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Effect of Pollination Levels on Yield and Quality of Maize Grown for Silage

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Abstract: Maize (*Zea mays* L.) hybrids with good yields of grain and whole-plant dry matter are preferred for forage production. The objective of this study was to examine the relationship between kernel development and nutritive value of maize silage, using controlled pollination to alter the extent of ear fill in 4 maize hybrids. Whole-plant acid detergent fiber (ADF), neutral detergent fiber (NDF), and crude protein (CP) were measured. Pollination control affected the ear fill for 0% and 100% pollination levels. Stem diameter and plant height were not affected by pollination treatment; however, they were different for the hybrids. Leaf content and stalk content were negatively correlated (r = -0.68** and -0.87**, respectively) with actual ear fill. Ear content was also positively correlated with dry matter (DM) yield (r = 0.69**) and was negatively correlated with ADF (r = -0.73**) and NDF (r = -0.73**). Harvest index varied among pollination treatments and the hybrids. The greatest DM yield (17.8 Mg ha^{-1}) obtained at 100% pollination level. Whole-plant DM content increased by 19% as pollination level increased from 0% to 100%. DM content was positively correlated with grain yield (r = 0.80**) and ear content (r = 0.81**) and it was negatively correlated with leaf content (r = -0.63**) and stalk content (r = -0.77**). Whole-plant NDF (r = -0.81**) and ADF (r = -0.75**) were negatively correlated with pollination levels or actual ear fill. DM content and DM yield increased with pollination levels as a function of ear fill. The results revealed that ear fill and kernel development are important factors in decreasing whole-plant NDF and ADF values.

Key Words: Silage maize, pollination, agronomic characters, dry matter yield, crude protein, acid detergent fiber, neutral detergent fiber

Tozlaşma Düzeylerinin Silajlık Mısırda Verim ve Kaliteye Etkisi

Özet: Kuru madde ve tane verimi iyi olan mısır çeşitleri yem üretiminde daha çok tercih edilmektedir. Bu çalışmanın amacı, kontrollü tozlaşma koşullarında dört silajlık mısırda tane gelişimi ve yem değerleri arasındaki ilişkileri incelemektir. Araştırmada, kontrollü döllenme koşullarında mısır çeşitlerinin asit deterjan fiber (ADF), nötral deterjan fiber (NDF) ve ham protein (CP) değerleri incelenmiştir. Tozlaşmanın kontrol edilmesiyle koçanda tane oluşumu etkilenmiştir. Tozlaşma uygulamalarının bitki boyu ve sap kalınlığına etkisi görülmemiştir. Ancak, mısır çeşitleri arasında bitki boyu ve sap kalınlığı bakımından farklılıklar belirlenmiştir. Koçanda tane oluşumu ile yaprak oranı (r = -0.68**) ve sap oranı (-0.87**) arasında negatif ilişki vardır. Koçan oranı ile kuru madde verimi arasında (r = 0.69**) pozitif ilişki olmasına karşın, ADF (r = -0.73**) ve NDF (r = -0.73**) oranı arasinda negatif ilişki belirlenmiştir. Mısır çeşitlerinde hasat indeksi tozlaşma uygulamalarına göre değişkenlik göstermiştir. En yüksek kuru madde verimi (17.8 Mg ha^{-1}) %100 açık tozlaşma uygulamasından elde edilmiştir. %100 tozlaşma uygulamasından elde edilen kuru madde oranı, %0 tozlaşma uygulamasına göre %19 daha yüksek olmuştur. Kuru madde oranı ile tane verimi (r = 0.80**) ve koçan oranı (r = 0.81**) arasında pozitif, yaprak oranı (r = -0.63**) ve sap oranı (r = -0.77**) arasında negatif ilişki belirlenmiştir. Mısır çeşitlerinde, tozlaşma oranı veya koçanda tane oluşumunun artmasıyla NDF ve ADF oranlarında azalma belirlenmiştir. Koçanda tane oluşumuna bağlı olarak kuru madde verimi ve kuru madde oranı da artmıştır.

Anahtar Sözcükler: Silajlik mısır, tozlaşma, agronomik özellikler, kuru madde verimi, ham protein oranı, asit deterjan fiber, nötral deterjan fiber

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Introduction

Forage maize, a summer-growing crop, is usually harvested and ensilaged in autumn to feed ruminants. Maize silage is a high-quality forage crop that is used on many dairy farms and on some beef cattle farms in Turkey. Approximately 600,000 hectares of grain maize are grown annually and 10% of this production is harvested for silage (TKB, 2007). Within the last 10 years, silage maize production has increased after harvesting of winter cereals like barley or wheat and in irrigated regions where the vegetation period is too short for grain production. There are several government programs to increase the number of farmers to produce maize silage.

Many environmental factors, management systems, and genetic factors influence yield and quality of maize forage (Struik, 1983; Deinum, 1988; Cox et al., 1994; Cusicanqui and Lauer, 1999). Forage maize producers usually are advised to plant hybrids with high grain-yielding potential since a high grain content increases maize forage palatability, energy level, and digestibility (Woody et al., 1983; Wolf et al., 1993) since corn silage nonstructural carbohydrates is mostly starch (NRC, 2001), and typically accounts for about 50% of total dry matter under good conditions (Irlbeck et al., 1993; Coors et al., 1994). Allen et al. (1991) observed a strong relationship between grain content and whole-plant digestibility (r = 0.80) on a broad range of hybrids, some with very low grain yields. However, Deinum and Bakker (1981) observed only a weak relationship between digestibility and ear filling percentage. Maize silage produced from plants containing a low proportion of grain have contained greater concentrations of acid detergent fiber and acid detergent lignin, and lesser concentrations of digestible organic matter, causing less milk production when added to dairy rations (Phipps et al., 1979; Russell et al., 1992). The ideal silage maize hybrid needs a grain fraction of at least 300 g kg^{-1} (Pinter, 1986). Similarly Barriere et al. (1997) concluded that the optimal grain content should be around 46%, corresponding to a starch content of about 30%. Nocek (1997) reported that over 30%-40% of starch in rations may cause acidosis and metabolic problems. NDF and starch content should be balanced to avoid milk fat depression and acidosis in dairy cattle rations (NRC, 2001) Kernel development is influenced by the climate and photo-period (Struik, 1983). In some regions of Turkey, kernel development is not a problem if planting is done as a first crop in early May, preferably between May 10 and 20. However, silage maize is mostly grown as a second crop after harvesting of winter cereals. Therefore, due to the short photo-period, complete kernel development and whole-plant dry matter concentration are rather low.

In order to adequately evaluate the relationship between kernel development or grain yield and whole-plant quality, maturity effects must be considered. The objective of this study was to evaluate the relationship between kernel developments or ear-fill and nutritive value of maize silage in 4 maize hybrids by altering the extent of ear fill under controlled pollination.

Material and Methods

This study was conducted in the experimental area of Field Crop Department, Faculty of Agriculture, University of Gaziosmanpaşa, Tokat, (40° 13' - 40° 22' N, 36°1' - 36° 40' E, altitude 623 m) Turkey. During this study, total rainfalls of 120.4, 134.6, and 135.0 mm and average monthly temperatures of 20.2, 19.6, and 19.4 °C were recorded in May to September 2001, 2002, and long-term period, respectively. The experimental design was a randomized complete block in a split plot arrangement with 4 replications. Main plots consisted of mid-late maturing hybrids (Pioneer 3163, Pioneer 3167, Pioneer 3223 and TTM 815) and subplots consisted of 0%, 50%, and 100% pollination treatments The hybrids were planted in 5-row plots at 0.60 cm row spacing at a density of 83,300 plants ha^{-1} and the sowing dates were May 17, 2001 and May 21, 2002. The plot size for each subplot was 5.0 m long and 3.0 m wide. Each of the subplots received 3 pollination treatments; 0% pollination where a shoot bag was placed over ear shots to prevent pollination, 50% pollination where the silk channel was split in half and one side was covered with a shoot bag while the other side was exposed to pollens, and 100% pollination where ear shoots were allowed to develop normally (Coors et al., 1997). The trials were fertilized according to soil test recommendations. Before planting, 180 kg ha^{-1} N (ammonium nitrate) and 100 kg ha^{-1} P_2O_5 were applied. An additional 180 kg ha^{-1} N (ammonium nitrate) was applied when the plant heights were about 45 cm. Weeds were manually controlled. The 3 centre rows of each plot were harvested when the kernel milk-line was between 50% and 75% in September (Wiersma et al., 1993). Eight plants were harvested from each subplot for whole-plant analysis and plants were split into leaf, stalk, and ear fractions. The samples were dried for 7 days at 60 °C. Ears were then shelled and grain weights were recorded to determine the harvest index. Harvest index (HI) was defined as the ratio between ear DM and fodder DM. Within each plot, the percentage of ear fill was calculated for the 50% pollination subplot relative to the dry weight of seed recorded for the 100% pollination subplot (Coors et al., 1997). Dry samples were ground with a hammer mill to pass a 1-mm screen. Whole-plant samples were analyzed for NDF, ADF, and CP. A 0.5 g sample was used for sequential detergent analysis to determine NDF and ADF (Goering and Soest, 1970; Soest et al., 1991). Total N was determined by the Kjeldahl method/procedure. Crude protein was calculated by multiplying the total N by 6.25. All calculations were made on a dry matter basis.

All data were analyzed with analysis of variance (ANOVA) procedures using the SAS package (SAS Institute, 1990). Treatment means were compared by Fisher's Least Significant Difference (LSD) test. The data for 2 years were therefore analysed as a split-plot and the values presented are means of 2 years. LSD for grain yield per plant and harvest index were calculated using only the 50% and 100% pollination levels, because grain development was completely prevented at the 0% pollination level. LSD for actual ear-fill percentages were calculated only at the 50% level by a randomized complete block analysis because percentages were based on grain weights relative to the weights at the 100% pollination level (Coors et al., 1997). Also, the General Linear Model (GLM) procedure of SAS was used to determine the simple correlation coefficients among all measured variables.

Results

Agronomic Characteristics

Pollination control for the ear-fill treatment was effective (Table 1). As expected, zero percent pollination prevented any kernel development. Ear-fill was normal for the 100% pollination for the 4 hybrids, and average grain yield was 94 g plant^{-1} (on dry matter basis). Hybrids varied in grain yield at the 100% pollination treatment. The lowest grain yield was obtained from the Pioneer 3167 (75 g plant^{-1}), while the highest grain yield was obtained from the Pioneer 3163 (116 g plant^{-1}). Plant height and stem diameter were not affected by pollination treatment (Table 1-3). The values for plant height ranged from 213 to 239 and for stem diameter from 18 to 21 mm. The highest plant height (239 cm) was obtained from the TTM 815, while the lowest plant height (213 cm) was obtained from the Pioneer 3163 and Pioneer 3167. Stem diameters were similar (21 mm) for the TTM 815 and Pioneer 3167. Pollination treatments were effective on whole-plant fractions (leaf, stalk, and ear content). Average stalk content was higher at the 0% pollination than 100% pollination treatment (490 g kg^{-1} and 273 g kg^{-1}, respectively) (Table 1). Increasing ear content decreased stalk content and leaf content. The ear content was 262, 401, and 550 g kg^{-1} for the 0%, 50%, and 100% pollination treatments, respectively. The harvest index (HI) varied among pollination treatments and hybrids. The HI values increased from the 50% (214 g kg^{-1}) to 100% (427 g kg^{-1}) pollination treatments (Table 2).

Yield and Quality Characteristics

The highest DM yield was obtained from the 100% pollination treatment (17.8 Mg ha^{-1}, Table 2). DM yield for Pioneer 3163 and Pioneer 3223 were higher than TTM 815 and Pioneer 3167 because of the influence of pollination. Whole-plant DM content increased 19% as pollination increased from 0% to 100% (Table 2). Whole-plant DM content values were 266 and 328 g kg^{-1} at 0% and at100% pollination, respectively. Whole-plant CP, NDF, and ADF results are shown in Table 2. Whole-plant NDF concentrations were 552, 536, and 447 g kg^{-1} at the 0%, 50%, and 100% pollination level, respectively. The whole-plant ADF decreased by 229 g kg^{-1} when pollination level increased from 0 to 100% (Table 2). Actual ear fill has negative correlation with ADF content (r = -0.70**, Table 4). Whole plant CP obtained at 0% and 100% pollination levels did not differ (Table 2). There were no differences in whole-plant CP (ranging between 65 and 74 g kg^{-}1) among the hybrids.

Table 1. Effect of pollination level on the grain yield, actual ear fill, plant height, stem diameter, proportion of fraction in 4 maize hybrids.

Hybrids	Pollination level	Grain yield	Actual ear fill	Plant height	Stem diameter	Proportion of fraction in whole-plant		
						Leaf	Stalk	Ear
	%	g plant^{-1}	%	cm	mm	g kg^{-1}	g kg^{-1}	g kg^{-1}
	0	0	0	242	21	209	562	228
TTM 815	50	28	33	234	20	222	406	370
	100	86	100	241	21	159	286	553
	0	0	0	210	19	244	475	281
Pioneer 3223	50	34	37	208	17	217	367	413
	100	97	100	223	20	166	248	583
	0	0	0	219	18	230	461	283
Pioneer 3163	50	31	28	204	16	220	346	431
	100	116	100	213	19	162	264	572
	0	0	0214	23	255	460	256	
Pioneer 3167	50	35	47	210	20	249	359	391
	100	75	100	214	21	214	294	490
	TTM 815	57	67	239	21	196	418	384
Hybrid	Pioneer 3223	66	69	214	19	209	363	426
average	Pioneer 3163	74	64	213	18	204	357	429
	Pioneer 3167	55	73	213	21	239	371	379
	LSD 1	15*	6*	16*	2*	23*	47*	ns
Pollination	0	0	0	221	20	236	490	262
level average	50	32	36	214	19	227	370	401
	100	94	100	222	20	176	273	550
	LSD 2	22**	8**	ns	ns	22**	37**	48**
	Interaction	ns	ns	ns	ns	ns	ns	ns

LSD 1 is the least significant difference between hybrids

LSD 2 is the least significant difference between pollination treatments

The LSD for grain yield and actual ear fill was calculated using only the 50% and 100% pollination treatments

*,** Indicate statistical significance at the 5% and 1 % levels of probability, respectively.

ns = not significant.

Data presented are means of 2 years.

Table 2. Effect of pollination level on the dry matter yield, harvest index, dry matter content, crude protein, ADF and NDF in 4 maize hybrids.

Hybrids	Pollination level	Dry matter yield	Harvest Index	Dry matter content	Crude protein	ADF	NDF
	%	Mg ha^{-1}			g kg^{-1}		
	0	11.9	0	263	72	278	527
TTM 815	50	11.4	186	264	78	255	514
	100	16.0	422	316	73	216	442
	0	11.6	0	274	66	298	561
Pioneer 3223	50	13.8	234	322	71	263	503
	100	19.2	460	343	69	211	404
	0	11.0	0	271	60	305	557
Pioneer 3163	50	11.6	238	320	73	287	562
	100	19.8	460	351	63	222	431
	0	13.7	0	257	77	298	564
Pioneer 3167	50	13.3	205	282	81	299	563
	100	16.5	359	300	65	268	510
	TTM 815	13.4	335	281	74	250	494
Hybrid	Pioneer 3223	14.8	407	313	69	257	489
average	Pioneer 3163	14.1	435	314	65	271	517
	Pioneer 3167	14.5	307	280	74	288	546
	LSD 1	ns	54*	24**	ns	26**	36**
Pollination	0	12.0	0	266	69	295	552
level average	50	12.5	214	297	76	276	536
	100	17.8	427	328	67	229	447
	LSD 2	1.8**	50**	21**	7**	25**	42**
	Interaction	ns	ns	ns	15*	ns	ns

LSD 1 is the least significant difference between hybrids
LSD 2 is the least significant difference between pollination treatments
The LSD for grain yield and actual ear fill was calculated using only the 50% and 100% pollination treatments
*,** Indicate statistical significance at the 5% and 1 % levels of probability, respectively. ns=not significant.
Data presented are means of 2 years.

Discussion

The variation of grain yields between hybrids (Pioneer 3167, 75 g plant^{-1}; Pioneer 3163, 116 g plant^{-1}) may be attributed to genetic factors although hybrids have similar maturity range (Cusicanqui and Lauer, 1999). Hybrids did not differ in grain yield at the 50% ear-fill treatment. In this study, the 50% pollination treatment did not reach the targeted 50% ear fill for any of the hybrids. Ear-filling ranged from 28% to 47% and actual ear-fill average was 36% for all the hybrids. When pollination is weak or absent, kernels do not develop properly and morphological composition alters (Deinum and Struik, 1986). Plant height and stem diameter were not related to DM yield (Table 4). This is consistent with the findings reported by Schmid et al. (1976) and Hunter (1986). However, Gallais et al. (1976) reported that plant height and stem diameter are related to plant DM yield. Such differences in the results might be attributable

Table 3. Correlation coefficient calculated among agronomic properties at different level of pollination treatments in 4 maize hybrids (n = 32, 48).

Characters	GY	ACF	PH	SD	LC	SC
ACF	0.98**					
PH	0.05	0.08				
SD	-0.86**	0.01	0.40**			
LC	-0.75**	-0.68**	-0.36**	0.15		
SC	-0.86**	-0.87**	0.20	0.23	0.57**	
EC	0.92**	0.91**	-0.05	-0.23	-0.74**	-0.96**

GY: Grain yield, ACF: Actual ear fill, PH: Plant height, SD: Stem diameter, LC: Leaf content, SC: Stalk content, EC: Ear content.
*,** Significant correlation at the 0.05 and 0.01 levels of probability, respectively.
Data presented are means of two years.

Table 4. Correlation coefficient calculated among agronomic properties and quality indices at different levels of pollination treatments in 4 hybrids (n = 32, n = 48) .

Characters	DMY	DMC	CP	ADF	NDF
GY	0.83**	0.80**	-0.10	-0.75**.	-0.81**
ACF	0.74**	0.66**	0.11	-0.70**	-0.69**
PH	-0.02	-0.26	0.14	-0.26	-0.24
SD	0.21	0.21	0.30*	-0.03	0.02
LC	-0.55**	-0.63**	0.13	0.74**	0.76**
SC	-0.66**	-0.77**	0.01	0.62**	0.62**
EC	0.69**	0.81**	-0.06	-0.73**	-0.73**

DMY: Dry matter yield, DMC: Dry matter content, CP: Crude protein, ADF: Acid detergent fibre, NDF: Neutral detergent fibre, GY: Grain yield, ACF: Actual ear fill, PH: Plant height, SD: Stem diameter, LC: Leaf content, SC: Stalk content, EC: Ear content.
*,** Significant correlation at the 0.05 and 0.01 levels of probability, respectively.
Data presented are means of 2 years.

to the environmental and cultural practices and genetic factors. The ear content was positively correlated with DM yield (r = 0.69**) and DM content (r = 0.81**, Table 4). These findings are in agreement with the results of a study by Struik (1983). Pioneer 3223 and Pioneer 3163 had the greatest HI of 407 and 435 g kg^{-1}, respectively. A similar result was reported by Coors et al. (1997).

The decrease in DM yield due to reduced pollination averaged over all 4 hybrids was 323 g kg^{-1}. Our results are similar to those of Leshem and Wermke (1981) and Deinum and Struik (1986) who removed the ear completely before pollination and caused a dramatic reduction in yield up to 500-600 g kg^{-1}. DM yield was positively correlated (r = 0.83**) with grain yield (Table 4). No differences occurred among the hybrids in DM yields (Table 2).

Whole-plant DM content differed in the hybrids. Pioneer 3223 (313 g kg^{-1}) and Pioneer 3163 (314 g kg^{-1}) had higher whole-plant DM content than TTM 815 (281g kg^{-1}) and Pioneer 3167 (280 g kg^{-1}). Whole-plant DM content of Pioneer 3163 and Pioneer 3223 were more affected by pollination treatments as compared to other varieties. DM content was positively correlated with grain yield (r = 0.80**) and ear content (r = 0.81**) and was negatively correlated with leaf content (r = -0.63**) and stalk content (r = -0.77**). Whole-plant DM content at harvest is important due to its effect on ensiling and animal DM intake (Gallais et al., 1976; Vattikonda and Hunter, 1983). Struik (1983) reported that DM content of the whole-plant was mainly affected by the DM content of the ear and the proportion of ear in the fresh material. In Europe, DM content is acceptable for ensiling in the range between 280 and 300 g kg^{-1} (Hunter, 1986). There have been variations on reported DM content based on hybrids, harvest stage, and agronomic treatments (Russell et al., 1992; Coors et al., 1997; Darby and Lauer, 2002).

Overall whole-plant NDF concentration level decreased by 190 g kg^{-1} as pollination level increased (Table 2). Coors et al. (1997) reported that NDF concentrations decreased by 150 g kg^{-1} as pollination level increased from 0% to 100%. Whole-plant NDF concentrations and HI values have a strong negative correlation (Cox et al., 1994; Cox and Cherney, 2001). So the increase in grain yield values probably resulted in a decrease in NDF concentrations at higher pollination, which has a negative correlation with NDF. The whole-plant NDF content is important in ration formulation because they reflect the amount of forage that animals can consume. As NDF percentage increases, dry matter intake generally decreases (Soest, 1994). There were significant differences among the hybrids for the NDF content. The greatest NDF content occurred for Pioneer 3167 (546 g kg^{-1}), and followed by Pioneer 3163 (517 g kg^{-1}), TTM 815 (494 g kg^{-1}), and Pioneer 3223 (489 g kg^{-1}). Pioneer 3167 and Pioneer 3163 statistically fell into the same group. Similarly, Pioneer 3163, TTM 815, and Pioneer 3223 were also statistically in the same group. Coors et al. (1997) reported that whole-plant ADF concentration decreased with ear fill, which had a negative correlation. Pioneer 3167 had higher ADF compared with those of TTM 815 and Pioneer 3223. There has been significant genetic variability for forage quality among maize hybrids (Roth et al., 1970; Widdicombe and Thelen, 2002). The range of NDF from 415 to 490 g kg^{-1} and ADF from 240 to 285 g kg^{-1} values were reported by Allen et al. (1991) and Hunt et al. (1992). Complete removal of ear shoots before pollination caused considerable declines in crop digestibility (Struik 1983) since grain filling is positively correlated with DM content and digestibility. This result should be expected when removing a more digestible part from the plant. ADF content increased, which was negatively correlated with the digestibility of forage (Soest, 1994).

Whole plant CP for the 50% pollination level was 76 g kg^{-1} and CP values of 69 and 67 g kg^{-1} occurred at 0% and 100% pollination levels, respectively. However, Coors et al. (1997) reported that whole-plant CP concentration decreased as pollination level increased from 0% to 100%. These differences could be due to the difference in the environmental conditions and the hybrids used in the studies.

In conclusion, DM content and DM yield increased with pollination levels as a result of increasing kernel development. Ear-fill or kernel development is one of the most important factors influencing whole-plant nutritional quality. Increasing ear fill would be caused by decreasing whole-plant NDF and ADF. Ear content showed strong correlation with whole-plant ADF (r = -0.73**) and NDF (r = -0.73**) concentrations. Leaf content and stalk content was negatively correlated (r = -0.68** and -0.87**) with pollination levels or actual ear fill. Studies on the effect of these quality differences in the hybrids on animal digestion and feeding performance should be conducted.

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