A Description of Silk Cut, a Stress-Related Loss of Kernel Integrity in Preharvest Maize

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ABSTRACT

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Silk cut is an important recurring problem of many commercial maize (*Zea mays*) hybrids exposed to late-season drought stress in southern Texas. Silk cut is the preharvest occurrence of one or more lateral splits in the kernel pericarp that expose the kernel tissues and embryo to either pre- or postharvest attack by fungi and insects. It can occur as multiple lateral splits anywhere on the seed surface but its primary and most common occurrence is as a single, lateral split at the kernel edge on either side or both sides of the embryo. Individual splits range from nearly microscopic to those that almost encircle the seed. Silk cut can be initiated at kernel moistures as high as 50% but is more commonly initiated and observed at kernel moistures of 28% and lower. In yearly observations from 1986 to 1994, silk cut was highest in incidence and severity on normal-yield-potential maize crops exposed to rapidly increasing environmental stress (decreasing soil moisture and high soil and air temperatures) during the latter stages of maturity but especially after black-layer formation. Hybrids with open ear tips and loose husks were among those most vulnerable to silk cut but incidence and severity varied widely across years, sites, and stress environments. Incidence also varied widely between adjacent plants. Total silk cut (kernels with silk cut colonized by fungi and noncolonized) on 105 and 110 ears from consecutive plants of two vulnerable hybrids averaged 23 and 31% but ranged from 0 to 94 and 0 to 97%, respectively. Average difference in silk cut incidence between ears of adjacent plants of these hybrids was 28 and 29% and individual differences ranged from 0 to 93 and <1 to 97%, respectively. Kernels on the top one-third of the ear had a higher average incidence of silk cut (44%) than those in the middle (38%) or bottom (shank end) (31%) positions.

Additional keywords: corn, drought stress, kernel streaking, popping, splitting

In 1985, grain from a maize (*Zea mays* L.) hybrid harvested in the Coastal Bend of Texas was rejected at the elevator because it had 50 ppb aflatoxin and up to 28% broken kernels (2). Hand-harvested ears and harvested grain rejected at the elevator had a high percentage of kernels with lateral splits in the pericarp that exposed the embryo and/or endosperm, which were often colonized by fungi (Fig. 1A-E). Visual inspection of harvested kernels and whole ears showed fungal colonization, predominantly by *Fusarium moniliforme* J. Sheld. and to a lesser extent by *Aspergillus flavus* Link:Fr. (Fig. 1A,B). Other fungi, such as *Penicillium* spp. and *Aspergillus niger* Tiegh., were also infrequently present. Fungal colonization ranged from single kernels to whole ears (Fig. 1B,C). Sometimes more than one fungus occurred on

the same ear but usually one predominated over the whole ear or area of an ear (Fig. 1B). The split kernels were similar to a kernel disorder or loss of kernel integrity called silk cut in various publications (3,5,6,7).

Silk cut is generally thought to be an infrequent problem on a limited number of inbreds (6,7) or hybrids (5,6). Observations made predominantly at Corpus Christi indicated that silk cut was a variable but important recurring problem on many commercial hybrids grown under drought stress conditions in southern Texas, where it was associated with reduced kernel quality and increased fungal colonization of split kernels, and possibly associated with increased aflatoxin content (2) in a manner suggested by Smart et al. (4). The objectives of our study were to describe silk cut, characterize its development, and identify primary spatial and environmental stress factors associated with its occurrence in southern Texas.

MATERIALS AND METHODS

Maize hybrids. The maize hybrids used were RX405W (Asgrow, Des Moines, IA),

P3170 (Pioneer Hi-Bred, Plainview, TX), P3358 (Pioneer), and Z61W (Zimmerman, Evansville, IN). These hybrids were chosen because they had demonstrated a moderate to high vulnerability to silk cut over one or more years at the same two field sites in which these experiments were conducted.

Planting dates and field sites. A late planting date of 11 March 1993 (mid-February to 1 March is normal) was used to enhance the probability of late-season drought stress. All experiments were established at two sites near Corpus Christi, located about 1 km apart, one with a Victoria clay and the other an Orelia (sandy clay loam) soil. The latter soil has a greater potential for drought stress because it has a plant available moisture of 12 to 14%, compared with 17% in the former (J. Matocha, *personal communication*).

Definition and evaluation of silk cut. For this study, we defined silk cut as the preharvest presence of one or more naturally occurring lateral splits in the pericarp of kernels on an ear of maize (Fig. 1A,C-E). At $\times 3$ or higher magnification, kernels were counted and evaluated for silk cut; those kernels with silk cut were classified as noncolonized (silk cut areas with no visible fungal colonization) or colonized by fungi (silk cut areas with visible fungal colonization). All kernels were stored at $\leq 12\%$ kernel moisture until evaluated for silk cut and other loss of kernel integrity. Unless noted, all kernels per ear, ear section, or sample were evaluated for silk cut. Other loss of kernel integrity (longitudinal splitting, white streaking, and other kernel abnormalities) were only noted and were not considered in analyses.

Initiation of silk cut. To determine time of silk cut initiation on kernels, four collections of five to six randomly selected ears per collection per hybrid were made after black-layer formation from three non-adjacent rows (90 m) of three hybrids (P3358, Z61W, and RX405W) at both the Orelia and Victoria sites. Collection dates were determined by moisture levels most likely to coincide with initiation of silk cut in one or more hybrids. A majority of kernels from each collected ear were evaluated for presence of silk cut, other loss of kernel integrity, and fungal colonization (presence or absence). Average kernel

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moisture was determined on each collection date for each hybrid.

Variability of silk cut incidence and severity in adjacent plants. After expression of silk cut was complete (preharvest kernel moisture at or below 12%), collections of single ears were made from 110 contiguous plants in single rows of each of two hybrids (P3358 and P3170) grown at the Orelia site in 1993. Each ear was hand

threshed and all kernels on each ear were evaluated for presence or absence of silk cut and fungal colonization of silk cut kernels. The difference in incidence of total (colonized and noncolonized) silk cut between adjacent plants was calculated by subtraction of each ear's incidence from that of adjacent ears and expressed as an absolute value. The relationship between incidence of silk cut on an ear and the pro-

portion of colonized silk cut kernels on that ear was evaluated with linear correlation (r) at the 0.05 and 0.01 levels of significance on data transformed to arcsine values (1).

Variability of silk cut incidence and severity on different areas of the ear. The association between kernel location on the ear and incidence and type of silk cut was evaluated from a sample of 150 ears (30-

Fig. 1. Kernels and ears of maize hybrid Pioneer 3358 grown at Corpus Christi, TX (unless noted). (A) Harvested kernels showing variable incidence and severity of silk cut and colonization by *Fusarium moniliforme*, Taft, TX, 1985. (B) Ears severely affected by silk cut and heavily colonized by *F. moniliforme* (top) and *Aspergillus flavus* (bottom), 1987. (C) Ear broken in half to reveal severe silk cut and fungal colonization on embryo side of kernels (left) but negligible silk cut on back of kernel (right), 1986. (D) Lateral view of kernels on an ear showing severe silk cut extending around the kernels that are heavily colonized by fungi, 1987. (E) Kernels from a single ear portion showing mostly severe silk cut (embryo side) and heavy fungal colonization by *F. moniliforme*, 1986. (F) Lateral view of kernels from unknown hybrid showing heavy, white, longitudinal streaks and small lateral splits (silk cut). Dark areas on cob (foreground) show residual *A. flavus* growth originating from kernels colonized by *A. flavus* after developing longitudinal splits, 1992.

ear samples from five separate areas of a field plot) of a single hybrid (P3170) grown at the Orelia site. All kernels were removed from each ear as one of three groups based on their approximate location at the top (upper third of the ear), middle (middle third), or bottom (shank end) of the ear. Silk cut evaluation was conducted on all kernels from each ear section of each collected ear. The relationship between incidence of silk cut and kernel location was evaluated on only the 132 ears with observable silk cut, by Student's *t* test at the 0.05 level of significance on data transformed to arcsine values (1).

Yearly observation of silk cut from 1986 through 1994. A variable number of maize experiments were established simultaneously each year at the Orelia and Victoria sites near Corpus Christi from 1986 through 1994. Measurement of silk cut incidence was one of the objectives of each experiment. Randomized complete block designs were used in most experiments and each had four or more replications; each replication was a length of row 6 m or longer with 20 or more ears of each hybrid collected from a plant population equivalent to 44,550 plants per ha (18,000 plants per acre) on a row width of 0.97 m. Each test had as few as one and as many as 40 hybrids with one or more tests established at each site each year. One commercial hybrid, P3358, was present in most tests from 1986 to 1993 and several others were present in most tests from 1991 through 1994, including P3170, RX405W, and Z61W. Most hybrids were observed for a minimum of 2 years. Planting dates varied from the second to third week in March. The research plots were continuous maize from 1985 through 1994; conventional tillage and agronomic practices common to the area were used.

Measurement of environmental stress factors. Environmental parameters (soil temperature at 9 and 15 cm depth, air temperature, relative humidity, and rainfall) were recorded on data microloggers (CR10 and CR21, Campbell Scientific, Logan, UT) at both experiment sites in 1993 to 1994 and at a single station site (Victoria) from 1986 to 1992.

RESULTS

Description of silk cut and other loss of kernel integrity. Silk cut occurs as one or more lateral splits in the kernel pericarp that expose the internal kernel tissues. It can occur as multiple splits but is present most frequently as a single, lateral split at the kernel edge on either side or both sides of the embryo (Fig. 1A,C,E). Individual splits range from nearly microscopic to those that almost encircle the seed (Fig. 1A,C–E). The lateral splits can occur anywhere on the seed surface but are most common on the embryo side, where they are always perpendicular to the embryo axis (Fig. 1A,C). Nonlateral splitting and

streaking are other loss of kernel integrity types (Fig. 1F) that occur independently or coincidentally with silk cut.

Initiation of silk cut. No silk cut was seen in the first collection (30 to 35% kernel moisture) soon after black-layer formation. A second collection at both locations showed extensive but variable (1 to 2%) development of silk cut in P3358 at 24% kernel moisture and very low levels (<1%) of silk cut in Z61W at 28% kernel moisture. In the latter, most silk cut was visible as thin, white, lateral lines beneath the pericarp surface on either side of the embryo. Kernels from P3358 at 24% kernel moisture had similar microscopic symptoms but also had visible splitting that exposed the endosperm (Fig. 2A,B), and a few of these kernels were colonized by fungi.

A third and fourth collection of ears of P3358 and Z61W at both locations made at 18 to 21% and <15% kernel moistures, respectively, had more kernels with a greater severity (larger and multiple pericarp splits) of silk cut and more fungal colonization than earlier collections but the low number of ears collected did not allow assessment of increase in incidence. There was no apparent increase in either silk cut severity or fungal colonization of silk cut kernels on mature, preharvest ears at kernel moistures below 15%. Silk cut incidence in the third hybrid (RX405W) was too low in all collections to obtain any silk cut initiation information.

Variability of silk cut incidence and severity in adjacent plants. Five of the 110 ears of P3358, none adjacent, were excluded from analysis because of poor

Fig. 2. Silk cut initiated on a kernel of hybrid P3358 before 24% kernel moisture at Corpus Christi, TX, in 1993. (A) Several lateral splits present on both sides of embryo and small, white, lateral areas in the pericarp that precede silk cut splitting (upper left). Bar = 1 mm. (B) Closeup of two splits showing pericarp projected outward exposing the endosperm. Bar = 1 mm.

seed set or other factors that precluded their evaluation for silk cut. Across the remaining 105 ears of P3358 (Fig. 3A), the incidence per ear of silk cut ranged from 0 to 94% for total silk cut (mean 23%), with 0 to 80% (mean 7%) visibly colonized by fungi and 0 to 79% (mean 16%) noncolonized. Between adjacent ears the difference in incidence of total silk cut ranged from 0 to 93% (mean 31%). There was only one grouping of adjacent ears (plants 95 through 100) with similar high levels of silk cut. Only 17 ears had 0% silk cut and they were nonadjacent, except for two groups of two and single groups of three and four ears.

Similar silk cut information was obtained from hybrid P3170 (Fig. 3B). Across the 110 ears of P3170, the incidence per ear of silk cut ranged from 0 to 97% (mean 31%) with 0 to 76% (mean 7%) visibly colonized by fungi and 0 to 86% (mean 24%) noncolonized. Between adjacent ears, the difference in incidence of

total silk cut ranged from <1 to 97% (mean 29%). Across all ears there appeared to be three to four indistinct groups (six to seven adjacent ears each) with similar moderate to high silk cut incidence. Only six ears had 0% silk cut and none were adjacent.

The correlation between incidence of silk cut and the proportion of kernels visibly colonized by fungi was significant at the 0.01 level for P3358 (Fig. 4A) and at the 0.05 level for P3170 (Fig. 4B) with linear correlation coefficients (r) of 0.45 ($n = 88$) and 0.23 ($n = 104$) respectively (1).

Variability of silk cut incidence and severity on different areas of the ear. The contribution of each ear section (T = top third, M = middle third, B = bottom third or shank) to total (cumulative) silk cut was determined for only those ears (132 of 150) that had observable silk cut (Fig. 5). Percent incidence per ear is displayed in order of increasing total silk cut. Across all 132 ears, the average silk cut incidence at T (44%) was significantly greater than at the

M (38%) and B (31%) positions of the same ears. On these 132 ears, whole ear incidence of total silk cut ranged from <1 to 98% (mean 38%).

Environments associated with incidence and severity of silk cut. The highly variable incidence of silk cut in adjacent plants and between sites, even in highly susceptible hybrids, made it difficult to identify specific environmental parameters conducive to its development. High air temperatures, usually with attendant low soil moisture and high soil temperatures, were common during crop maturation in 1993, as they were in previous years when silk cut incidence was readily detected in vulnerable hybrids.

Beginning at silking in 1993 (23 May) the occurrence of air temperatures of 30°C or higher at both sites abruptly increased from <10 h per week to >40 h per week (4 weeks) and again abruptly increased to >70 h per week (6 weeks) until maturity in most hybrids at both sites (1 August, kernel moistures ≤14%). Air temperatures ≥35°C occurred for over 20 h per week during the last 2 weeks prior to maturity. Maize planted at the Orelia site showed foliar stress symptoms earlier and matured more rapidly under stress at the end of the 1993 season than the crop planted at the Victoria site, but the difference was only a few days. The average incidence of silk cut in vulnerable hybrids in 1993 was always highest at the Orelia site, with incidence sometimes twice that at the Victoria site.

In yearly observations from 1986 through 1994, silk cut was highest in incidence and severity on maize crops of normal yield potential exposed to rapidly increasing environmental stress (decreasing soil moisture and high soil and air temperatures) during the latter stages of maturity, especially after black-layer formation. Silk cut development was generally higher on maize grown at the Orelia rather than the Victoria site except in years when early and midseason stress caused a much-reduced yield potential and kernel size. The smaller, softer kernels generally had less silk cut development. Silk cut development was less in high-yield maize crops with large-kernel ears if there was sufficient soil moisture available before and after black-layer formation to avoid drought stress. These soil conditions usually coincided with somewhat lower air temperatures than those commonly associated with late season drought stress.

DISCUSSION

Previous photographs of silk cut (3,5–7) show pericarp splits occurring only on the side of the kernel opposite the embryo. Although we commonly observed splitting on this side of the kernel, both initial and primary occurrence of silk cut were predominantly on the embryo side of the kernel. The most common and initial symptom of silk cut was a single, mid-kernel

Fig. 3. Incidence and type of silk cut in kernels of individual ears of adjacent plants in single rows of maize grown on Orelia soil at Corpus Christi, TX, in 1993. (A) 105 plants of maize hybrid Pioneer 3358. (B) 110 plants of hybrid P3170.

split in the pericarp that occurred perpendicular to the kernel axis on either side or both sides of the embryo on the outside edge of the flat surface of the kernel (Fig. 1A). Ullstrup (5–7) noted that the primary fungal colonizer of silk cut kernels was *F. moniliforme*, which was also our observation, but *A. flavus* was also common (2).

Silk cut and associated fungal colonization were evident after maturity but initiated prior to maturity. The specific timing of silk cut initiation and development was difficult to assess but our observations indicated that it occurred in a spatially variable manner during the latter stages of kernel maturation and drydown. In our experiments, silk cut was readily found in some ears of susceptible hybrids at kernel moistures of 28%. This is consistent with observations in other years but silk cut has been observed at kernel moistures as high as 50% (G. N. Odvody, unpublished).

Another loss of kernel integrity sometimes associated with environmental stress and with silk cut was a longitudinal white streaking under the kernel pericarp. In some hybrids it often progressed into longitudinal splits in the pericarp sometimes with associated fungal colonization. Kernel popping or splitting (3,5–7) is another common but minor loss of kernel integrity that is noted in years of high rainfall or wet and fluctuating soil moisture conditions during the early stages of grain filling. This syndrome can affect a few to all kernels of an ear and typically produces variously sized, single splits across the crown or sides of the kernel. The split can occur at any angle and resembles a bursting of the seed with excessive moisture. These split, high-moisture kernels are readily colonized by fungi and the residual kernel material disintegrates upon harvest. In our study a small number of ears had both silk cut and “popped” kernels present.

Our data indicate that the incidence and severity of silk cut on adjacent field plants were highly variable in even the most vulnerable hybrids. Assessment of a hybrid's vulnerability to silk cut required a large number of ears because silk cut incidence varied from 0 to 98% on adjacent plants. That variability, plus reduced incidence and severity of silk cut in most hybrids in normal or marginal-drought years, may account for its previous lack of recognition and observation. Silk cut and other associated loss of kernel integrity may be most prominent in southern Texas because severe stress environments periodically occur here and are more common during the latter stages of maturity. Silk cut was observed on mature, irrigated maize in the Rio Grande valley in 1991 and 1992 (G. N. Odvody, unpublished) and on dryland maize in central Texas (Bell County) in 1993 and 1994 (G. N. Odvody, unpublished), but it appeared to be most common

Fig. 4. Incidence and type of silk cut in kernels of individual ears of (A) 105 adjacent plants of hybrid P3358 and (B) 110 adjacent plants of hybrid P3170 grown in single rows on Orelia soil at Corpus Christi, TX, in 1993. Ears of maize are sorted in order of increasing total silk cut

Fig. 5. Incidence of silk cut on different areas of the same ears of maize hybrid P3170 grown on Orelia soil at Corpus Christi, TX, in 1993.

under dryland production in southern Texas.

Our analysis of silk cut incidence and kernel location on the ear indicated that silk cut was highest at the ear tip and lowest at the base (shank end). Kernels at the top of the ear are the last to be pollinated and the last to accumulate photosynthate, so they may be the most vulnerable to late season stress factors. Some of the most vulnerable hybrids had an open ear tip, which may have promoted accelerated drying compared with ears having husks tightly closed at the ear tip. The physical factors associated with the occurrence of silk cut are unknown but may involve a cycle of rapid drying of kernel surfaces by day followed by rehydration at night. We propose that when these events occur early in the maturation process, the premature hardening of kernel surfaces during the day may promote a splitting of the kernels at their weakest points during nighttime rehydration. Most single splits and early, initial splits generally have an appearance of being pulled apart, as opposed to the bursting type of splitting seen with kernel popping. The stress-related kernel streaking and longitudinal splitting that are often associated with silk cut may also be influ-

enced by some of the same external stress environments and kernel physical factors. Kernel popping occurs at higher moistures, but, like silk cut and longitudinal streaking and splitting of kernels, it may also be influenced by fluctuating kernel moistures interacting with an external, variable stress environment.

The highly variable nature of silk cut made it difficult to identify environments conducive to its development but yearly observations from 1986 through 1994 allowed some generalizations about environmental parameters that influence the incidence of silk cut on vulnerable hybrids. Our observation that silk cut was highest in incidence and severity on maize crops of normal yield potential exposed to rapidly increasing environmental stress is consistent with photographs (3,5-7) showing silk cut kernels of apparently normal size and shape. Those hybrids consistently vulnerable to silk cut under variable stress environments should probably not be grown in this region. Because hybrids with open ear tips and loose husks are among the most vulnerable to silk cut, similar, untested hybrids should be regarded as being potentially at risk for increased silk cut until proven otherwise.

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