Field Drying of TopCross High-Oil Corn Grain

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ABSTRACT

Most high-oil (HO) corn (*Zea mays* L.) grown in the USA utilizes the TopCross system, which involves planting a blend (TC Blend) of two types of corn. Field grain drying of TC Blends may be slower than normal (low oil) corn hybrids of similar maturity, which could result in later harvest or increased costs of artificial drying after harvest. The objective of this study was to determine whether HO grain produced by TC Blends dries to moisture percentages typically associated with corn harvests on the same calendar dates as normal corn grain. Field drying of corn grain was followed in five TC Blends and their normal counterparts (check hybrids) grown in strip plots established at multiple locations in central Ohio in 1995 and 1996. Moisture measurements of grain from HO and check hybrids during field drying and at harvest were determined using the USDA approved air-oven drying method, commercial electronic moisture testers, or both. Differences in field grain drying and grain moisture at harvest between the TC Blends and their respective check hybrids were generally small and not significant ($P = 0.05$), with only one of the five pairs showing large differences each year. Differences in grain drying were greater in 1995 than in 1996, suggesting that environmental conditions may influence differences in the time required for HO and check hybrid grain to reach harvest moisture levels. Results of this study indicate that HO corn can be produced without additional grain-drying costs.

High-oil corn (HOC) contains one and one-half to two times more oil and higher quality proteins than normal yellow dent corn (Lambert, 1994; Watson, 1987). It is attractive as a livestock feed, especially for swine and poultry, because it has greater energy value than normal yellow dent corn and can replace more expensive dietary sources of fats and proteins. Feeding trials with HOC indicate that it has improved feed efficiency and results in increased rate of gain compared with conventional corn (Lambert, 1994; Alexander, 1988).

Commercial HO single-cross hybrids have not been widely used by growers because their grain yield potential is lower than normal dent hybrids (Watson and Freeman, 1975; Lambert, 1994). Recently, there has been interest in producing HOC using the TopCross[1] grain production system licensed by Optimum Quality Grains, L.L.C. (hereafter referred to as Optimum). The TopCross system minimizes the yield disadvantage associated with conventional HOC hybrids and enhances grain nutrient composition (Edge, 1997; Lambert et al., 1998). The TopCross HO grain production system involves planting a blend (TC Blend[1]) of two types of corn (Edge, 1997). One type, representing 90 to 92% of the seed in the blend, is a hybrid that is designated as the *grain parent*. The second type, representing 8 to 10% of the seed in the blend, is a special *pollinator*. The grain parent is a male sterile (produces no viable pollen) version of an elite hybrid. The pollinator is a special line available from Optimum and licensed to seed companies. Pollinators are either synthetics, *pseudo hybrids*, or open-pollinated populations (Edge, 1997). The primary function of pollinators is to provide pollen to male sterile grain parents; however, they contribute little to grain yield. The pollen shed from these pollinator plants contain genes that cause production of kernels with larger-than-average embryos. Because most of the oil and essential amino acids are in the embryo, the increased embryo size of HOC results in greater oil content and enhances the protein quality of the grain.

The blends used to produce TopCross grain are designated TC Blend seed corn products (hereafter referred to as TC Blends; Edge, 1997). According to the U.S. Grains Council (1999), essentially all U.S. HOC production utilizes the TopCross system. In 1998, more than 400 000 ha were planted to TC Blends (U.S. Grains Council, 1999).

Although HOC may be a profitable alternative to normal (low oil) corn, production costs associated with TopCross corn are greater. The TC Blend seed is more expensive than normal hybrid seed, and growers may need to use higher seeding rates to compensate for the lower grain yields of pollinator plants in TC Blends (Thomison, 1997). In addition, greater grain moisture at harvest, compared with normal corn, may increase drying costs for HOC (Lambert, 1994). Lower grain moisture at harvest among hybrids of similar maturity is preferred because it allows earlier harvest and reduces the costs of artificial drying.

Corn growers in Ohio have reported higher grain moisture and lower test weights for HOC produced from TC Blends than for normal hybrids of similar maturity. Previous research has indicated that HO single-cross hybrids, having the same date of anthesis as normal-oil hybrids, often have higher grain moisture content at harvest time (Misevic et al., 1988; Miller et al., 1981). Limited information is available on the effects of the TopCross production system on HOC grain drying and moisture content at harvest. Most university performance trials of TC Blend have not included normal (low

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[1] TopCross and TC Blend are registered trademarks of Optimum Quality Grains, Des Moines, IA. Trade names are used in this publication solely for the purpose of providing specific information. Mention of a trade name, proprietary product, or specific equipment does not constitute a guarantee or warranty by the Ohio State University and does not imply approval of the named product to the exclusion of other products that may be suitable.

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Abbreviations: HO, high oil; HOC, high-oil corn; GDD, growing degree days.

oil) counterparts (check hybrids), which has prevented a comparison of field drying and harvest grain moisture in TopCross vs. normal grain. A recent Wisconsin evaluation comparing the agronomic performance of four TC Blends and their normal counterparts indicated higher moisture in TopCross grain at harvest (Lauer, 1995). The field-drying characteristics and harvest moisture content of HO grain relative to normal corn grain will be an important consideration for growers assessing the additional costs associated with the production of TC Blends. The objective of this study was to determine whether HO grain produced by TC Blends dries to harvest moisture content on the same calendar dates as normal corn grain.

MATERIALS AND METHODS

The unique nature of the TopCross grain production system makes an effective evaluation of TC Blend performance in conventional small plots difficult and questionable. Due to the limited number of pollinator plants in a TC Blend and the resulting reduction in pollen shed, as well as the potential for xenia effects (from neighboring normal corn), we conducted these evaluations of grain moisture loss using field-scale strip plots (61 to 183 m in length) that would better approximate and simulate a comparison of TC Blend and normal corn hybrid performance in grower fields.

Strip plots were established in central Ohio at Buckeye Lake, South Charleston, and Washington Courthouse in 1995 and at Hebron, South Charleston, Washington Courthouse, and Columbus in 1996. Five TC Blends (Pfister brand Super-Kernoils) were compared with their normal (low oil) grain parents. The normal grain parents were a 50:50 fertile/male sterile mix. The TC Blends contained the same pollinator in both years. The relative maturity and growing degree day (GDD) ratings (from VE to R6; Ritchie et al., 1989) of the normal grain parents (hereafter referred to as check hybrids) ranged from 108 to 110 d and 1483 to 1500 GDD, respectively. Each TC Blend and check hybrid was planted in a strip plot at least four rows wide (0.76-m row spacings) and 61 m in length at each location. The soil types, fertilizer rates, and planting and harvest dates varied with location (Table 1). Insect and weed management strategies appropriate for minimizing crop stress were followed at each location. The previous crop at each location was soybean [*Glycine max* (L.) Merr.], and the strip plots were established using no tillage.

If pollen from normal (low oil) corn pollinates the male sterile hybrids in a TC Blend, the HO trait is not expressed in the TopCross grain produced by these TC Blends. To minimize contamination of TC Blends by pollen from check hybrids, we used the following testing protocol for comparing TC Blends and their fertile grain-parent counterparts. At each location, a 61-m buffer, separating the TC Blend plots from the neighboring check hybrids, was planted with TC Blend seed to minimize foreign pollen contamination. The TC Blends were randomly assigned to one plot each at one end of the buffer and check hybrids at the other. Borders (6.1–15.2 m) on other sides of the isolation field were also planted with TC Blend seed to minimize edge row effects and ensure adequate pollen shed. At all locations, the only nearby foreign pollen source was that of the grain parent check hybrids. This method for evaluating TC Blends and check hybrids is similar to that used by various seed companies (Gaspar, 2000; Thomison et al., 1997).

Ten ears were sampled for grain moisture from each TC Blend or hybrid check strip at five weekly intervals in 1995 and six weekly intervals in 1996 at each location. The first sample date occurred when corn achieved the late dent stage (R5; Ritchie et al., 1989) and the kernel milk line was visible within the upper one-fourth of the kernel length (Crookston and Kurle, 1988). Ears were sampled until kernel moisture content was near 200 g kg^{-1} or until kernel moisture stopped decreasing due to cool temperatures. The 10 ears were randomly selected from plants in a 15.2 m length of row in the center of each strip plot to ensure minimal pollen contamination although ears from obviously stunted or damaged plants were avoided. Because pollinator plants were generally barren or produced small, poorly developed ears, only ears from grain parent plants were sampled in TC Blend plots. The small, poorly filled ears of pollinator plants were distinguished from similar ears of grain parent plants using kernel appearance because ears from the latter were characterized by larger, dented kernels with smaller embryos. The 10 ear samples were shelled by hand, and moisture content (expressed on a wet weight basis) was determined on a 200-g subsample of grain using the USDA approved air-oven method for determining moisture in shelled whole-kernel corn (ASAE, 1986). Grain moisture content was also estimated with a stationary electronic grain-moisture tester (Model GAC2000, DICKEY-john, Auburn, IL) and recorded on a wet weight basis. While the air-oven method is more accurate in determining true grain moisture than electronic testers (Paulsen et al., 1983), it is more laborious and time consuming, and therefore less likely to be used under the field conditions and production environments where comparisons of HOC and conventional corn will occur.

At harvest, an additional sample of 10 ears per plot was collected. These ears were shelled by hand, and a subsample of grain from each plot was submitted to the Ohio State University Grain Quality Laboratory (Wooster, OH) and the Optimum Grains Laboratory (Urbandale, IA) for grain nutrient composition analysis. Oil content was determined by near infrared transmittance analysis (Itnyre, 1992). When plots were harvested by combine, grain moisture content was measured on a wet weight basis using a hand-held grain moisture tester (Model DjGMT, DICKEY-john, Auburn, IL).

Simple linear regression was used to calculate how soon grain from each plot dried to targeted moisture levels. Two equations, one for each moisture determination method, were fitted to the data for each hybrid at each location using Julian day as the independent variable and grain moisture as the

Table 1. Locations, cultural practices, and soil types for TopCross high oil corn (HOC) grain moisture loss evaluations, 1995 and 1996.

Year	Location	Planting date	Fertilizer rate (N–P–K)	Harvest date	Soil type
			kg ha^{-1}		
1995	**Buckeye Lake**	**23 May**	**224–0–0**	**8 Nov.**	**Mesic Aquic Hapludalf**
	South Charleston	**1 May**	**196–0–0**	**13 Oct.**	**Mesic Typic Argiaquoll**
	Washington Courthouse	**23 May**	**202–69–110**	**1 Nov.**	**Aeric Ochraqualf**
1996	**Columbus**	**21 May**	**224–0–0**	**7 Oct.**	**Aquic Hapludalf**
	Hebron	**31 May**	**215–91–103**	**31 Oct.**	**Mesic Aquic Hapludalf**
	South Charleston	**20 May**	**202–0–0**	**22 Oct.**	**Mesic Typic Argiaquoll**
	Washington Courthouse	**21 May**	**179–0–0**	**14 Nov.**	**Aeric Ochraqualf**

Table 2. Monthly total precipitation and mean monthly temperatures for 1995 and 1996 test sites.

Year	Location	Apr.	May	June	July	Aug.	Sept.	Total or mean‡
					Precipitation, mm			
1995	Buckeye Lake	88 (98)†	146 (115)	127 (127)	109 (107)	172 (105)	41 (76)	683 (628)
	South Charleston	80 (102)	181 (116)	162 (105)	67 (104)	93 (89)	30 (78)	613 (594)
	Washington Courthouse	87 (90)	178 (118)	73 (90)	37 (98)	117 (90)	49 (76)	541 (562)
					Temperature, °C			
	Buckeye Lake	8.6 (10.7)	14.4 (16.3)	21.7 (20.8)	23.6 (22.9)	24.5 (22.0)	16.2 (18.3)	18.2 (18.5)
	South Charleston	9.8 (10.6)	15.7 (16.3)	22.3 (21.2)	24.1 (23.2)	25.2 (22.2)	17.2 (18.4)	19.0 (18.7)
	Washington Courthouse	10.6 (11.1)	15.1 (16.7)	21.6 (21.2)	23.4 (23.1)	24.5 (22.3)	17.3 (18.9)	18.8 (18.9)
					Precipitation, mm			
1996	Columbus	212 (96)	255 (109)	208 (112)	266 (119)	31 (94)	214 (75)	1168 (605)
	Hebron	121 (98)	226 (115)	102 (127)	150 (107)	27 (105)	142 (76)	768 (628)
	South Charleston	180 (102)	176 (116)	97 (105)	106 (104)	21 (89)	119 (78)	699 (594)
	Washington Courthouse	153 (90)	245 (118)	152 (90)	119 (98)	39 (90)	128 (76)	836 (562)
					Temperature, °C			
	Columbus	9.6 (10.6)	15.8 (16.3)	21.9 (21.3)	22.4 (23.4)	22.7 (22.6)	18.4 (18.9)	18.5 (18.9)
	Hebron	9.1 (10.7)	14.8 (16.3)	20.9 (20.8)	21.2 (22.9)	21.4 (22.0)	17.2 (16.7)	17.4 (18.2)
	South Charleston	9.1 (10.6)	15.7 (16.3)	22.0 (21.3)	22.3 (23.2)	22.4 (22.3)	17.8 (18.4)	18.2 (18.7)
	Washington Courthouse	9.7 (11.1)	15.7 (16.7)	20.9 (21.2)	22.0 (23.1)	22.7 (22.3)	18.6 (18.9)	18.3 (18.9)

† Numbers in parentheses indicate departure from long-term average (30 yr).
‡ 7-mo total for precipitation (mm) or 7-mo mean for temperature (°C).

dependent variable. The resulting equations were used to compute the estimated days when the grain dried to 250 and 200 g kg^{-1} moisture content (Graybill, 1976). The recommended grain moisture level at which to harvest corn in Ohio for dry grain storage is 250 g kg^{-1} (Ohio State Univ. Ext., 1995). At this grain moisture content, kernel damage and harvest losses from combine harvest are minimized. However, many growers may wait until grain dries down to 200 g kg^{-1} or less to minimize drying costs.

In 1995, there were two testing methods, 10 hybrids, and three locations requiring 60 simple linear regressions of grain moisture on Julian day. For 1996, with four locations, there were 80. Hence, there were 140 regressions analyses. Eighty-two, or more than one-half, of the regressions had coefficients of determination (r^2) values $\geq$0.9, and 137, or 98%, had r^2 values $\geq$0.5. In 1995, the regression coefficients were between -0.72 and -0.36 for the GAC2000 method and between -0.80 and -0.36 for the oven-drying method. In 1996, the coefficients were between -0.57 and -0.22 and between -0.61 and -0.23 for the GAC2000 and oven-drying methods, respectively.

Data from the strip tests were combined each year and analyzed as a randomized complete block split plot with three replications in 1995 and four replications in 1996. Type of corn, HOC (TC Blend) vs. low-oil corn (check hybrid), was assigned to the whole plot, and grain parent was assigned to the subplot. Least significant differences at 0.05 probability level were calculated using the results of the analysis of variance.

RESULTS AND DISCUSSION

The 1995 growing season had less precipitation and higher temperatures compared with 1996 (Table 2). Total precipitation from April to September at the three sites in 1995 ranged from 21 mm below to 53 mm above the long-term average, and air temperatures from April to September were 0.1°C below to 0.3°C above the long-term average. In contrast, precipitation at the four sites in 1996 was 105 to 587 mm above normal and 0.4 to 0.8°C below normal. However, precipitation at the experimental sites in 1995 was distributed better during the grain-filling period than in 1996, during which all four sites experienced below-average August rainfall.

There were significant ($P < 0.05$) differences in grain oil content between TC Blends and check hybrids in both years (Table 3). The five TC Blends averaged 30 and 29 g kg^{-1} more oil than the check hybrids in 1995 and 1996, respectively. There were significant differences in grain oil content among the TC Blends in 1996 but not in 1995 (Table 3). Differences in grain oil content among the check hybrids were not significant in either year.

Average grain moisture at combine harvest was 183 and 249 g kg^{-1} in 1995 and 1996, respectively. Warmer- and drier-than-normal weather in September 1995 facilitated rapid grain-drying at test sites, whereas wetter and cooler conditions in September 1996 slowed grain drying (Table 2). Differences in grain moisture content between the TC Blends and check hybrids were not significant in either year (Table 3). Grain parent effects on moisture content were significant, and differences in grain moisture content were significant among the check

Table 3. Grain oil content and moisture at harvest of high-oil (HO) TC Blends and check hybrids averaged across strip tests in Ohio, 1995 and 1996.

		1995		1996	
Type	Brand and TC Blend or Hybrid	Oil†	Grain moisture‡	Oil	Grain moisture
		g kg^{-1}			
HO TC Blends	Pfister SK3034-2	75	189	80	263
	Pfister SK3001-2	73	175	66	250
	Pfister SKX577-2	75	192	71	252
	Pfister SKX592-2	70	191	69	250
	Pfister SK2650-2	72	181	65	234
	$\bar{x}$	73	186	70	250
Check hybrids	Pfister 3034	45	189	44	263
	Pfister 3001	43	175	40	249
	Pfister X577	42	191	41	261
	Pfister X592	42	164	41	237
	Pfister 2650	41	177	40	228
	$\bar{x}$	43	179	41	248
	LSD (0.05)				
	Types	6	29	2	27
	Hybrid	4	12	2	25
	Hybrid within types	6	16	3	36
	Types within hybrids	8	31	4	41

† Expressed on a dry weight basis.
‡ Determined by a hand-held grain moisture meter (Model DjGMT, DICKEY-john, Auburn, IL) and expressed on a wet weight basis.

Table 4. Estimated day of year when grain of high-oil (HO) TC Blends and check hybrids, averaged across three Ohio locations in 1995, dried to 250 and 200 g kg^{-1} moisture as determined by the oven-drying method and GAC2000 grain moisture tester.

		Oven drying		GAC2000	
Type	Brand and TC Blend or Hybrid	250 g kg^{-1}	200 g kg^{-1}	250 g kg^{-1}	200 g kg^{-1}
		Day of year			
HO TC Blends	Pfister SK3034-2	277	288	284	296
	Pfister SK3001-2	274	284	282	293
	Pfister SKX577-2	274	284	282	291
	Pfister SKX592-2	281	290	281	289
	Pfister SK2650-2	272	281	277	288
	$\bar{x}$	276	285	281	291
Check hybrids	Pfister 3034	273	284	280	291
	Pfister 3001	269	279	277	286
	Pfister X577	271	281	278	288
	Pfister X592	266	273	272	280
	Pfister 2650	268	276	273	283
	$\bar{x}$	269	279	276	286
	LSD (0.05)				
	Types	14	18	10	11
	Hybrid	5	6	3	4
	Hybrid within types	8	9	5	6
	Types within hybrids	15	18	11	11

hybrids and the TC Blends in 1995. In 1996, there were no significant grain parent effects or significant differences in grain moisture levels at harvest among the TC Blends or the check hybrids (Table 3).

In 1995 and 1996, both the oven-drying method and GAC2000 moisture tester measurements (Tables 4 and 5) indicated that the dates on which grain dried to 250 and 200 g kg^{-1}, respectively, were later for the TC Blends than for the check hybrids. Averaged across years, differences were about 5 d for the oven-drying method and 4 d for the GAC2000 method. However, these differences in grain drying between TC Blends and check hybrids, as measured by both testing methods, failed to achieve significance.

Grain parent effects on grain drying and differences in grain drying between grain parents within and between corn types were not consistent each year (Table 4 and 5). Some of this variability may be attributed to varying environmental conditions, during which grain dried in 1995 and 1996. Because TC Blends that dry down similarly to their normal hybrid counterparts are available, we conclude that TopCross HOC may be produced without additional drying costs.

Measurements of grain moisture were higher with the GAC2000 than with the oven-drying procedure. As a result, estimates of days when grain reached 250 and 200 g kg^{-1} were consistently later based on the GAC2000 than the oven-drying technique (Tables 4 and 5). However, both methods of moisture determination indicated that differences in grain drying between TC Blends and check hybrids were not significant. Previous studies have shown that electronic moisture testers may record higher corn grain moisture than that determined by the USDA air-oven reference method (Paulsen et al., 1983; Maier, 1993).

Previous investigators have attributed some of the differences in field drying between HOC and normal corn to differences in kernel composition, the proportion of embryo to endosperm tissue, and differences in the drying properties of embryo and endosperm tissues. Misevic et al. (1988) proposed that the increased moisture content of HOC at harvest observed in their study could result from a larger embryo, a harder textured (flinty) endosperm, or both. The embryo of a HOC kernel is larger than that of a normal corn kernel, and this increases the embryo/endosperm ratio (Lambert, 1994).

Table 5. Estimated day of year when grain of high-oil (HO) TC Blends and check hybrids, averaged across four Ohio locations in 1996, dried to 250 and 200 g kg^{-1} moisture as determined by the oven-drying method and GAC2000 grain moisture tester.

		Oven drying		GAC2000	
Type	Brand and TC Blend or Hybrid	250 g kg^{-1}	200 g kg^{-1}	250 g kg^{-1}	200 g kg^{-1}
		Day of year			
HO TC Blends	Pfister SK3034-2	290	304	302	318
	Pfister SK3001-2	292	306	301	313
	Pfister SKX577-2	290	301	300	311
	Pfister SKX592-2	290	301	298	311
	Pfister SK2650-2	291	302	296	309
	$\bar{x}$	291	303	299	312
Check hybrids	Pfister 3034	291	306	299	313
	Pfister 3001	285	295	295	306
	Pfister X577	287	298	298	309
	Pfister X592	288	297	295	305
	Pfister 2650	288	300	298	313
	$\bar{x}$	288	299	297	309
	LSD (0.05)				
	Types	7	9	7	8
	Hybrid	3	5	5	7
	Hybrid within types	5	7	7	10
	Types within hybrids	8	11	9	12

Embryo tissue absorbs three to five times more water than the endosperm (Ratkovic et al., 1982). Syarief et al. (1984), in evaluating the moisture-absorbing properties of different kernel parts, found that diffusion coefficients increased with increasing moisture content over a range of 50 to 300 g kg^{-1} moisture content on a dry weight basis. The diffusion coefficient of the germ (embryo) was 3.5 to 3.8 times that of the floury endosperm and 4.5 to 5.7 times that of horny (flinty) endosperm.

In a recent Illinois study, Lambert et al. (1998) found that the TopCross method increases kernel embryo size of the male sterile hybrid and oil content but does not affect harvest grain moisture content. However, their study did not use commercial TC Blends but rather two-row plots of detasselled male sterile hybrids bordered by a HO pollinator (Lambert et al., 1998); grain moisture content at harvest was determined on two rows of male sterile hybrids that did not contain pollinators.

Past research (Miller et al., 1981; Misevic et al.,1988) that associated slower drying with HOC has compared HOC hybrids with conventional corn hybrids that differ in their genetic backgrounds. Because HO-TC Blend grain parents are genetically identical to their respective check hybrids except for cytoplasmic male sterility, grain-drying properties may not vary as much as they do between single-cross HO and conventional corn hybrids.

This study focused on grain drying of TC Blends and check hybrids under field conditions before harvest. Although the study showed that grain from HOC achieved recommended combine grain moisture later than grain from check hybrids, differences were small and not significant. However, varying environmental conditions, including cultural practices and weather, may mask or magnify potential differences in field grain drying. An evaluation of HOC grain drying in the north-central Corn Belt and in late plantings of TC Blends would help address these concerns. Future investigations should also consider a comparison of postharvest drying of TopCross and check hybrid grain, which would allow an assessment of HO grain drying under more controlled environmental conditions.

SUMMARY

The oil content of HOC grain from TC Blends averaged 70% greater than in grain from check hybrids. This increase in grain oil content was achieved without significant effects on harvest grain moisture content. Based on two methods of grain moisture determination, differences in field grain drying between TC Blends and their respective check hybrids were small and not significant. We conclude that TopCross HOC can be produced without additional grain-drying costs.

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