Photosynthetic and Yield Characteristics of Winter Wheat under Two Rounds of Irrigation during Spring

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Abstract: To clarify the effect of photosynthetic and yield characteristics of winter wheat under 7500 kg/hm² grain yield when irrigated twice in spring, field experiments were conducted in the low plain of Hebei Province, which is in the Helonggang Region, an area suffering from serious water scarcity. The photosynthetic and yield characteristics of winter wheat were studied by using 8 wheat varieties and by irrigating water twice during spring from 2018 to 2019 under the condition of 42.6 mm of precipitation during the wheat growing season. Results showed that the yield of wheat varieties was 7805.3–9435.0 kg·hm⁻². Under the irrigation condition, the yield difference between strong gluten wheat and medium gluten wheat was irregular. In this study, both the average daily photosynthetic rate and photosynthetic potential were higher in Shinong 086 and lower in Shiluan 02-1, but the yield was higher in Shiluan 02-1. Varieties with high light efficiency need to be selected to obtain a high yield of wheat. Moreover, agronomic measures should be optimised, a reasonable population structure should be established and the contradiction between population development and ontogenesis must be addressed. The above conclusions can provide a theoretical basis for guiding wheat variety selection and supporting technology formulation.

1. Introduction
Hebei Province is one of the largest wheat planting areas in China. During the wheat growing period, little rainfall occurs, and the average annual rainfall is 109 mm, which can only meet one-fourth of the water demand [1]. Rainfall is the most important cultivation measure in local agricultural production to make up for the water deficit of farmlands through irrigation to ensure food security and sustainable development.
of agriculture by stabilising wheat yield. More studies have been conducted on the influence of spring
water management on winter wheat growth and development [2], water use efficiency [3] and yield
formation [4]. However, few studies have focused on photosynthetic and yield characteristics of different
winter wheat at the water content required for yield formation. Zhao Guangcai et al. [5] believed that
Hebei Province is suitable for planting wheat with strong and medium gluten. Many studies have been
conducted in Hebei Province on the photosynthetic physiological basis of high and stable yield of winter
wheat with strong gluten and medium gluten and the corresponding cultivation measures, but most of
them are affected by the idea of ‘good seed and good method’, and different varieties adopt different
management measures to explore the physiology of high yield on this basis. This study adopted uniform
agronomic cultivation measures to study the stability, adaptability and stress resistance of various varieties
at the same production level to provide a theoretical basis for defining the growth characteristics of winter
wheat and determining the suitable high-yield technology.

2. Materials and Methods

2.1. Experimental variety
In accordance with the development of varieties in recent years, eight varieties with water saving
properties, high yield, stable yield and stress resistance suitable for planting in the plain areas of
Hebei Province were selected. The medium gluten varieties, which are also drought resistant, are
Shixin 828, Yingbo 700, Shinong 086 and Henong 956. The strong gluten varieties are Gaoyou 5218,
Gaoyou 5766, Shiluan 02-1 and Gaoyou 2018, whose fertility rules are representative.

2.2. Experimental material planting
This study was conducted in the dry farming water-saving agriculture experimental station of Hebei
Academy of Agricultural and Forestry Sciences during the wheat growing season from October 2018 to
June 2019. The station is located in the central and southern part of Hebei plain belonging to the wheat
growing area of Helonggang, which has the typical characteristics of semi-arid agricultural production
area in north China. Winter wheat and summer maize are grown twice a year in this area. Average annual
sunshine duration, frost-free period, evaporation, precipitation and temperature are 2509.4 h, 188 days,
1785 mm, 510 mm and 12.8 °C, respectively [11]. The experimental soil type is loam. Before sowing (3
October 2018), soil in the topsoil layer (0–20 cm) was taken for soil fertility analysis. The nutrient content
of soil is as follows: organic matter content, 14.39 g·kg⁻¹; total nitrogen content, 1.48 g·kg⁻¹; available
nitrogen content, 101.36 mg·kg⁻¹; available phosphorus content, 21.95 mg·kg⁻¹; and available potassium
content, 113.68 mg·kg⁻¹.

Field sampling survey was completed from October 2018 to June 2019. Wheat was sown on 21
October 2018 and harvested on 10 June 2018. Sowing density was 260.0 × 10³–322.5 × 10⁴ plant·hm⁻².
The row spacing was 15 cm. Each variety had 3 repeating plots, and each plot had an area of 13.3 m². Two
plots were used for the experimental sampling place, and one plot was used for the mature-period
measured production place. Field management was the same as high-yielding fields.

2.3. Observational measurement item
2.3.1. Observation of growth period Sub-plot records reached the date of each growth period beginning from the emergence of seedlings.

2.3.2. Basic seedlings and total stems In the initial stage of tillering, 3 representative samples were determined in each variety plot and the basic seedlings were calculated according to the area of 1 m n rows. The average of each point was taken to calculate the basic seedlings of the plot. The total number of stems (tassels) at fixed points in early winter, rising stage, jointing stage, booting stage, flowering stage and maturity stage were counted, and the total number of stems or tassels per hectare was calculated.

2.3.3. Plant characteristic investigation Thirty seedlings were taken from different growing stages in different communities as investigation samples. Plant height, stem number, secondary rooting number and leaf area of each plant were investigated. In the maturity stage, in addition to the above characteristics, internode length of the main stem, internode diameter of base, spike length, total spikelet number per spike, infertile spikelet number and spike grain number were determined.

2.3.4. Measurement of photosynthetic rate In this study, the photosynthetic characteristics of flag leaves of wheat were analysed by using the CI-340 portable photosynthetic measurement system produced by CID. The analysis took place on a sunny morning. Six leaves with the same light direction and growth status were selected for each treatment, and closed-circuit measurement was performed with the CI-340 photosynthetic apparatus. The measurement indexes included net photosynthetic rate (Pn), stomatal conductance (gs), intercellular CO₂ concentration (Ci) and transpiration rate (E), and air temperature, air humidity, photosynthetic effective radiation (PAR) and CO₂ concentration were recorded simultaneously.

2.3.5. Population photosynthetic potential The photosynthetic potential (LAD) is the time of duration of the upper leaf area per unit land area (1 hm²), which is 10,000 m²·d·hm⁻². The calculation formula

\[
LAD = \frac{(LA_2+LA_1) \times (t_2-t_1)}{2}
\]

where LA₁ is the area of the previous leaf, m²; LA₂ is the leaf area of the last one, m²; t₁ is the previous sampling time; and t₂ is the time of the next sampling.

The total photosynthetic potential of wheat after flowering was equal to the sum of the photosynthetic potential of the population from 0 to 10 days after flowering, 10 to 20 days after flowering, and 20 days after flowering to the maturity stage. The total photosynthetic potential of the whole growth stage is equal to the sum of the photosynthetic potential of the whole growth stage.

3. Results

3.1. Diurnal variation of photosynthesis in flag leaves of different varieties

As can be seen from Table 1, the change trend of PAR is a parabola under clear and cloudy conditions on 21 May 2019. PAR varies from 430 to 1,367 μmol·m⁻²·s⁻¹ in a day from 8:30 to 17:30, with the lowest at 17:30 and the highest at 12:30. During the measurement date, the peak value of Tc for photosynthesis was
consistent with PAR, which ranged from 26.9 °C to 36.6 °C. RH change is different from PAR change and Tc change. RH peaked at 8:30, reaching 72.4%. Afterwards, RH gradually decreased as the temperature increased. After noon, it gradually increased as the temperature decreased. Overall, the day was a wet one. The change in the atmospheric CO₂ concentration is similar to that of temperature, but the range of variation is relatively small.

Table 1. Diurnal changes of PAR, T, CO₂, RH.

| Sampling time | PAR (μmol·m⁻²·s⁻¹) | T (°C) | CO₂ (μmol·mol⁻¹) | RH (%) |
|---------------|-------------------|-------|-----------------|-------|
| 8:30          | 965±33.2          | 26.9±1.1 | 435.8±4.6       | 72.4±1.4 |
| 9:30          | 1019.9±40.3       | 33.5±0.2 | 433.3±3.8       | 48.6±0.5 |
| 10:30         | 913.8±30.5        | 32.4±1.9 | 402.6±1.2       | 53.2±2.3 |
| 11:30         | 994.1±51.3        | 36.1±2.1 | 408.2±0.3       | 47.2±1.6 |
| 12:30         | 1220.1±43.4       | 36.4±1.2 | 401.4±1.4       | 45.5±2.1 |
| 13:30         | 1148.6±40.2       | 36.2±1.0 | 403.8±2.1       | 43.7±1.5 |
| 14:30         | 551.6±33.1        | 31.7±0.4 | 414.3±3.0       | 50.1±2.3 |
| 15:30         | 419.9±20.1        | 30.3±1.1 | 416.6±1.1       | 52.8±1.1 |
| 16:30         | 394.3±10.5        | 27.7±0.5 | 418.9±0.1       | 61.8±0.9 |
| 17:30         | 329.8±11.5        | 27.2±0.7 | 419±0.3         | 60.5±1.3 |

The diurnal variation of net photosynthetic rate (Pn) in the flag leaves of 8 wheat varieties was basically similar under the above climatic conditions. The diurnal variation of the photosynthetic rate was a ‘bimodal’ curve, with two peaks from 8:30 am to 10:30 am and 14:30 pm to 15:30 pm, respectively. Differences exist between the time and height of the peak of net photosynthetic rate (Pn) in different varieties. For Shilan 02-1, Gaoyou 5218, Gaoyou 2018, Gaoyou 5766, Henong 956, Shixin 828, and Gaoyou 5766, the first peak appeared at 8:30–10:30, while the first peak of Shinong 086 appeared at 11:30. In addition, figure 1 (a) shows that the second peak of the photosynthetic rate in the flag leaves of all varieties is lower than the first peak, and the rate of Pn decline at noon is higher than the rate of rise in the afternoon, that is, the photosynthetic rate at noon decreases fast but recovers slowly. The second peak of Shixin 828 was higher than that of other varieties. The order of the daily mean value of Pn of each variety in a day from large to small is as follows: Shinong 086 (16.18 μmol·m⁻²·s⁻¹) > Yingbo 700 (14.51 μmol·m⁻²·s⁻¹) > Shixin 828 (14.50 μmol·m⁻²·s⁻¹) > Gaoyou 2018 (14.05 μmol·m⁻²·s⁻¹) > Henong 956 (13.83 μmol·m⁻²·s⁻¹) > Gaoyou 5218 (13.54 μmol·m⁻²·s⁻¹) > Gaoyou 5766 (12.16 μmol·m⁻²·s⁻¹) > Shilian 02-1 (11.09 μmol·m⁻²·s⁻¹).

The diurnal variation of transpiration rate showed a single peak curve, which was inconsistent with the change in the photosynthetic rate. All the peaks of the transpiration rate appeared at about 12:30, declined rapidly and decreased slowly after 14:30, with little change. The daily average transpiration rate of each variety in one day ranged from 3.36 to 4.59 mmolH₂O·m⁻²·s⁻¹, and the highest value ranged from 6.0 to 8.4 mmolH₂O·m⁻²·s⁻¹.

The diurnal variation curves of stomatal conductance of different cultivars were not consistent. The
Stomatal conductance of Gaoyou 5218, Shinong 086 and Shixin 828 was higher at 8:30 or 9:30, then decreased and increased again to a higher value at 10:30–11:30. The stomatal conductance of other species was similar. With the increase in PAR and temperature, stomatal conductance of various varieties decreased rapidly after reaching the peak value at 12:30 or before (probably due to high temperature and low humidity) and increased again around 15:30 pm in the Shinong 086 and Gaoyou 2018 varieties.

The diurnal variation of intercellular CO₂ concentration of each variety was different from the above changes, and the variation curve between varieties was not quite consistent. Both are lower at noon. The main reasons for the decrease in the intercellular CO₂ concentration were the high temperature and the decrease in the atmospheric CO₂ concentration in the field at noon. The average daily intercellular CO₂ concentration varies greatly among varieties. The order from high to low was Shinong 086 (330.72 μmolCO₂·mol⁻¹) > Gaoyou 5218 (328.25 μmolCO₂·mol⁻¹) > Yingbo 700 (325.42 μmolCO₂·mol⁻¹) > Henong 956 (323.63 μmolCO₂·mol⁻¹) > Gaoyou 2018 (317.56 μmolCO₂·mol⁻¹) > Shixin 828 (314.60 μmolCO₂·mol⁻¹) > Shiluan 02-1 (302.05 μmolCO₂·mol⁻¹) > Gaoyou 5766 (290.33 μmolCO₂·mol⁻¹).
Transpiration rate (m mol H₂O • m⁻² • s⁻¹)

Determination of the

Shiluan 02-1
Gaoyou 5218
Shinong 086
Gaoyou 2018
Gaoyou 5766
Yingbo 700
Henong 956
Shixin 828

Stomatal conductance (cm² s⁻¹)

Determination of the

Shiluan 02-1
Gaoyou 5218
Shinong 086
Gaoyou 2018
Gaoyou 5766
Yingbo 700
Henong 956
Shixin 828
3.2. Population and individual growth characteristics and yield characters of various varieties

To prevent too many tillers from becoming panicles and thus prevent the population from becoming too large and then lowering in the later stage, the suitable basic seedlings recommended in the examination and approval of various varieties were adopted during sowing. The basic seedlings of 8 species ranged from 260.0 to 3.225 million per hectare. The self-regulation of winter wheat was different from the tiller panicle characteristics of varieties, and the tiller panicle characteristics of all varieties reached 658.8–8831 thousand per hectare at maturity. All the above indexes are within the best recommended range of high yield as obtained during the examination and approval of each variety.

Figure 2. Dynamics of culm (spike) numbers of the different high-yield wheat varieties.

The plant height during maturity varies greatly due to the different characteristics of varieties, with
the highest in Gaoyou 5218 (81.8 cm) and the lowest in Shiluan 01-1 (72.0 cm), with a difference of more than 10 cm. The number of secondary roots of each species is also different. The number of roots in Helong 956 reached 26.8 root·plant⁻¹, and the number of roots in Shinong 086 was less at only 16.4 root·plant⁻¹. The difference between the two varieties was more than 10. Shixin 828 had the largest internode diameter (0.341 cm), and that of Gaoyou 5766 was the smallest (0.228 cm). With the increase in node position, the diameter of the stem node of each variety gradually became longer, reaching the longest at spike neck node (22 cm or above). The spike neck node is long and the base internode is short, which is the physiological characteristic of wheat varieties with lodging resistance and high yield.

**Table 2.** Plant heights, adventitious roots, internode lengths, internode diameters of different high-yield wheat varieties.

| Varieties    | Plant height | Secondary Root (root) | BID | Internode length (top-down) |
|--------------|--------------|-----------------------|-----|-----------------------------|
|              |              |                       |     | 1  | 2  | 3  | 4  | 5  | 6  | 7  |
| Shinong 086  | 77.9a        | 16.4c                 | 0.267b | 27.01 | 15.55 | 10.77 | 8.74 | 6.77 | 2.00 |
| Yingbo 700   | 78.4a        | 22.2b                 | 0.254bc | 28.66 | 17.30 | 10.79 | 8.17 | 4.79 |
| Shixin 828   | 73.8b        | 21.2b                 | 0.341a | 25.57 | 17.98 | 10.92 | 6.68 | 4.28 |
| Henong 956   | 73.2b        | 26.8a                 | 0.294b | 22.15 | 15.34 | 11.01 | 8.20 | 5.64 | 1.50 |
| Gaoyou 5218  | 81.8a        | 22.3b                 | 0.288b | 29.03 | 19.30 | 10.90 | 7.84 | 4.35 |
| Gaoyou 5766  | 76.4a        | 20.9b                 | 0.228c | 23.14 | 18.26 | 12.63 | 9.19 | 5.30 |
| Shiluan 02-1 | 72.0b        | 20.3b                 | 0.254bc | 22.33 | 15.28 | 11.03 | 7.08 | 6.07 | 3.50 |
| Gaoyou 2018  | 73.9b        | 20.4b                 | 0.271b | 23.73 | 14.96 | 9.89  | 8.13 | 6.05 | 3.75 | 1.00 |

BID: basal internode diameter 1: internode below the spike, cm; 2: penultimate leaf, cm; 3: the third to last leaf, cm; 4: fourth from last leaf, cm; 5: the fifth to last leaf, cm; 6: the sixth to last leaf, cm; 7: penultimate seventh leaf, cm.

As can be seen from Table 3, the panicle length of each variety of winter wheat varies greatly. The panicle length of Henong 956 reached 8.3 cm, whereas that of Shiluan 02-1 was only 6.6 cm. The total number of spikelets per panicle was not different, and the variation range of different varieties per panicle was 16.0–18.9 spike. The number of infertile spikelets was 2.7–4.4 spike, and the number of spikelets was 26.8–33.4 grain. The biological yield of all varieties was above 15944 kg·hm⁻², and the measured final yield was 7805.3–9435.0 kg·hm⁻². The order from high to low was Shixin 828 > Shiluan 02-1 > Gaoyou 2018 > Gaoyou 5766 > Henong 956 > Yingbo 700 > Gaoyou 5218 > Shinong 086. The range of 1000-grain weight was 35.24–44.95 g, and the order from high to low was Yingbo 700 > Shixin 828 > Henong 956 > Shiluan 02-1 > Gaoyou 5218 > Shinong 086 > Gaoyou 5766 > Gaoyou 2018.

**Table 3.** Dry matter weights and yields at the maturity stage of different high-yield wheat varieties (kg/hm²).
Varieties | Spikelet number (spike) | Number of infertile spikelets (spike) | Grain number per spike (grain·spike⁻¹) | The grain yield (kg·hm⁻²) | Biological yield (kg·hm⁻²) | The actual measurement (kg·hm⁻²) | Thousand Kernel Weight (g)
--- | --- | --- | --- | --- | --- | --- | ---
Shinong 086 | 18.05b | 4.36a | 26.82d | 8822.7c | 15944.1e | 7880.0c | 44.13a
Yingbo 700 | 18.22ab | 3.59b | 29.22c | 8505.8c | 17817.6c | 8444.3b | 43.95a
Shixin 828 | 16.03d | 3.59b | 31.53b | 10018.2a | 20518.0b | 9435.0c | 44.13a
Henong 956 | 16.61c | 2.71d | 31.36b | 10901.3a | 22463.5a | 8853.5 | 41.01a
Gaoyou5218 | 18.92a | 3.79b | 32.38a | 8938.8c | 18216.4c | 7805.3 | 38.41b
Gaoyou5766 | 16.41cd | 3.15c | 28.96c | 9120.3b | 20196.0b | 9435.0ab | 38.41b
Shiluan 02-1 | 16.83c | 3.33bc | 28.50c | 9141.5b | 17868.7c | 9070.1ab | 38.41b
Gaoyou2018 | 18.35ab | 3.30bc | 33.43a | 9324.2b | 16619.3d | 8920.4b | 36.58c

3.3. Dynamic changes of the growth process and photosynthetic potential of different varieties
3.3.1. Growth process of different varieties of winter wheat
Table 4 shows that the growth period of each variety is basically the same. All seeds were planted at the right time; thus, the growth process of the vegetative growth stage is basically the same between different varieties. Specifically, the growth period of strong gluten wheat was slightly later than that of medium gluten wheat.

| Varieties  | Sowing Seedling | Winter | Standing | Jointing | Booting | Heading | Anthesis | Mature | Total |
|------------|----------------|-------|----------|----------|---------|---------|----------|--------|-------|
| Shinong 086 | Date(month - day) | 10-21 | 10-28 | 11-28 | 03-24 | 04-07 | 04-26 | 05-03 | 05-09 | 06-08 | 230 |
|            | Days (day)      | 7     | 31      | 116     | 14     | 19     | 7       | 6     | 30    |       |
| Yingbo 700 | Date(month - day) | 10-21 | 10-28 | 11-28 | 03-26 | 04-10 | 04-26 | 05-03 | 05-09 | 06-06 | 226 |
|            | Days (day)      | 7     | 31      | 118     | 15     | 16     | 7       | 6     | 28    |       |
| Shixin 828 | Date(month - day) | 10-21 | 10-28 | 11-28 | 03-23 | 04-04 | 04-22 | 04-29 | 05-05 | 06-04 | 225 |
|            | Days (day)      | 7     | 31      | 115     | 12     | 18     | 7       | 6     | 30    |       |
| Henong 956 | Date(month - day) | 10-21 | 10-28 | 11-28 | 03-25 | 04-10 | 04-24 | 05-01 | 05-07 | 06-06 | 228 |
|            | Days (day)      | 7     | 31      | 117     | 16     | 14     | 6       | 6     | 30    |       |
| Gaoyou5218 | Date(month - day) | 10-21 | 10-28 | 11-28 | 03-28 | 04-14 | 04-26 | 05-03 | 05-09 | 06-09 | 231 |
|            | Days (day)      | 7     | 31      | 120     | 17     | 12     | 7       | 6     | 31    |       |
| Gaoyou5766 | Date(month - day) | 10-21 | 10-28 | 11-28 | 03-27 | 04-14 | 04-24 | 05-03 | 05-09 | 06-08 | 230 |
|            | Days (day)      | 7     | 31      | 119     | 18     | 10     | 9       | 6     | 30    |       |
| Shiluan 02-1 | Date(month - day) | 10-21 | 10-28 | 11-28 | 03-28 | 04-14 | 04-26 | 05-03 | 05-09 | 06-09 | 231 |
|            | Days (day)      | 7     | 31      | 120     | 17     | 12     | 7       | 6     | 31    |       |
| Gaoyou2018 | Date(month - day) | 10-21 | 10-28 | 11-28 | 03-29 | 04-14 | 04-26 | 05-04 | 05-09 | 06-11 | 233 |
|            | Days (day)      | 7     | 31      | 121     | 16     | 12     | 8       | 5     | 33    |       |
3.3.2. Dynamics of photosynthetic potential of different species

The development of photosynthetic potential of various varieties showed a trend of single peak curve (Figure 3). The photosynthetic potential increased most during the period from jointing to booting, followed by the two stages from booting to flowering and from rising to jointing. The photosynthetic potential accumulated in each stage was more than $53 \times 10^4 \text{ m}^2 \cdot \text{d} \cdot \text{hm}^{-2}$, with the least amount accumulated 20 days after flowering and 30 days after flowering. In general, the photosynthetic potential of all varieties was above $364 \times 10^4 \text{ m}^2 \cdot \text{d} \cdot \text{hm}^{-2}$ after spring and above $75 \times 10^4 \text{ m}^2 \cdot \text{d} \cdot \text{hm}^{-2}$ after flowering. The order of the total photosynthetic potential of different varieties in spring from high to low is as follows: Yingbo 700 > Shiong 086 > Gaoyou 2018 > Gaoyou 5766 > Shiluan 02-1 > Henong 956 > Shixin 828 > Gaoyou 5218. The order of the total photosynthetic potential after flowering is as follows: Yingbo 700 > Shiong 086 > Gaoyou 5766 > Henong 956 > Gaoyou 2018 > Shiluan 02-1 > Shixin 828 > Gaoyou 5218.

![Figure 3. Dynamic changes of photosynthetic potential in different varieties.](image)

4 Conclusion and discussion

In this study, under the condition of 42.6 mm rainfall during the growth period, the yield level of each wheat variety was 7805.3–9435.0 kg·hm$^{-2}$ through two rounds of irrigation during spring. From the perspective of yield composition factors, the number of grains per panicle of such varieties as Gaoyou 2018 and Gaoyou 5218 was high, but the 1000-grain weight was lower, and the final yield difference between different varieties was small. The final formation of wheat yield is the comprehensive performance of all yield components [1]. The panicle number of wheat in this study ($658.8 \times 10^3$–$833.1 \times 10^4$ spike·ha$^{-1}$) was higher than the results of Guo et al. [6] ($395.0 \times 10^3$–$630.3 \times 10^4$ spike·ha$^{-1}$) and Li et al. [7] ($475.8 \times 10^3$–$800.0 \times 10^4$ spike·ha$^{-1}$). The yield of this study was also higher than that of the above two studies. Further analysis shows that the difference between yield and panicle number is related to irrigation quality and irrigation times. In this study, fresh water was irrigated twice in spring; Guo et al. [6] irrigated brackish water and Li et al. [7] irrigated water only once in spring. In areas where water resources are extremely scarce, irrigation and other measures...
have a greater impact on wheat yield than the difference between varieties [8, 9]. When irrigation conditions were similar, the difference in yield was related to the adaptability of wheat varieties to the cultivation environment. In view of different cultivars in the same cultivation environment and the same cultivars in different production conditions, more in-depth research should be conducted.

In this study, both the average daily photosynthetic rate and photosynthetic potential were higher in Shinong 086 and lower in Shiluan 02-1, but the yield was higher in Shiluan 02-1. The photosynthetic rate of this study was lower than that of Guo et al. [6] (24.99–36.09 μmol·m⁻²·s⁻¹), but the final yield was higher. Although wheat yield formation is related to photosynthetic rate, this factor is insufficient for a variety to improve its photosynthetic performance [1]. For a high yield of wheat, varieties with high light efficiency need to be selected, and optimised agronomic measures must be adopted [10]. A reasonable population structure should be established and the contradiction between population development and ontogenesis [11] must be addressed to maximise the role of integrated agronomic measures in improving wheat yield.

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