

WANG Yanzhe, CUI Yanhong, ZHANG Lihua, LI Jincai, LIU Jianfeng, WANG Ronghuan

Effects of synchronization between silk receptivity and pollen grain vigor on kernel sets of corn (*Zea mays* L.)

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Abstract Kernel sets in corn were affected by silk receptivity, pollen grain vigor, and the synchronization of silking and pollen shedding. Grain yield decrement was often caused by poor kernel set ability under field conditions. This study was conducted with two corn hybrids—Yedan 12 and Yedan 19—in both field and laboratory to observe silk receptivity, pollen vigor, synchronization of silking and pollen, and their effects on the kernel sets. The results showed that silk receptivity could be maintained over a relatively longer period of time after silks emerged, but both kernel set percentage and kernel weight decreased as silks aged when pollination occurred. Pollen grains that shed earlier had higher TTC-dehydrogenase activity, higher germination percentage, more rapid pollen tube growth rate, and higher percentage of kernel sets and kernel weight than those that shed later. The effect of delayed silking on kernel set ability was more significant compared with delayed pollen. Synchronization of silking and pollen shedding showed different characters in different hybrids: “partial overlapped” for Yedan 12 and “overlapped” for Yedan 19.

Keywords maize, silk receptivity, pollen vigor, synchronization of silking and pollen shedding

1 Introduction

Corn is one of the monoecious crops with male and female flowers in separate places; kernel sets are dependant upon

Received April 16, 2007; accepted May 23, 2007

WANG Yanzhe
Department of Biological Science and Engineering, Hebei University of Economics and Business, Shijiazhuang 050061, China

CUI Yanhong (✉), LI Jincai, LIU Jianfeng, WANG Ronghuan
Department of Agronomy, Agricultural University of Hebei, Baoding 071001, China
E-mail: cyh@hebau.edu.cn

ZHANG Lihua
Institute of Cereal and Oil Crops, Hebei Academy of Agriculture and Forestry Sciences, Shijiazhuang 050031, China

both silk receptivity and pollen grain vigor and also their synchronization. Bassetti and Westgate (1993a; 1993b) described the dynamics of silk emergence and senescence on individual ears of maize. Potential kernel number declined as silks lost receptivity and senescence with age (Bassetti and Westgate 1993a; 1993b; 1993c; Anderson et al., 2004). Uribelarrea et al. (2002) reported on pollen production and pollination dynamics in maize, while Lizaso et al. (2003) predicted potential kernel sets in maize from simple flowering characteristics. A minimum pollen shed density per exposed silk was required to achieve the maximum kernel sets and grain yield (Westgate et al., 2003). However, the effect of delayed pollination or delayed silking on kernel weight was unknown. Bolanos and Edmeades (1993) reported that anthesis-silking interval (ASI) is a key trait for obtaining high grain yield in maize; grain yield will decrease as ASI increases. Increased plant density (Uribelarrea et al., 2002), water-stress conditions (Hall et al., 1982; Bolanos and Edmeades, 1993; Bassetti and Westgate, 1993c; Zinselmeier et al., 1995; Zhang and Kirubi, 2002), low nitrogen supply (Lafitte et al., 1997), shading (Earley and Miller, 1966), plant density (Springfield and Thatcher, 1974), leaf damage (Shapiro, 1986), and temperature (Struik et al., 1986) may promote an increase in ASI and reduce the kernel number and grain yield. Hybrids may have different pollen shedding-silking patterns, and they will also have some effects on kernel setting. This study was conducted with two different corn hybrids to investigate the effect of delayed pollination, delayed silking and their interaction on the kernel number and kernel weight. The pollen shedding-silking pattern of two hybrids was also observed.

2 Materials and methods

Field observation was conducted in the specimen garden at the Agricultural University of Hebei in 2004 with two corn hybrids—Yedan 12 and Yedan 19 at a density of 67 500 plants per hectare after winter wheat. Field plot was 300 m² for each hybrid and sowing date was on June 18 and 20 for Yedan 19 and Yedan 12, respectively. Top soil at depth of 30 centimeters contained 1.46% of organic matter, 1.3 g/kg

of total nitrogen, 81.26 mg/kg of soluble nitrogen, 44.6 mg/kg of soluble phosphorus, and 156.67 mg/kg of soluble potassium. Three hundred and six hundred kilograms of urea per hectare were applied at seedling stage and 12-leaf stage, respectively. Plants with the same growth and development status were selected and labeled for sampling. The two hybrids were also sown on ten sowing dates at two-day intervals after the field sowing to supply enough fresh pollen grains as needed.

2.1 Silk receptivity

Ears from labeled plants were bagged before silk emergence and pollination was done from 9:00 to 11:00 a.m. each day. From the first day of silk emergence until full senescence, ten bagged ears were pollinated each day artificially with fresh pollen grains and bagged again after finishing pollination. Silks were cut off at the point 1 centimeter above the top of the ear husk before pollination and the silk number was counted. The kernel number was counted and kernel weight was measured after harvest. Silk receptivity was denoted by kernel set percentage.

2.2 Pollen grain vigor

From the first day of pollen shedding, ten labeled plants were selected to collect pollen grains at 9:00 a.m. each day as samples for measuring pollen grain vigor. The TTC-dehydrogenase activity was measured according to Zhang's method (1992). Pollen grains were cultivated with agar-culture medium *in vitro* (Cook and Walden, 1965), the germination percentage of pollen grains was counted and pollen tube length was measured under a microscope after 3 h of cultivation.

2.3 Kernel set ability from pollination

From the first day until the end of pollen shedding, pollen grains were collected each day at 9:00 a.m. from labeled plants and pollinated artificially to ten bagged ears with silks emerging for 2–3 days. Ears were bagged again after finishing pollination. Silks were cut off at the point 1 cm above the top of the ear husk before pollination, silk and kernel numbers were counted and kernel weight was measured after harvest.

2.4 Synchronization of silk receptivity and pollen grain vigor

According to the kernel set percentage at different silking and pollen shedding stages, the interaction between silk receptivity and pollen grain vigor, and the effect of delayed silking time and delayed pollen shedding time on kernel setting were calculated. Plants in the field plot of each hybrid were counted for both pollen shedding and silk emergence each day during anthesis and silking to observe the synchronization of silk emergence and pollen shedding.

3 Results

3.1 Silk receptivity

Silk receptivity was related to silk age after emergence. It was about 90% or higher during the first eight days after silking, and declined significantly between ten to eighteen days when silk receptivity was totally lost. Minimal difference in receptivity was found between the two hybrids (Fig. 1). Kernel weight decreased gradually as silk aged when pollination occurred (Fig. 2). The results showed that both kernel number and kernel weight decreased if pollination was delayed.

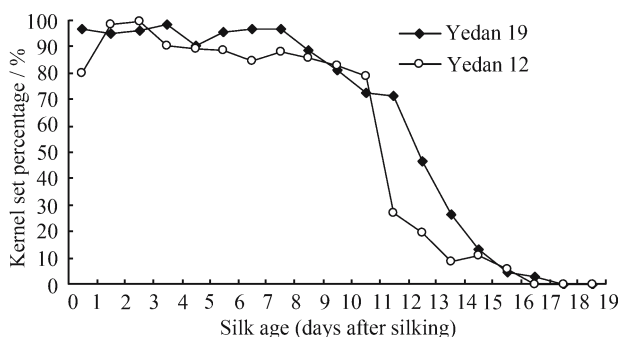


Fig. 1 Effect of silk age on kernel set percentage

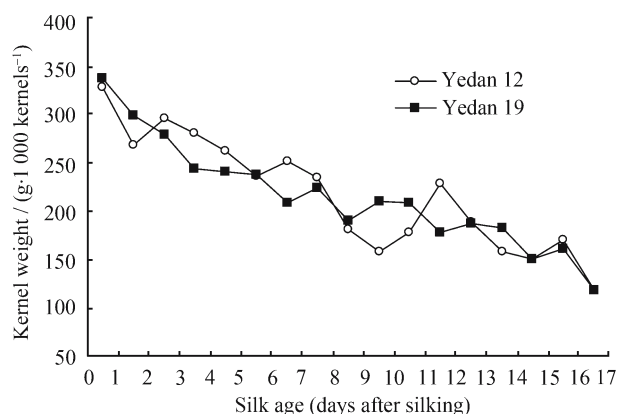


Fig. 2 Effect of silk age on kernel weight

3.2 Pollen grain vigor

Pollen grain vigor was related to the time of shedding. The TTC-dehydrogenase activity of pollen grains shed during the first two days remained about 95% or higher and declined gradually for five or six days, after which rapid decline occurred. The pollen grain germination percentage and length of pollen tubes within a period of time were also the measures of pollen grain vigor. The percentage of pollen grain germination decreased after the first day of shedding. The length of pollen tubes shortened significantly after four days. The percentage of kernel set was higher when pollinated with pollens shed from the first four days and declined rapidly when

pollinated with pollens shed after four days. The kernel weight decreased as pollen shedding was delayed. The results showed that the earlier pollen grains shed, the higher pollen vigor and germination percentage would be, the more rapidly pollen tubes grew, and the higher kernel set percentage and kernel weight would be than those that shed later (Table 1).

3.3 Interactive effect of silk receptivity and pollen grain vigor on kernel setting

The interactive effect of silk receptivity and pollen grain vigor on kernel setting was calculated from kernel sets of different ages for both silking and pollen shedding. The kernel set percentage did not change significantly for silks at different ages when pollinated with fresh vigorous pollen, but significant differences were found for vigorous silks when pollinated at different ages (Fig. 3). The results showed that kernel set was affected more by pollen grain vigor than by silk receptivity.

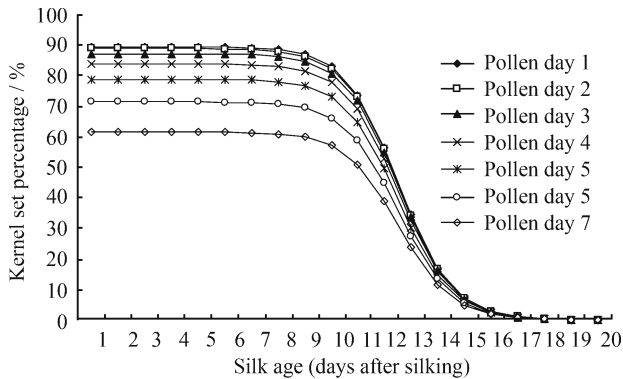


Fig. 3 Interactive effect of silk and pollen vigor on kernel set percentage

The delayed pollination affected the kernel sets, but the effect was not major because silk receptivity could remain for a relatively long time. No significantly difference was found between silk ages on the first day and the eighth day when pollinated with fresh vigorous pollens (Fig. 4). The delayed silking had a significant effect on kernel set (Fig. 5). The

result showed that the effect of delayed silking on kernel set was more significant than that of delayed pollination; it was important for kernel sets of the ears to have silks pollinated as early as possible after silks emerged.

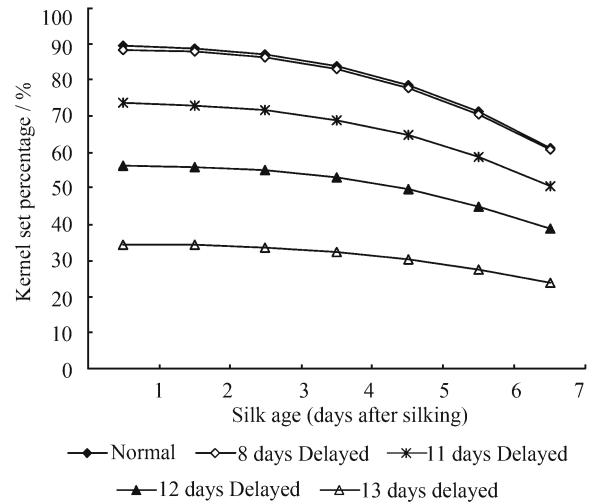


Fig. 4 Effect of delayed pollination on kernel set percentage

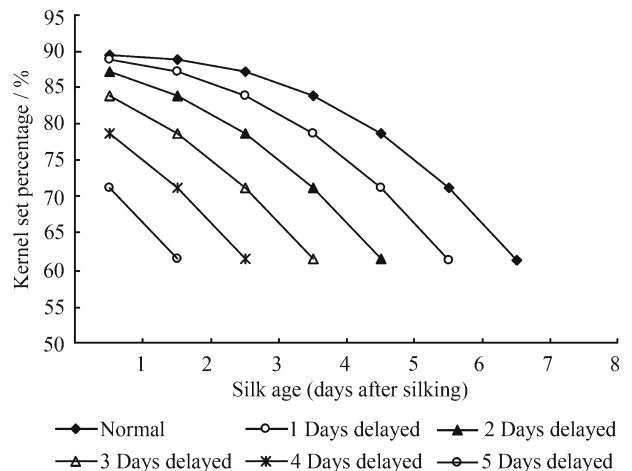


Fig. 5 Effect of delayed silking on kernel set percentage

Table 1 Pollen grain vigor and kernel sets with different shedding times

Item	Hybrid	Days of pollen shedding						
		1	2	3	4	5	6	7
TTC-dehydrogenase activity /%	Yedan12	94.41	96.33	90.00	80.10	80.00	78.20	45.30
	Yedan19	95.57	95.32	89.24	81.30	76.98	59.88	37.44
Pollen grain germination /%	Yedan12	94.80	90.98	82.15	82.57	53.60	45.83	2.40
	Yedan19	94.02	88.58	75.48	60.57	56.40	49.57	1.00
Length of pollen tube /μm	Yedan12	37.95	39.96	42.29	47.70	34.98	25.86	15.48
	Yedan19	46.00	41.76	36.57	37.84	28.73	24.91	0
Percentage of kernel sets /%	Yedan12	98.76	97.94	96.82	93.22	91.83	88.03	79.47
	Yedan19	92.70	94.81	92.15	90.27	82.41	61.01	55.60
Kernel weight /(g·per 1 000 kernels)	Yedan12	193.94	166.44	172.86	153.47	158.15	146.75	100.03
	Yedan19	269.80	228.74	218.16	191.66	221.58	197.21	167.41

3.4 Synchronization of silking and pollen shedding

A significant difference was found between the two hybrids in synchronization of silking and pollen shedding. The pollen of Hybrid Yedan 19 shed throughout the time of silking (Fig. 6). No silks of Hybrid Yedan 12 emerged during the first three days of pollen shedding and there were still about 15% of silks that did not emerge when pollen shedding finished (Fig. 7). Synchronization of silking and pollen shedding showed different characteristics in different hybrids, “partial overlapped” for Yedan 12 and “overlapped” for Yedan 19.

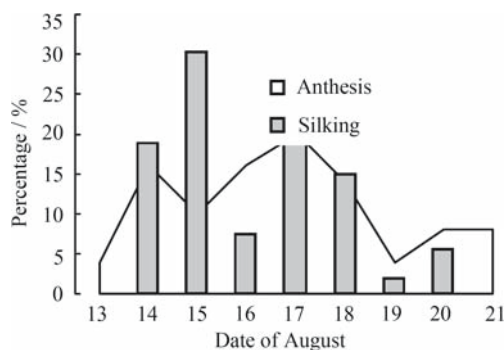


Fig. 6 Synchronization of anthesis and silking (Yedan19)

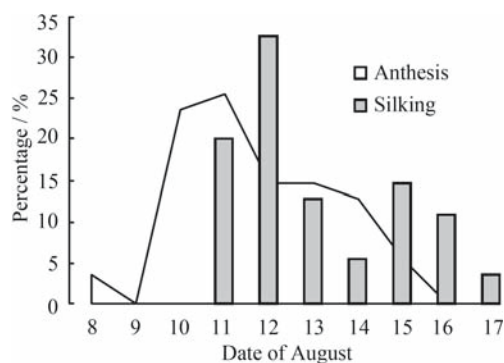


Fig. 7 Synchronization of anthesis and silking (Yedan12)

4 Discussion

The potential kernel number declined as silks lost receptivity and senesced with age (Bassetti and Westgate, 1993a; 1993b; 1993c), and kernel set and yield stability were impacted by variation among hybrids for silk elongation and senescence (Anderson et al., 2004). In this observation, silks vigor remained comparatively higher for about 7–10 days after silks emerged and decreased quickly afterwards. Both potential kernel number and kernel weight decreased as silks aged and senesced. Kernel weight reduction might be affected by the supply of photosynthates during kernel development. At the initial time of silk emergence, only a small number of florets were fertilized and enough photosynthates were

supplied to limited kernel development. However, in later days after silking, much more florets were fertilized and not enough photosynthates were supplied to kernel development. Although the silks that emerged can sustain comparatively higher vigor for a period of time, pollination time after silk emergence was crucial for grain yield in the field production of corn.

In field production, kernel sets of corn are not limited primarily by pollen amount when all plants in the population are male fertile (MF), and the potential kernel set can be predicted from simple flowering characteristics (Lizaso et al., 2003). The increased plant density may promote a reduction in pollen production per plant and lengthen the duration of pollen-shedding of an individual tassel (Uribebarrea et al., 2002). Kernel set and grain yield may be affected if pollen shedding density per exposed silk is lower than a minimum (Uribebarrea et al., 2002; Westgate et al., 2003). In this observation, delayed pollen grain shedding had weaker pollen vigor, lower percentage of germination and slower pollen tube growth rate. The kernel number and kernel weight were also reduced when pollinated with late shedding pollen. It was estimated that pollen vigor could also have some effects on the kernel sets and grain yield when the pollen shed density was higher than the minimum required.

Anthesis-silking interval (ASI) is an important trait for obtaining high grain yield in maize (Bolanos and Edmeades, 1993). The increased plant density may promote an increase in ASI (Uribebarrea et al., 2002) and in return, a higher ASI under water-stress conditions will reduce kernel number because of a lack of pollen for late-appearing silks (Hall et al., 1982). However, the shortened ASI will increase grain yield (Sarquis et al., 1998) and kernel number (Carcova et al., 2000). In this observation, the synchronization of pollen shedding and silking in two hybrids was different, i.e. ASI for Yedan 19 was only one day and that of Yedan 12 was four days. The kernel number and kernel set percentage of Yedan 19 were higher than those of Yedan 12 when pollinated naturally under field conditions.

In the field production of corn, grain yield was correlated to plant uniformity (Nafziger et al., 1991; Liu et al., 2004; Andrade et al., 2005), and kernel yield decreased linearly with decreasing uniformity of silking for the population (Fonseca et al., 2004). Uniformity of silking was apparently important for a higher grain yield when pollination and silking were synchronized, but would reduce grain yield if pollination and silking were asynchronous.

Acknowledgements This study was supported by the National Food Crops Production Scientific and Technical Project (No. 2004BA520A07), and the Natural Science Foundation of Hebei Province (No. 398079).

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