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BRIEF COMMUNICATION

Photosynthetic rate and yield formation in different maize hybrids

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Abstract

The relationship between photosynthetic rate and yield formation processes of the newer and older maize hybrids were investigated. Leaf area at flowering (source) and kernel number (sink) of the newer hybrids were greater than the older ones although their light-saturated photosynthetic rate (P_{sat}) were not greater than the older ones before flowering. After flowering, P_{sat} and chlorophyll content of the newer hybrids declined more slowly than the older ones. They not only distributed almost all photosynthates produced after flowering to grain but also reallocated some reserved photosynthates produced before flowering to grain. The newer hybrids exhibited greater grain mass than the older ones mostly because they could optimally regulate the photosynthetic rate and yield formation processes to maximize grain mass.

Additional key words: chlorophyll content, dry mass, photosynthetic rate, *Zea mays* L.

It is well known that photosynthesis is the basis of the formation of crop yield. However, many authors believe that there has been no change in photosynthesis rate to accompany the grain yield increases, or even negative relation between photosynthesis and grain yield (Evans 1993, Reynolders *et al.* 2000, Richards 2000). Increases in grain yield of maize hybrids have resulted from increased dry matter accumulation because the harvest index has largely remained constant (Crosbie 1982, Tollenaar 1991, Hu *et al.* 1998). Several researchers believed that the new maize hybrids can produced more dry matter because they remain photosynthetically active during mid to late grain filling and the delayed leaf senescence is an improved characteristic of the new hybrids (Fakorede and Mock 1980, Duvick 1992, Tollenaar and Aguilera 1992, Rajcan and Tollenaar 1999).

Final kernel mass depends on the relationship between kernel sink capacity and the availability of assimilates to fill this sink (Borrás *et al.* 2002). Although grain mass mostly accumulates at effective filling-period, beginning about 7 - 14 d post-midsilk, there is still part of the grain mass which is from the assimilate reserves in the shoot before flowering (Sayre 1948, Johnson and Tanner 1972). The kernel sink capacity starts after ovary fertilization and precedes the linear grain-filling period stage (Cirilo and Andrade 1994, Otegui and Bonhomme 1998). Therefore, the period before effective grain filling period is also very important for the grain yield formation (Tanaka 1983, Simmons and Jones 1985).

The objective of this study was to link up the yield formation processes of maize hybrids released in different years with their photosynthetic rate before and after flowering, trying to ascertain the relationship between photosynthetic rate and yield increase of maize hybrids.

Field experiments were conducted at Shandong Agriculture University Research Farm, Taian, Shandong (36°18'N, 117°13'E). Plots were overseeded with hand planters on 28 June 2003 and were thinned at the seedling stage to a final stand of 45 plants m^{-2}. The soil type is silt loam and fertilization was applied as recommended. Plants of each hybrids were arranged in two randomize complete blocks. Each plot consisted of four 8 m rows with 0.76 m inter-row spacing. Rows always had an east-west orientation. Four rows at each side of the experimental area were used as border. There were three

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Abbreviations: PPFD - photosynthetic photon flux density, P_{sat} - light-saturated photosynthetic rate, VPD - air vapour pressure deficit.
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border plants from each side of the sampling plants. Six maize (*Zea mays* L.) hybrids were used: Baimaya (BA) and Jinhuanghou (JI) (double-cross hybrids) were introduced from USA in 1931 and 1947 respectively and were widely grown in China in the 1950s; Zhongdan 2 (Z2) and Danyu 6 (D6) (single-cross hybrids) were the most widely grown hybrids in north China during the 1970s after its initial release; Niedan 13 (N13) and Nongda 108 (N108) (single-cross hybrids) were released in 1990s and were widely grown in China till now.

Plant dry matter was measured at flowering stage in samples of 5 plants. The samples were taken from the central rows of each plot, leaving borders of 1 m between successive harvests. All plants were separated into stems, leaves, ears, oven-dried (forced air at 80 °C) to constant mass, and weighed. Grain yield and plant dry matter was determined at physiological maturity in samples of 10 - 20 plants from the two central rows of each plot. The mass of individual kernels was determined in two samples of 500 kernels each. Kernels per plant were counted in all harvested ears. The light-saturated photosynthesis rate (P_{sat}) was measured at top, middle and bottom leaves at 20 d before flowering, mid-flowering and 20 d after flowering respectively. P_{sat} was measured with a portable photosynthetic system (*CIRAS-1*, *PP Systems*, Hitchin, UK) at 1800 μmol m^{-2} s^{-1} photon flux density (PPFD) using the automatic light source of the *CIRAS-1* photosynthetic system. Cloudless days were used for measurements because incident PPFD prior to measurement can influence leaf photosynthesis. Five plants of each hybrid were selected for measuring. Measurements were taken on a 2.5 cm^2 area in the center part of the leaf blade that did not include the midrib. The flow rate of air through the chamber was set to 200 cm^3 min^{-1}. The CO_2 concentration of the intake air was maintained at 350 μmol mol^{-1} and air vapour pressure deficit (VPD) was about 2 kPa during the measuring. Leaf temperature was maintained at 30 °C by

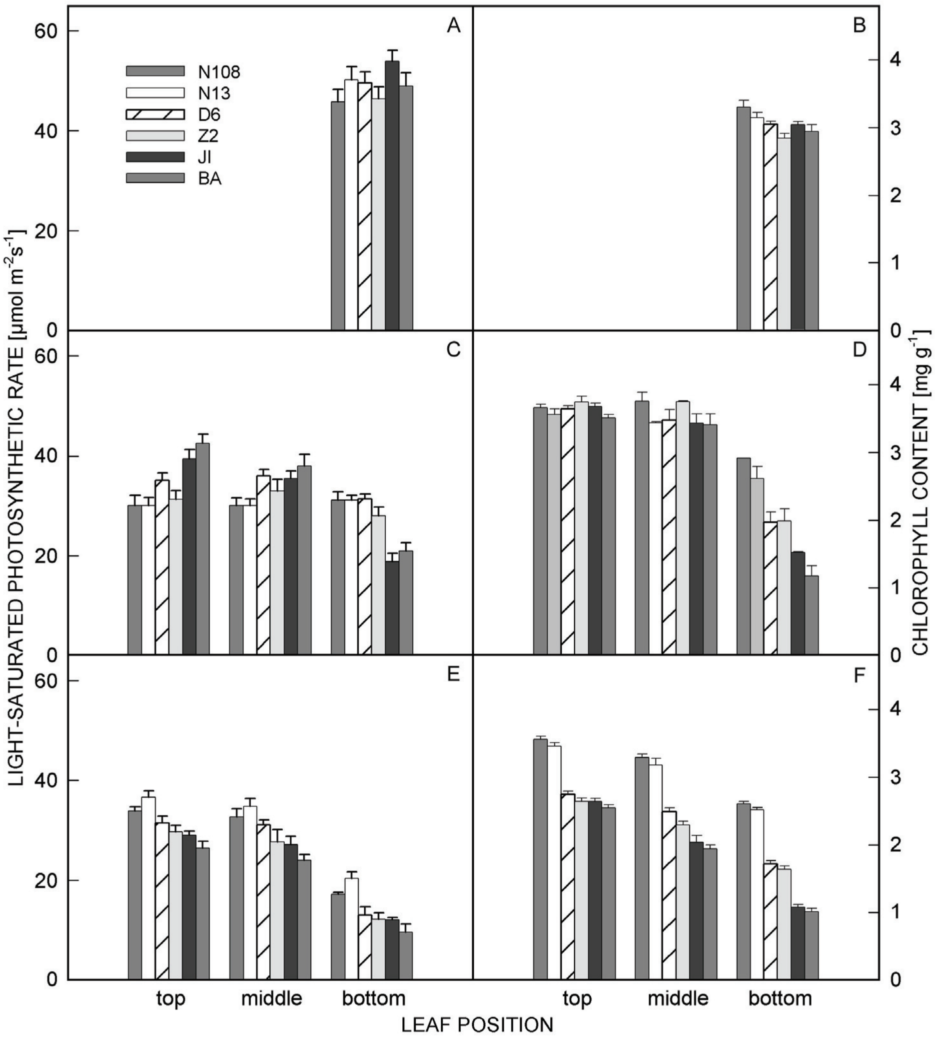

Fig. 1. Light-saturated photosynthetic rate (P_{sat}) (*A*,*C*,*E*) and chlorophyll content (*B*,*D*,*F*) at different leaf positions of maize hybrids released in different years at 20 d before flowering (*A*,*B*), flowering (*C*,*D*) and 20 d after flowering (*E*,*F*). Data represent the mean ± SE (*n* = 5).

Table 1. Leaf area at flowering (LA), leaf mass at flowering (LM), shoot mass at flowering (SM), plant mass at flowering (PMBF), plant mass produced after flowering (PMAF), plant mass at harvest (PMAH), grain mass at harvest (GM), kernel mass at harvest (KM), kernel number per plant at harvest (KN), harvest index at harvest (HI), grain mass from shoot (GMFS) and from dry matter produced after flowering (GMAF) of maize hybrids released in different years. Means ± SE, $n = 20$. Means followed by the same letter within a row are not significantly different ($P < 0.05$).

Parameter	Baimaya	Jinhuanghou	Zhongdan 2	Danyu 6	Niedan 13	Nongda 108
LA [cm^2 $plant^{-1}$]	7640.81±382.0c	7298.59±364.9c	9280.33±464.0b	9038.11±451.9b	11155.57±555.6a	11397.79±569.8a
LM [g $plant^{-1}$]	35.44±1.77c	37.22±1.86c	51.14±2.56b	49.02±2.45b	61.39±3.07a	59.17±2.96a
SM [g $plant^{-1}$]	94.48±5.72c	100.26±5.52c	136.70±6.83b	135.92±6.79b	170.68±8.54a	168.46±8.42a
PMBF [g $plant^{-1}$]	129.92±7.99c	137.48±7.37c	187.84±9.39b	184.94±9.24b	232.07±11.65a	227.63±11.38a
PMAF [g $plant^{-1}$]	123.65±5.67c	125.09±5.76c	141.79±7.09b	136.20±6.81b	152.05±7.65a	167.69±8.39a
PMAH [g $plant^{-1}$]	253.57±12.67c	263.47±13.73c	329.63±16.48b	321.14±16.57b	394.12±18.45a	394.32±19.76a
HI	0.46±0.02a	0.45±0.02a	0.48±0.02a	0.49±0.02a	0.51±0.03a	0.50±0.03a
GM [g $plant^{-1}$]	116.64±5.83c	118.56±5.93c	158.22±7.91b	157.36±7.87b	201.00±10.05a	197.16±9.86a
KM [g $kernel^{-1}$]	0.27±0.01a	0.26±0.01a	0.27±0.01a	0.28±0.01a	0.30±0.02a	0.31±0.02a
KN [$plant^{-1}$]	432.00±21.63c	456.00±22.81c	586.00±29.32b	562.00±28.12b	670.00±33.54a	636.00±31.84a
GMFS [g $plant^{-1}$]	0	0	23.79±11.89	26.01±13.02	51.98±25.99	49.76±24.88
GMAF [g $plant^{-1}$]	116.64±5.83c	118.56±5.93	134.13±6.76	131.35±6.57	149.02±7.45	147.40±7.37

the *CIRAS-1* thermoelectric coolers. 3 leaves per position were sampled at the same time that P_{sat} was measured and then the central part of the leaf blades without midrib were cut into pieces for chlorophyll content assays. Chlorophyll content was determined according to Arnon (1949).

Plant mass of the newer hybrids increased about 44 % whereas the harvest index only increased about 9 % compared with the older ones (Table 1). This finding confirms the reports that increases in grain yield of maize hybrids have resulted from increased dry matter accumulation (Crosbie 1982, Tollenaar 1991, Hu *et al.* 1998). Although P_{sat} of the newer hybrids before flowering were lower than those of the older ones (Fig. 1), they could enlarge leaf area more quickly than the older ones, then their leaf area, leaf mass, shoot mass and plant mass at flowering were all significantly greater than those of the older ones (Table 1). Grain yield in maize is primarily determined by kernel number and kernel mass (Poneleit and Egli 1979). At harvest, kernel numbers of the newer hybrids were significantly greater than the older ones whereas their kernel masses were only slightly greater than the older ones (Table 1). Thus the newer hybrids prepared greater source and sink capacity for the subsequent growth.

Valentinuz and Tollenaar (2004) found that leaves in the central section of the canopy were the last leaves which senesce. We also found that the reduction in P_{sat} and chlorophyll content of all hybrids began from the bottom leaves, then the top and middle ones, with the senescence of the older hybrids leaves was earlier than the newer hybrids (Fig. 1). So the newer hybrids produced more dry matter than the older ones after flowering (Table 1). The supply of photosynthates by the source and the demand of photosynthates by the sink are buffered by photosynthates temporarily reserved in the shoot (Rajcan and Tollenaar 1999). About 30 % of the grain mass in the 1990s hybrids and 16 % in the 1970s hybrids was reallocated from shoot (Table 1). Furthermore, hybrids differed in the capacity of distributing photosynthates produced after flowering to kernels (Borrás and Otegui 2001). In the newer hybrids, almost all photosynthates produced after flowering supplied grain, whereas in the 1950s hybrids, there were about 5 % of the photosynthates produced after flowering supplied shoot (Table 1), which might be by reason that sink reduction decreased photosynthate translocation into grains (Wang *et al.* 1997).

In a whole, the newer hybrids exhibited greater grain yield than the older ones not because they had greater maximum photosynthetic rates or their photosynthetic rates were greater than the older ones all the time but because they could optimally regulate the photosynthetic rate and yield formation processes to maximize grain yield.

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