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Abstract
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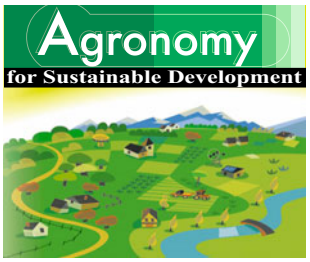

Research article

Seed quality of high protein corn lines in low input and conventional farming systems

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Abstract – Seed quality is a major issue for crop establishment especially in low input farming systems, where varieties often grow under more stressful conditions than in conventional farming systems. Corn (Zea mays L.) seed for organic (low input) production will eventually need to be grown organically, thus research is needed to ensure excellent seed quality in organic corn seed production. The objective of this study was to compare seed quality and composition differences between a group of high protein corn genotypes grown under low input and conventional farming systems, and to compare the relative seed quality of these genotypes to two well known inbreds, B73 or Mo17. Twenty high protein breeding genotypes were planted during two growing seasons in conventional and organic nurseries near Ames, Iowa, to produce seeds for laboratory tests. The germination, saturated cold, accelerated aging, and soak test percentages of seeds produced organically were 5 to 11% lower than for seeds produced conventionally. Protein, measured by near-infrared reflectance, was unaffected by the production location, but the oil content of seeds produced organically was significantly higher (between 0.2 and 0.3% higher) than in the conventional system. Location by genotype interactions for most tests were non significant both years, indicating that genotypes selected for high seed quality in a conventional system will also have high seed quality when grown in a low input, organic system.

1. INTRODUCTION

Modern agriculture uses high levels of chemical inputs; however, alternative cropping systems such as organic and low-input agriculture are gaining importance as alternatives for mid- and small-size family farms. The premium prices currently paid in the market for organically produced commodities offer small-size farmers new opportunities for generating profit, achieving sustainability in production and minimizing impacts on the environment. In past years organic seeds were in short supply and varieties produced organically did not have seed quality comparable to farmers' preferred varieties. Thus, organic producers were allowed to plant seeds grown under conventional systems. However, changes in organic farming regulations of the USDA National Organic Program (NOP) will mandate organic farmers to plant seeds produced under organic conditions. Organic producers, small seed companies and universities are concentrating their efforts on developing varieties that meet the new organic crop production regulations (Adam, 2005).

Seed production in organic conditions is increasing because of these changing rules for organic production and also because it offers organic farmers the possibility of producing and keeping their own seed for the following crop by using open-pollinated varieties. Open-pollinated varieties are more vigorous and can represent an alternative to hybrids derived from inbreds (Goldstein, 2001). Inbred lines are difficult to produce in organic conditions because of the lack of vigor throughout their development, leading to increased weed pressure.

In any cropping system, seed germination and vigor are the most important attributes of seed quality to assure uniform emergence and satisfactory stand establishment. Many factors can affect germination and seed vigor. McDonald (1998) attributed physiological seed quality losses to environmental stress and premature or late harvest. Grain composition also affects seed quality. Previous studies determined that there is a significant interaction between the environment where seeds are grown and genotype in maize lines with different grain composition. Inbreds with lower seed protein content had poorer seed quality than higher protein lines. Higher protein lines showed better seed quality independently of the

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percentage of oil content in the seed (Munamava et al., 2002). This study points to the importance of genotypic adaptation to environment. To develop varieties with high seed quality, breeding programs must test their materials in multiple environments.

Most chemical fungicides and insecticides are restricted in organic corn production. This restriction forces farmers to manage crops and use cultural practices to reduce the impact of diseases, insects and weed pressure. Planting time is usually delayed to avoid the wet and cold soils of early spring, which can expose seeds to soil pathogens for a long period of time before emergence, and to reduce contamination by genetically modified pollen from conventional farmers. Higher soil temperatures allow faster seedling emergence and growth, lowering the risk of stand problems. But late planting can have additional adverse consequences, such as unexpected additional delays in planting associated with abundant spring rainfall, yield reductions, or the occurrence of an early fall frost when seeds are still immature on the plant. These problems associated with late planting are usually avoided in a conventional cropping system by planting early and using chemical seed treatments that protect the seed during emergence and plant establishment.

Several seed quality tests are used to assess the germination and vigor of a seed lot. The standard germination test is the official test used for labeling seeds for sale. However, the standard germination test results are poor predictors of field emergence because the tests are conducted under favorable conditions for seed germination and growth (Shah et al., 2002). In contrast, seed vigor tests are conducted under stressful growing conditions, such as cold and wet planting conditions, or hot and humid seed aging conditions. Testing seeds under these stressful conditions is very important to determine the ability of the seed lots to have good performance and uniform emergence in the field. High vigor seeds are particularly important in the organic farming systems, where seeds are planted without seed treatment. Untreated seeds must have rapid seedling emergence in the field to avoid the detrimental effect of soilborne pathogens.

Organic crop practices are different than in conventional systems, and they can affect seed quality. To our knowledge, the impact of the cultural practices used in organic farming on seed quality has not been assessed. The objective of this study was to compare seed quality and composition differences between a group of high protein corn genotypes grown under organic (low input) and conventional farming systems, and to compare the relative seed quality of these genotypes to two well known inbreds, B73 or Mo17.

2. MATERIALS AND METHODS

2.1. Origin of maize genotypes

The germplasm included in this project were 20 high protein narrow-base synthetic genotypes and two public inbred checks, Mo17 and B73. The narrow-base synthetic genotypes were selected from a wide-based synthetic composed of high yielding lines that also had higher protein content. This wide-based synthetic was developed from breeding crosses of a Chilean population (CHZM 05015, PI 467165) crossed with non-Stiff Stalk Corn Belt lines. The breeding cross and high yielding lines developed from it were from the U.S. Germplasm Enhancement of Maize project (GEM; Pollak, 2003). Synthetics are cross-pollinated varieties that present good combining ability when open pollinated (Lammerts van Bueren et al., 1998).

In the Ames IA nursery in 2001, the wide-based synthetic was composed by crossing selected GEM lines in paired rows and harvesting as single ears. Protein content of the ears was analyzed by Near Infrared Reflectance (NIR) to select the materials for the next growing season. The selection was based on a minimum of 12.5 g kg^{-1} protein content. The top 10 ears with the highest protein content, ranging from 12.52 g kg^{-1} to 13.51 g kg^{-1}, were bulked for recombination. In 2002, in a winter nursery near Ponce PR, seed from the bulk was sib mated, harvested as single ears, and 20 ears with adequate seed supply were selected for the experiment. We did not choose the ears with highest protein content because we did not know if an interaction between genotype and environment (temperate versus tropical) existed. In 2003 and 2004 seed from the 20 ears were planted in Ames IA nurseries to obtain seed for the seed quality experiments.

2.2. Field experiments

The twenty genotypes were planted in two locations near Ames during the growing seasons of 2003 and 2004. These locations were selected for their very different farming system. One location was under conventional and the other under certified organic farming systems. This classification was based on the type of fertilizer and methods of weed, disease and insect control used in crop production. While the conventional system made use of high amounts of chemical inputs for production, such as synthetic fertilizers and other chemicals, the organic system did not use any synthetic products (Poudel et al., 2002). These locations were chosen to evaluate the seed germination, vigor, and composition characteristics of the selected genotypes, and compare their performance to the well established lines B73 and Mo17. The field experimental design was a completely randomized design with two replications.

The conventional experiments were planted on 18 May 2003 and 7 May 2004. The organic experiments were planted on 28 May 2003 and 7 June 2004. Seeds from the conventional farming system were harvested on 19 September 2003 and 24 September 2004; and in both years seeds from the organic farming system were harvested on 30 September. Pollinations were conducted from 28 July to 4 August 2003 and 23 July to 29 July 2004 in the conventional experiments; and from 7 to 14 August 2003 and 14 to 20 August 2004 in the organic experiments.

Weeds were controlled with pre- and post-emergence herbicides in the conventional system. A rotary hoe was used immediately after planting in the organic nursery and cultivation

was conducted as necessary to control the weed pressure in both systems. Hand weeding was also used in both nurseries.

All plants were self-pollinated during the summer of 2003 and 2004 to produce seed for the laboratory experiments. In the fall, when seeds reached black layer, plants from each row were harvested individually. However, because of a frost forecast in 2004, seeds from the organic nursery were harvested prematurely. All the seed was needed for the seed quality tests. In order to maintain the high quality of the seed, ears of the conventional and organic nurseries were dried immediately after harvest in experimental-size, forced-air, stacked-drawers dryers (designed at the ISU Seed Science Center) at room temperature (25 °C). Seed moisture was monitored every 24 h until seeds reached a moisture content of 120 g H_2O kg^{-1} fresh weight (fw).

Ears were mechanically shelled in an experimental-size sheller (Custom Seed Equipment, Model LS91, Altoona, IA) with a rubber cylinder and concave to avoid mechanical damage. Seeds were stored in a 10 °C and 50% relative humidity cold room until being used for the laboratory tests. All laboratory tests were conducted in a completely randomized design with two replications of 100 seeds. Tests were completed within 6 months of storage.

2.3. Seed quality tests

2.3.1. Standard germination test

The seeds were germinated on fiberglass trays (Hoffman Manufacturing Company, Albany, OR). The seeds were planted on top of two sheets of crepe cellulose paper (KIMPAK, Kimberly Clark Corporation, Neenah, WI) and moistened with 825 mL of water using a watering table (Algona Food Engineering Company, Algona, IA). Four samples of 100 seeds were planted on each tray. Samples were assigned to trays at random. Trays were placed inside carts (Lakeside Manufacturing Inc., Milwaukee, WI) separated by approximately 10 cm from each other. Carts with the trays were placed inside a growth chamber at constant 25 °C and received 12 h of fluorescent light per 24 h for a period of 7 days. Evaluation of seedlings was done according to AOSA Rules for Testing Seeds (2005).

2.3.2. Saturated cold test

Plastic trays and support screens (Hoffman Manufacturing Company, Albany, OR) were used for the saturated cold test. One paper towel (Anchor Paper Company, St. Paul, MN) was wrapped around the support screen and two paper towels were placed on top of the screen. One thousand ml of water were added to the tray. Sieved soil was sprinkled until paper towels were covered (AOSA Seed Vigor Testing Handbook, 2002). Trays were pre-chilled at 10 °C for 24 h before planting. Six samples of 100 seeds each were planted on each tray. The seed embryos were carefully turned facedown on the soil to increase stress. Trays were placed inside carts separated from each other by approximately 10 cm and placed in a 10 °C constant temperature room for 7 days in the dark. After 7 days carts were moved to a constant 25 °C growth chamber for 3 days and 24 h of light. The percentage of normal seedlings was determined according to the AOSA Rules for Testing Seeds (2005).

2.3.3. Accelerated aging

Accelerated aging acrylic boxes (Hoffman Manufacturing Company, Albany, OR) with screens were used to age the seed. The boxes were filled with 40 mL of distilled water and the screen was replaced carefully to avoid splashing water on the screen. One hundred seeds per sample were placed on top of the screen and the lid of the box was closed. Boxes were incubated in a 43 °C chamber (VWRScientific, Chicago, IL 60666) for 72 h (AOSA Seed Vigor Testing Handbook, 2002). Immediately after the aging period, all box lids were removed to stop the aging of the seed and samples were planted in a standard germination test as described above, and evaluated following the AOSA (2005).

2.3.4. Electrical conductivity

Samples of 100 seeds were weighted and placed in a beaker with 200 mL of distilled water. Electrical conductivity readings of the steep water were recorded at 6 hours and 24 h after soaking. The electrical conductivity was measured using a precision measuring instrument, the inoLab pH/Cond Level 1 (WTW Measurement Systems, Inc. 3170 Metro Parkway, Ft. Myers, FL 33916-7597). The cell constant was calibrated before each replication using the control standard solution 0.01 mol/L of KCl (WTW Measurement Systems, Inc.).

Soak test

After the electrical conductivity measurements were completed, the seeds from each entry were soaked in the same 200 mL of distilled water for an additional 24 h (for a total of 48 h) and then planted in the standard germination test. Seedlings were evaluated following the standard germination rules (AOSA, 2005).

2.3.5. Fast green test

Samples of 100 seeds were submerged in fast green solution for 30 seconds. A 0.1% fast green solution was prepared adding 1 g of FCF (Fisher Scientific, Fair Lawn, NJ 07410) to 1000 mL of water. After seeds were stained, they were rinsed with tap water, dried on top of paper towels at room temperature (approximately 25 °C) and evaluated under magnifying lens according to the procedures and evaluation criteria provided by the ISU Seed Testing Laboratory (1992).

2.4. Seed composition

2.4.1. Near infrared reflectance

Seed protein and oil content was measured using an Infratec 1241 NIR bulk conveyor system (FOSS NIRSystems Inc. 7703 Montpelier Road Suite 1, Laurel, MD 20723). Bulked samples from each entry were divided into three sub samples. Data were automatically recorded and analyzed based on moisture content of 155 g H_2O kg^{-1} fresh weight (fw).

2.5. Experimental design and data analysis

For each of the two locations, field experimental plots were planted in a completely randomized design and the lines had two replications in the field. Each replication consisted of two rows of eighteen seeds each. Laboratory experiments were conducted twice for every field replicate. The averages of the two laboratory replications for each location by genotype combination were statistically analyzed using PROC MIXED in the SAS 9.1 TS software (licensed to Iowa State University). The data from laboratory experiments (standard germination, saturated cold, accelerated aging, soak, fast green, electrical conductivity tests, seed weight, and protein and oil content) were analyzed separately for each year, with location and genotype as fixed effects and field replicates as random effect. Both the equal variance and normality assumptions were validated; thus the analysis was performed on untransformed data. Separate contrasts were calculated between B73 or Mo17 and the overall mean of the selected genotypes to compare the seed quality characteristics of the selected group of genotypes versus the seed quality of these two well known inbreds.

3. RESULTS AND DISCUSSION

3.1. Field experiments

High protein corn genotypes along with inbred lines B73 and Mo17 were grown in organic (low input) and conventional farming systems to study seed quality and grain composition. High vigor seeds are important in organic farming because seed treatments are not commonly used and organic practices may affect seed quality differently than in conventional farming systems. The field conditions at planting in the organic and conventional nurseries in 2003 were optimal. In 2004, excessive rainfall in early spring contributed to a 30 day delay in planting the organic relative to the conventional nursery. In 2003, the conventional and low input experiments accumulated similar numbers of growing degree days (GDD base = 10 °C or GDD_{10}) from planting to harvest, 1323 and 1307 respectively. However, there were approximately 200 GDDs difference between the conventional system (1317) and the low input system (1119) in 2004. The lower GDDs in the low input system in 2004 were due to delayed planting and excessive rainfall in the spring and early harvest. In order to avoid the detrimental effects of an early frost on seed quality, ears from the organic nursery were harvested prematurely in 2004. We know from previous work that Mo17 harvested prematurely (50–55% moisture content) has a significant reduction in seed quality even when artificially dried using ambient air (DeVries et al., 2007). Because the high protein genotypes had a genetic background partly related to Mo17 we suspected the premature harvest would have had a seed quality effect. However, the seed quality was less affected by premature harvest than it would have been by leaving the corn in the field subject to frost (Woltz et al., 2006).

Table I. Growing degree days, precipitation and stress degree days of experiments during 2003 and 2004.

	Conventional	Organic
2003		
$GDD_{10}^{\dagger}$	1323	1307
Precipitation (mm)	220	258
2004		
GDD_{10}	1317	1119
Precipitation (mm)	449	268

† GDD_{10}: growing degree days in degree Celsius = [(minimum temperature + maximum temperature) × 2^{-1}] – 10 °C.
If maximum temperature is > 30 °C, then maximum temperature = 30 °C.
If minimum temperature is < 10 °C, then minimum temperature = 10 °C.
Source: Iowa Environmental Mesonet, Iowa State University Department of Agronomy. http://mesonet.agron.iastate.edu.

Table I shows accumulated precipitation in 2003 and 2004 for the low input and conventional experiments. Precipitation during 2004 was better distributed than in 2003. In 2003, the experiments had 46 stress degree days (base = 30 °C) with a greater impact during seed development, while in 2004 both experiments had only 3 stress degree days before pollination (data not shown).

There was a significant interaction between genotype × year ($P < 0.0001$) for seed quality, thus years were analyzed separately. The significant differences in seed quality, associated with the year effect, were likely the consequence of the weather and farming system differences during 2003 and 2004. These results emphasize the important interaction between weather conditions, such as excessive spring rain and increased risk of an early fall frost due to delayed planting, and cultural practices such as planting late for a warm seed bed and to avoid neighboring GMO pollen, when producing seeds in an organic farming system.

3.2. Seed quality tests

3.2.1. Standard germination test

There were significant differences ($P<0.05$) in germination percentages for seeds from the low input and conventional locations in 2003, but not in 2004 (Tab. II). Genotype differences were significant in 2004, but the location × genotype interaction for standard germination was not significant for both years. The mean germination percentages of seeds produced

Table II. Probability values (P value) for the percentage of normal seedlings in the standard germination, saturated cold test, accelerated aging, soak test, electrical conductivity values in $\mu S\, g^{-1}$ of seed, and fast green test of 22 corn genotypes harvested in 2003 and 2004 in two locations (conventional and low input).

	Standard germination	Saturated cold	Accelerated aging	Soak test	electrical conductivity	Fast green
	P value					
2003						
Genotype	0.058	<.0001	0.026	0.0002	<.0001	0.025
Location	0.002	<.0001	<.0001	<.0001	<.0001	<.0001
Genotype × Location	0.840	0.591	0.192	0.199	0.015	0.995
2004						
Genotype	<.0001	<.0001	0.004	<.0001	<.0001	0.003
Location	0.338	<.0001	<.0001	<.0001	0.004	<.0001
Genotype × Location	0.559	0.362	0.173	0.002	0.584	0.520

in a conventional system were 80% in 2003 and 89% in 2004 (Fig. 1). These values were higher than the mean germination percentages of seeds produced in the low input system, 2003 (75%) but not in 2004 (87%). These findings suggest that other factors, such as crop conditions during the growing season, soil fertility and nutrient availability during the crucial phases of seed development and maturation may have influenced seed quality. Nitrogen plays important roles in many metabolic functions in plants and it is also a key nutrient for plant growth and crop yield. According to Poudel et al. (2002), processes such as mineralization during the spring in organic and low chemical input farming systems can negatively affect the availability of nitrogen to the plants, resulting in slower plant development and lower yields (Lammerts van Bueren et al., 1998).

The mean germination percentage of the 20 genotypes (77%) was not significantly different ($P < 0.05$) from the germination percentage of the inbred checks B73 (83%) and Mo17 (83%) in 2003 (Fig. 2). However, the mean germination percentage of the 20 genotypes (89%) was not different from B73 (90%) but significantly higher than the check Mo17 (81%) in 2004 ($P < 0.05$). Thus, the genotypes in 2003 had similar germination potential relative to the inbred checks and better germination potential than Mo 17 in 2004. B73 and Mo17 are well established lines adapted to the growing conditions in Iowa and have good seed production characteristics. It is important that the selected genotypes have good seed germination, similar to or better than that of these inbred checks.

3.2.2. Saturated cold test

There were significant differences ($P < 0.05$) for genotype and location in seeds produced in the low input and conventional systems for 2003 and 2004 (Tab. II). The interaction between location and genotype for 2003 and 2004 was not significant, which allowed the effects of genotypes and locations to be discussed independently. The mean saturated cold test for seeds in the conventional system was 92% in 2003 and 87% in 2004. The mean saturated cold test percentages for seeds grown in the low input system in 2004 (69%) was significantly lower than in 2003 (85%) (data not shown). This lower saturated cold germination percentage in 2004 could be partially attributed to harvesting the seed prematurely to avoid an early fall frost in 2004. Materials were harvested at moisture ranging from 430 g H_2O kg^{-1} fw to 520 g H_2O kg^{-1} fw, before the seeds achieved desiccation tolerance. Some materials with a longer seed development and maturation requirement are too immature to achieve desiccation tolerance during artificial drying, according to Cordova-Tellez and Burris (2002a). Seed corn harvested at 400 g H_2O kg^{-1} fw is not physiologically mature, but the seed vigor has reached its maximum levels and proper drying conditions can preserve the high seed quality. Seeds harvested at higher moisture levels (500 g H_2O kg^{-1} fw and higher) are too immature to safely dry artificially, even when they are dried under ideal conditions. These results are very important because organic seed producers in the Midwestern states may encounter similar problems due to delayed planting in the spring to avoid seed exposure to cold, wet soils.

Comparisons between the mean of the 20 genotypes (89%) and the inbred checks were significant ($P < 0.05$) for both checks (83%) in 2003 (Fig. II). These results indicated that, under normal growing conditions the seed quality of the selected genotypes as measured by the saturated cold test was higher than that of the adapted inbred checks.

3.2.3. Accelerated aging

There were significant genotype and location differences in the percentage of normal seedlings after aging in 2003 and 2004 (Tab. II). The interaction between location × genotype was not significant ($P < 0.05$) for both years. Results indicated that seeds produced in a conventional system had a higher accelerated aging percentage (88% in 2003 and 74% in 2004) than seeds produced in a low input system (73% in 2003 and 63% in 2004) (Fig. 1). The accelerated aging percentages of the 20 genotypes were not different ($P < 0.05$) from the inbred checks in 2003, but they were significantly ($P < 0.05$) higher than Mo17 in 2004 (Fig. 2). These are promising results as they indicate that, under normal growing conditions, the selected genotypes could have better seed quality than the inbred checks. In 2004 the accelerated aging percentages were lower than in 2003 (Fig. 1). A seed lot with high germination and high vigor will deteriorate at a slower rate than a seed lot with high germination and low vigor. Low seed vigor as determined by the accelerated aging test can be associated to seed immaturity (Shah et al., 2002).

3.2.4. Soak test

The germination percentage of seeds soaked in water for 24 hours showed that location × genotype interactions were significant ($P < 0.002$) in 2004 (Tab. II). Thus, data for 2004

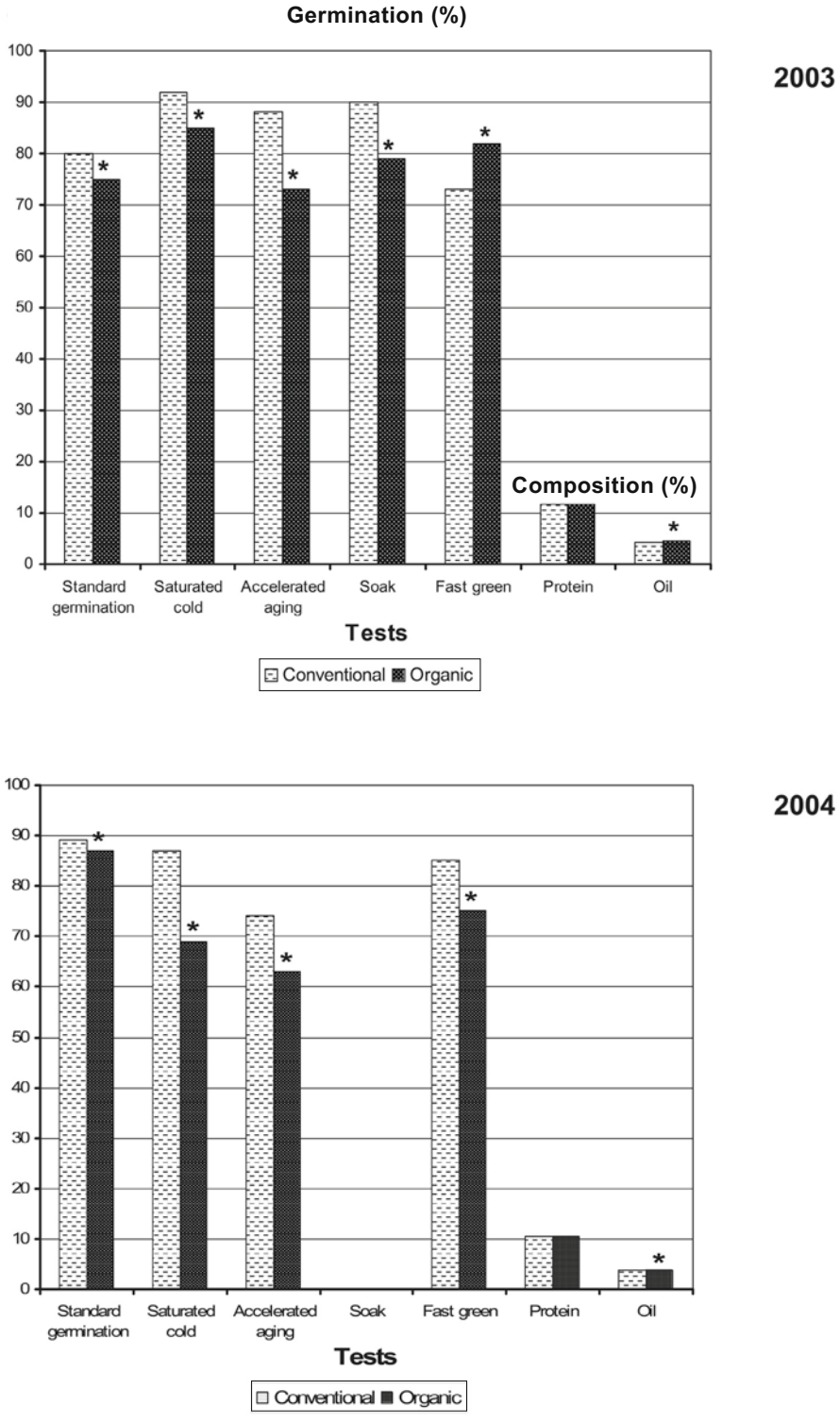

Figure 1. Means standard germination, saturated cold test, accelerated aging, and fast green expressed as germination percentage and seed protein and oil content in percentage of total seed composition for 20 high protein corn genotypes harvested in two locations (conventional and low input) for 2003 and 2004. Significance at the 0.05 level of probability is denoted by a star if the difference among means exceeds the least significant difference.

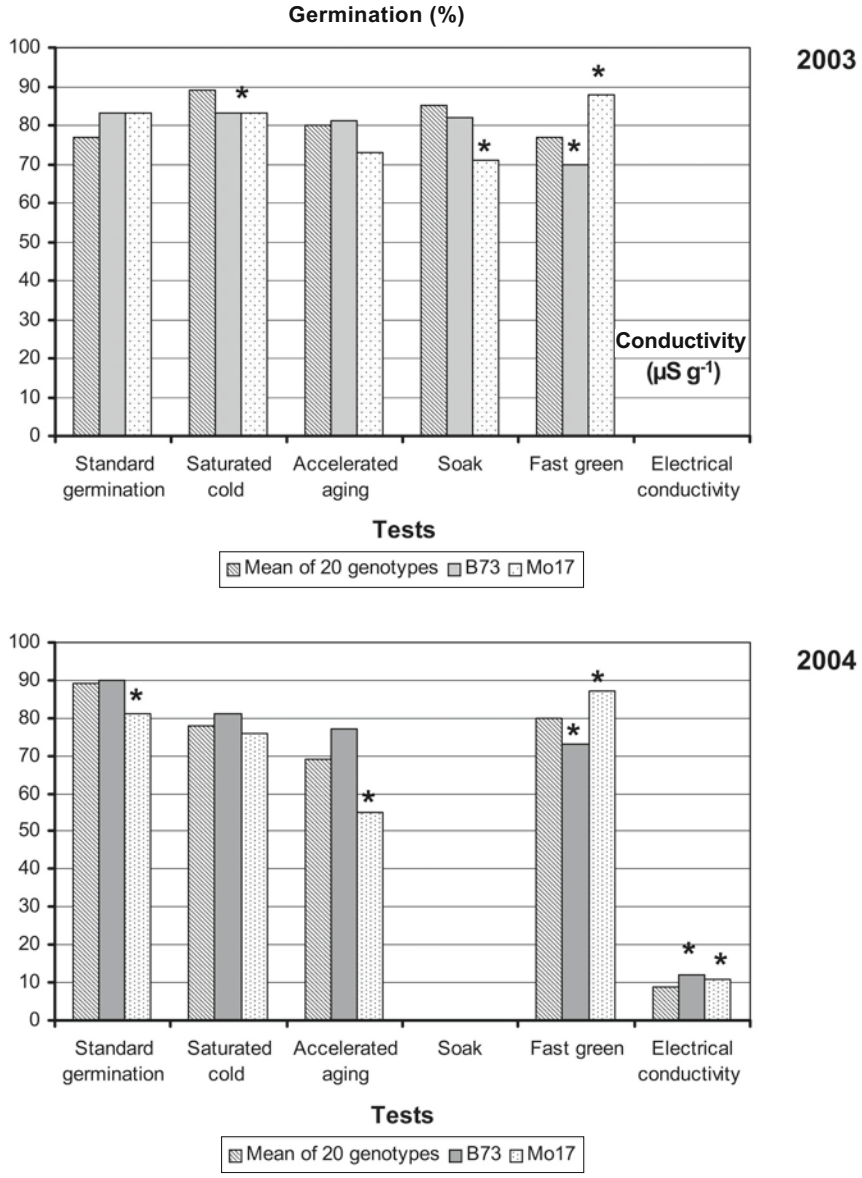

Figure 2. Pair means comparison among the standard germination, saturated cold test, accelerated aging, soak test, and fast green test overall mean expressed as germination percentage and electrical conductivity expressed as µSiemens per gram of seed of 20 genotypes versus the mean of the check inbred checks B73 and Mo17 harvested in two locations (conventional and low input) during 2003 and 2004. Significance at the 0.05 level of probability is denoted by a star if the difference among means exceeds the least significant difference.

were reanalyzed by location. In 2003, the soak test germination percentage of seeds produced in the locations under conventional cropping system were higher (90%) than in locations under low input or organic cropping systems (79%) (Fig. 1). The mean of the 20 genotypes was significantly higher (85%) than the mean of Mo17 (71%), but not different than B73 (82%) (Fig. 2). The comparisons between the mean soak test percentage of the 20 genotypes and the check inbreds for 2004 are shown in Table III. In the conventional system, mean values of the 20 genotypes were 92% and in the low input system they were 75% for 2004. There were significant differences between the mean soak test percentage of the 20 genotypes produced in the low input system with B73 and Mo17 (Tab. III). Cerwick et al. (1995) reported that flooding tolerance is partially related to genetic background. When germination is affected by flooding, replanting is an option to reestablish a satisfactory stand in the field, however, planting delays can affect production due to the shorter growing season. Our results suggest that higher protein genotypes might have a better tolerance to flooding conditions than Mo17, while B73 showed similar values to the 20 genotypes. Therefore, seeds from selected materials would be able to recover after flooding conditions (Cerwick et al., 1995) and farmers could reduce the need for replanting.

Table III. Pair means comparison among the soak test and electrical conductivity overall mean of 20 genotypes versus the mean of the inbred checks B73 and Mo17 harvested in two locations (conventional and low input) during 2003 and 2004.

	Conventional Farm		Organic Farm	
	Soak test	Electrical conductivity	Soak test	electrical conductivity
	%	μS g^{-1}	%	μS g^{-1}
2003				
Mean of 20 genotypes	†	8	†	10
B73	†	9	†	15
$LSD_{(0.05)}$	–	1.4	–	1.4
Mo17	†	10	†	12
$LSD_{(0.05)}$	–	1.4	–	2.0
2004				
Mean of 20 genotypes	92	†	75	†
B73	89	†	86	†
$LSD_{(0.05)}$	8.3	–	8.3	–
Mo17	67	†	69	†
$LSD_{(0.05)}$	8.3	-	8.3	-

Pair of means of the 20 genotypes and each inbred check within a column are significantly different at the 0.05 level of probability if their difference exceeds the least significant difference value at $P < 0.05$.

† Location × genotype interactions for soak test in 2004 and electrical conductivity in 2003 were significant at $P < 0.05$.

3.2.5. Electrical conductivity

There was a significant location × genotype interaction ($P < 0.015$) for electrical conductivity in 2003 (Tab. II). The mean electrical conductivity values for the 20 genotypes and the inbred checks for 2003 and 2004 are in Table III and Figure 2. The mean electrical conductivity value for the 20 genotypes in the conventional system was 8 μS g^{-1} and in the low input system 10 μS g^{-1} in 2003. In the conventional system, the electrical conductivity value of B73 was similar to the genotypes while Mo17 had a significantly higher electrical conductivity value of 10 μS g^{-1} (Tab. III). In the low input system the electrical conductivity of the inbred checks were significantly higher (15 μS g^{-1}) for B73 and not different (12 μS g^{-1}) for Mo17. In 2004 the electrical conductivity of the genotypes and the inbred checks were significantly different at the $P<0.05$ (Fig. 2). The results from this test are an indication of the integrity of the seed's membranes. The higher the values of electrical conductivity, the greater will be the leakage of solutes from the seeds and thus the lower the seed vigor (Halloin, 1986). Poor vigor seeds leak solutes into the surrounding soil (Cordova-Tellez and Burris, 2002b) at planting which modify the microenvironment around the seed increasing their vulnerability to pathogens. A higher electrical conductivity in the adapted inbred checks and the 20 genotypes indicated that the lower seed vigor in the low input system could be associated with environmental factors such as soil fertility, disease, and weed management.

The electrical conductivity values were somewhat higher in 2004 than in 2003. These results corroborate that harvesting the seeds early while they were immature lowered seed quality in 2004. These findings also highlight the importance of early planting when producing seeds for the low input as well as the conventional system to avoid the risks of an early frost or the need for premature harvest. Before seeds reach physiological maturity some specific metabolic processes, such as the migration of lipid bodies to the plasma membrane, have not occurred. The migration of the lipid bodies occurs during seed maturation as a step towards the acquisition of desiccation tolerance. The lipid bodies migrate from the cytoplasm to align along the plasma membrane (Perdomo and Burris, 1998). Their function is to regulate water loss from the seed during and after maturation. If these lipid bodies are not aligned properly, the unprotected cell membrane could collapse. The collapse of the cell membrane compromises the integrity of the cell and increases leakage of solutes, resulting in loss of seed quality (Perdomo and Burris, 1998). Cordova-Tellez and Burris (2002b) also found correlation between lower values of cell solute leakage and higher germination percentages.

3.2.6. Fast green test

The location × genotype interaction was not significant ($P<0.05$) in both years but the genotype effects were significant ($P<0.05$) (Tab. II). The level of physical damage to seeds as determined by the fast green test ranged from 0% to 30%. Fast green values for 2003 and 2004 were similar (Fig. 2). In 2003 the mean of 20 genotypes was 77%, not different from B73 (70%) and lower than Mo17 (88%). In 2004 the mean of the 20 genotypes was 80%, significantly higher than B73 (73%) and lower than Mo17 (88%). Seeds can experience physical injuries due to handling during harvest, planting, transportation and improper storage conditions (McDonald, 1998). The similar results in 2003 and 2004 indicate that harvest, drying, shelling and handling of the seeds were done properly. Also, seeds can be dried too fast and show cracks in the pericarp due to moisture stress in the endosperm (Hawkins et al., 2005). Improper seed drying increases the susceptibility of the seeds to physical damage during handling. However, seeds for these experiments were hand harvested and shelled with laboratory equipment to minimize seed damage. They were also dried at room temperature and with abundant air flow in the drier. Thus, differences in fast green percentages in this study are likely to be the results of pericarp differences, such as thickness or tolerance to abrasion, among the genotypes.

3.3. Seed Composition

3.3.1. Near infrared reflectance

The protein content among genotypes was significantly different for both years and in both farming systems (Tab. IV).

Table IV. Probability values (*P* values) for protein and oil content in percentage in seeds of 22 corn genotypes harvested in 2003 and 2004 in two locations (conventional and low input).

	SEED COMPOSITION	
	Protein	Oil
2003	——— *P* value ———	
Genotype	0.0004	<.0001
Location	0.7753	<.0001
Genotype × Location	0.1631	0.5089
2004		
Genotype	<.0001	<.0001
Location	0.1176	<.0001
Genotype × Location	0.9771	0.0695

But the protein content was not significantly different between locations. Mean seed protein in seed produced under both cropping systems was 11.6% in 2003 and 10.4% in the conventional and 10.6% in the low input system in 2004 (Fig. 1). Location and location × genotype interactions (non significant, $P < 0.05$) had no effect on protein content suggesting that selection for high protein can be done in either conventional or low input cropping system.

Oil content was affected by location and genotype ($P < 0.05$) (Tab. IV). The oil content of seeds produced in a low input system was significantly higher ($P < 0.05$) than in a conventional system in both years of production. In 2003 the oil content in the low input system was 4.5% and in the conventional system was 4.2% (Fig. 1). In 2004, percentage of oil content in the low input system was 3.9% and in the conventional system was 3.7%. Thus, cropping system used where seeds are produced did not influence protein content but did influence oil content. In addition to benefits related to feed or food utilization, selection of high protein genotypes is advantageous because high protein is related to high seed quality (Munamava et al., 2002). Uribelarrea et al. (2004) found that abundant nitrogen supply stimulated protein synthesis in high protein genotypes and that protein and oil had a positive correlation. In our case, however, higher inputs of nitrogen did not result in higher protein or oil (e.g. conventional cropping system).

4. CONCLUSION

The standard germination, saturated cold, accelerated aging, soak test, and fast green tests indicated that seed quality was affected by genotype and location where seeds were produced. The seed quality of seeds produced in the location under low input cropping system was, in most cases, lower than for seeds produced under the conventional system. This lower seed quality could be attributed, in part, to the early harvest of the organic seeds in 2004 to avoid freezing injury in the field. However, the seed quality was lower in 2003 than in 2004. These results indicate that environmental differences between these two locations, one under conventional and the other under low input production system, such as weed and insect pressure or nutrient availability, can have a strong influence on seed quality. The interaction between location and genotype for most seed quality tests were not significant in 2003 and 2004. Thus, the relative seed quality ranking of the genotypes was consistent in both locations. These results indicate that selection of high seed quality genotypes for the low input system can be accomplished in the conventional system.

Harvesting seed very early, when it was still immature, decreased the overall quality of the seed as measured by several seed quality tests. This negative effect of harvesting seed early must be considered when producing seeds under a low input cropping system. The normal practice of delaying planting in the spring to avoid the cold, wet soils can jeopardize seed quality because it increases the risk of frost damage to immature seeds in early fall. The risks and benefits of timely planting must be considered when producing organic corn seed.

Genotype influences the protein and oil content of the seed. Protein was unaffected by location where seeds were grown, but oil content was dependent on the location. The oil content of seeds produced in the low input system was significantly higher than in the conventional system. This is important when selecting high protein lines from a conventional system as protein content will remain high when lines are transferred to the low input farming system. The higher oil content of seeds produced in the low input system merits further investigation.

Results from these experiments also indicate that corn varieties for organic seed production need to be improved to produce seeds of comparable quality to seed produced under a conventional system. It is likely that corn varieties for organic seed production need to have better seed quality than corn for conventional seed production, and that seed quality needs to be a selection criterion in organic breeding programs. High quality seeds will ensure a successful stand establishment under a wide range of field conditions. Varieties adapted to low input farming systems represent one way of achieving better seed quality and thus, field emergence and plant stand. Other options to explore in the future are approved seed treatments for organic production, improved organic seed treatments, and genetic materials not receptive to foreign pollen, allowing organic farmers and seed producers to plant at the normal time.

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REFERENCES

Adam K.L. (2005) Seed production and variety development for organic systems. ATTRA, Publication #IP272/273, National Sustainable Information Service, http://www.attra.org/attra-pub/seed_variety.html (verified May 15, 2007).

Association of Official Seed Analysts (AOSA) (2002) Seed vigor testing handbook, Contribution 32. AOSA, Lincoln, NE.

Association of Official Seed Analysts (AOSA) (2005) Rules for testing seeds. AOSA, Las Cruces, NM.

Cerwick S.F., Martin B.A., Reding L.D (1995) The effect of carbon dioxide on maize seed recovery after flooding, Crop Sci. 35, 1116–1121.

Cordova-Tellez L., Burris J.S. (2002a) Alignment of lipid bodies along the plasma membrane during the acquisition of desiccation tolerance in maize seed, Crop Sci. 42, 1982–1988.

Cordova-Tellez L., Burris J.S. (2002b) Embryo drying rates during the acquisition of desiccation tolerance in maize seed, Crop Sci. 42, 1989–1995.

DeVries M., Goggi A.S. , Moore K.J. (2007) Determining seed performance of frost-damaged maize seed lots, Crop Sci. 47, 2089–2097.

Goldstein W. (2001) Developing open-pollinated corn varieties for organic farmers, in: Organic Farming Research Foundation Project Report #99–52, Michael Fields Agricultural Institute, East Troy, WI.

Halloin J.M. (1986) Seed improvement through genetic resistance to pathogenesis, in: S.H. West (Ed.), Physiological-pathological interactions affecting seed deterioration. CSSA Spec. Publ. No. 12, ASA, CSSA, and SSSA, Madison, WI, pp. 77–95.

Hawkins L., Windham G., Williams W.P. (2005) Effect of different postharvest drying temperatures on *Aspergillus flavus* survival and aflatoxin content in five maize hybrids, J. Food Protect. 68, 1521–1524.

ISU Seed Testing Laboratory Staff (1992) Fast green test for corn. Iowa State University Extension Publication SL-95.

Lammerts van Bueren E.T., Hulscher M., Jongerden J., Haring M., Hoogendoorn J., van Mansvelt J.D., Ruivenkamp G.T.P. (1998) Defining a vision and assessing breeding methods. Discussion paper, Sustainable organic plant breeding, Subproject 1. Louis Bolk Inst., Driebergen, the Netherlands.

McDonald M.B. (1998) Seed quality assessment, Seed Sci. Res. 8, 265–275.

Munamava M.R., Goggi A.S., Pollak L.M. (2002) Seed quality of maize inbred lines with different composition and genetic backgrounds, Crop Sci. 44, 542–548.

Perdomo A., Burris J. (1998) Histochemical, physiological, and ultrastructural changes in the maize embryo during artificial drying, Crop Sci. 38, 1236–1244.

Pollak L.M. (2003) The history and success of the public-private project on Germplasm Enhancement of Maize (GEM), Adv. Agron. 78, 45–87.

Poudel D.D., Horwath W.R., Lanini W.T., Temple S.R., Van Bruggen A.H.C. (2002) Comparison of soil N availability and leaching potential, crop yields and weeds in organic, low-input and conventional farming systems in northern California, Agr, Ecosyst. Environ. 90, 125–137.

Shah F.S., Watson C.E., Cabrera E.R. (2002) Seed vigor testing of subtropical corn hybrids, Mississippi Agric. Forestry Exp. Stn. Res. Report 23, 2.

Uribelarrea M., Below F.E., Moose S.P. (2004) Grain composition and productivity of maize hybrids derived from the Illinois Protein strains in response to variable nitrogen supply, Crop Sci. 44, 1593–1600.

Woltz, J.M., TeKrony D.M., Egli D.B. (2006) Corn seed germination and vigor following freezing during seed development. Crop Sci. 46, 1526–1535.