then increase from the heading to the pre-ripening stage and finally decrease from the pre- to the mid-ripening stages (Fig. 2-B). The average Φ_{PSII} during active growth stages was ranked in the order of 2037>2038>2040>Xi'nong 979. The wheat varied tendency of q_P was similar to the Φ_{PSII} (Fig. 2-C). The average q_P during active growth stages was ranked in the order of 2037>2038>2040>Xi'nong 979. The average F_v'/F_m' during active growth stages was ranked in the order of 2037>2038>Xi'nong 979>2040 (Fig. 2-D).

2.4. Nitrogen distribution proportion and translocation characteristics

Table 2 demonstrated that the grains had the highest N distribution proportion, and the remaining leaves showed the lowest N distribution proportion. The flag leaves, penultimate leaves and rachis+glumes of line 2037 had the highest N distribution proportions, while the remain leaves and culms+ sheath of line 2040 had the highest N distribution proportion, indicating that the N accumulations of the above-

Table 1 Yield and its four primary components of the three large-spike lines and the multiple-spike cultivar Xi'nong 979 (control, CK) during the maturity stage of 20 individual plants

Lines or cultivars	Spike number ($\times10^4$ ha^{-1})	Grain number per spike	Kernel weight per spike (g)	1 000-grain weight (g)	Yield (kg ha^{-1})
CK	704.1±32.0 a	42.0±1.8 b	1.8±0.1 c	41.0±0.6 b	9 651.7±560.4 a
2037	475.9±17.7 b	51.0±2.2 a	2.3±0.1 b	47.1±1.7 a	11 566.3±581.6 a
2038	480.7±89.8 b	56.3±1.8 a	2.7±0.1 a	46.2±1.3 a	10 697.6±2 113.7 a
2040	532.7±53.1 ab	52.4±1.7 a	2.7±0.1 a	48.7±0.7 a	11 313.1±1 206.6 a

Different lower case letters in the same column indicate significant differences among the different lines and cultivar at P=0.05 (by Duncan's test). The values are presented as means±SE (n=3). The same as below.