Relationship between seed harvesting method and seed physiological quality for a number of Pioneer maize hybrids

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Abstract

The seed germination and seed vigor of eight Pioneer Hi-Bred maize hybrids were evaluated immediately after harvesting and a year later. The aim was to determine whether the seed showed loss of germination and vigor when shelled mechanically. The seed was cleaned but not dressed, and then germinated according to the ISTA standard procedure in four seed analysis laboratories. In addition, the seed of two randomly chosen hybrids was divided into four fractions based on size and shape, and the germination of each fraction was examined separately. All the germination results were acceptable according to the ISTA (2010) standard (over 90%), but a higher germination percentage was observed after manual shelling than after mechanical shelling. The number of abnormal seedlings, however, was higher for mechanically shelled seeds than for those harvested as whole ears. When the seed of separate seed fractions was tested, the germination percentage was lowest for the medium-sized round fraction and highest for the large flat fraction. The seed vigor of three of the hybrids was highest when maize seeds were harvested shelled rather than on the ear. For all the hybrids the germination percentage was lower for both groups when analyzed a year after harvesting. Better germination results were obtained for all the hybrids after whole ear harvesting than in the shelled group, but the difference was not significant. In the vigor tests the results obtained for mechanically shelled seed were superior to those for whole ear harvesting for the same three hybrids, but again the difference was not significant. The experiments should be repeated over several years to determine whether mechanically shelling maize seed negatively affects seed germination and vigor.

Keywords: harvesting, maize seed, germination, vigor

Introduction

In dry years in Hungary, seed production fields for hybrids belonging to different maturity groups may ripen at the same time, but it is not always possible to harvest the seed as whole ears rapidly, on a single occasion, due to lack of a sufficient number of combines and to space limitations in seed driers. In most cases, if the ears are harvested below 20% moisture content, seed shedding may result in losses of 5–25% during processing, according to data from Pioneer Hi-Bred ZRt. These losses could be avoided by shelling the ears during harvesting, but at present the seed production laws do not authorize this mode of harvesting. When Mounsey et al (2002) evaluated the effect of combine harvesting on seed quality, they reported higher seed shedding losses for harvesting at 20% moisture content, and recommended shelled harvesting as an alternative solution, rather than the traditional harvesting of whole ears. The germination tests performed by these authors showed no difference between hand-harvested and shelled samples below a moisture level of 24%. If ear harvesting is delayed due to wet weather, the seeds may germinate on the ear, or Fusarium species may cause ear and grain rot.

Many authors have investigated or modeled the effects of chilling stress during germination (Burris, 1975; Loeffler et al, 1985; Nijenstein, 1985; Bruggink et al, 1991; Hope and Maamari, 1994). Odiemah (1991) studied the effects of various environmental factors on the seed of hybrid maize. The extent of the physiological damage depends on the seed moisture content (Gáspár, 1980) and the genotype. The physiological quality of the different seed fractions may also vary by genotype and year of production (Thielebein, 1958; Pásztor, 1962; Germ, 1966; Fiala, 1973; Eisele, 1981; Berzy et al, 1996).

In a continental climate there is always a danger of frost during harvesting. In spite of the possibility that the seeds will be immature, Woltz et al (2006) suggested that harvesting should be carried out early enough to avoid frost, in order to prevent severe reductions in seed germination and vigor.

The detrimental effects on seed physiological quality may also be the result of human error (e.g. harvesting seed at incorrect moisture content, drying the seeds at inappropriate drying temperatures). When analyzing the impact of drying at tempera-

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tures of 35°C, 40°C, 45°C and 50°C inbred parents were found to differ in their tolerance to high drying temperatures (Navratil and Burris, 1984). These authors found that cold test emergence showed little response to drying temperatures up to 45°C. Seed dried at 50°C had significantly lower shoot and root dry weights and percentage germination than when using a drying temperature of 35°C (Seyedin et al, 1984), probably due to enzymatic modifications (Anderson and Gupta, 1986) that resulted in higher membrane permeability (Herter and Burris, 1989a, b). Poorer quality was observed when seed drying was delayed until more than 84 hours after harvesting (Borba et al, 1998).

However, little attention has been paid to the effect of harvesting techniques as a possible stress factor. Based on the data reported by Shieh and McDonald (1982), it was aimed to discover whether there was any significant difference between shelled or whole ear harvesting in the biological value of two randomly selected hybrid seed fractions, especially as regards germination ability, which is considered to be the most significant trait. The results over several years of experiments indicate that it may prove necessary to elaborate a new system of field quality control criteria, allowing shelled harvesting as well as ear harvesting in the case of seed production.

The present work was aimed at determining whether the germination ability of seed from shelled harvesting reached the level laid down in the official standards and whether it was poorer than that of seed from traditional ear harvesting. The investigations also covered the response of hybrid maize seed from shelled harvesting to various stress factors in the course of germination.

Materials and Methods

Seed production fields where the seed dried down early were randomly selected at eight locations near Szarvas in Hungary (between 20º17' and 20º 30' E, 46º42' and 47º26' N; 81-93 m.a.s.l.) in September 2009. These were each planted with the parental lines of a different Pioneer hybrid, and on each field half the maize was harvested as whole ears and the other half shelled to ensure an approximately equal quantity of seed from each treatment. This year was much drier than is usually experienced in Hungary, where the mean rainfall sum for the maize vegetation period is 360 mm (Table 1). The experiment was set up on a field scale to facilitate the application of the results in practice. The only factors examined in the experiment were the effect of the harvesting method on seed quality, which is discussed below, and genetic purity, which was reported by Varga et al (2012). The parental lines of the following eight hybrids were grown on the seed production fields: PR39F58, PR39R86, PR39R20, PR35Y65, PR38H67, PR39G83, Anasta SV and PR39H32. At each location both treatments were harvested at the same time, on the same day, at the same grain moisture content, which was below 20% at all the locations for both whole ear and shelled harvesting. The shelled harvesting was carried out using a John Deere 98.80 STS axial flow combine, while the whole ears were harvested with OXBO 8430XP and 8420 XP machinery. The shelled seeds were transported straight to the drying chambers (MAXON, Luchthaven, USA), where they were stacked to a height of 80-90 cm. Composite samples of approx. 20-25 kg per variety were taken using an automatic sampler when the lots were removed from the dryers. Samples (approximately 40 kg) of the maize harvested as whole ears were taken from the loading hoppers, dehusked manually and put into jute bags. These were then placed on the conveyor belt taking the dehusked ears into the drying chambers.

The shelled seeds were put in the dryers 2-6 hours after harvest and the whole ears after 3-12 hours. In both cases, moisture extraction involved drying at 38°C, increased to a maximum of 42°C during the last stages of drying. After reaching a moisture content of 12.5%, the whole ears were shelled and all the samples were passed through a 6.5-10.5 mm mesh.

The undressed seeds were then germinated in four accredited seed testing laboratories in Szarvas (Pioneer Hi-Bred ZRt; accredited by ISTA), Budapest (Central Agriculture Office; accredited by ISTA and the Hungarian Accreditation Board), Székesfehérvár (Regional Agricultural Office; accredited by the Hungarian Accreditation Board) and Martonvásár (ARI HAS Seed Testing Laboratory).

It was deemed advisable to divide the seed of two randomly selected hybrids into four fractions (large flat: LF; large round: LR; medium flat: MF; medium round: MR) and to germinate each fraction separate-

Table 1 - Locations and hybrids tested in the experiment.

Hybrid	Location	Soil type	Seed moisture at harvesting [%]	Precipitation sum* in the season [mm]	Amount of irrigation water [mm]	Water total [mm]	Effective heat units [°C]
PR38H67	Fábiánsebestyén	Chernozem	12.7	159.3	275	434.3	1605.5
PR39R86	Békésszentandrás	Alluvial soil	14.2	223.4	211	444.4	154.,9
PR39G83	Kunszentmárton	Meadow chernozem	14.5	48.1	320	368.1	No data
PR39F58	Tiszab□	Loam	13.3	188.8	200	388.8	1695.55
PR39R20	Csabacs□d	Chernozem	14.9	284.1	160	444.1	1709.55
PR35Y65	Karcag	Meadow chernozem	14.0	248.9	225	473.9	1636.25
PR39H32	Kisújszállás	Heavy clay	14.2	226.2	178	404.2	1589.85
Anasta SV	Kunmadaras	Meadow chernozem	18.1	131.6	175	306.6	1468.55

* Data from the Hungarian Meteorological Service

Table 2 - Effect of shelled or ear harvesting on the number of normal and abnormal seedlings developing from the seed of Pioneer maize hybrids (2010).

	Normal seedlings (%) at harvesting		Normal seedlings (%) (a year later)		Abnormal seedlings (%) at harvesting		Abnormal seedlings (%) (a year later)	
Hybrid	Shelled Lab mean	Ear Lab mean	Shelled Lab mean	Ear Lab mean	Shelled Lab mean	Ear Lab mean	Shelled Lab mean	Ear Lab mean
PR39F58	94.89	96.83	–	–	2.64	1.34	–	–
PR39R86	94.41	96.34	–	–	3.26	2.31	–	–
PR39H32			–	–	3.00	1.63	–	–
PR39G83	97.65	98.25	95.43	95.93	1.94	1.44	3.56	3.31
PR38H67	94.05	95.88	91.5	89.83	3.55	2.94	5.19	8.19
PR35Y65	95.20	98.94***	92.81	95.37	3.44***	0.75	5.81	3.87
PR39R20	95.58	97.63*	94.12	95.62	2.66	1.31	4.12	3.06
Anasta SV	69.80	97.38	–	–	2.40	1.25	–	–
		***$LSD_{0.1\%}$ = 3.56		$LSD_{5\%}$ = 4.62	***$LSD_{0.1\%}$ = 2.43		$LSD_{5\%}$ = 3.43	
		$LSD_{5\%}$ = 2.01						
PR39F58 MF	94.17	95.75	–	–	2.00	1.17	–	–
PR39F58 MR	92.08	95.58	–	–	4.42**	1.58	–	–
PR39F58 LR	96.67	96.33	–	–	2.17	2.00	–	–
PR39F58 LF	96.83	96.42	–	–	1.75	1.67	–	–
PR39R86 MF	94.25	94.25	–	–	3.00	2.00	–	–
PR39R86 MR	91.5	93.67	–	–	4.25	3.25	–	–
PR39R86 LR	93.58	97.5	–	–	4.83**	2.33	–	–
PR39R86 LF	95.25	98.58	–	–	2.92*	0.92	–	–
	$LSD_{5\%}$ = 4.25				**$LSD_{1\%}$ = 2.2			
					*$LSD_{5\%}$ = 1.65			

ly. The germination of the seed fractions was examined in three laboratories (Székesfehérvár, Szarvas, Martonvásár).

All the germination tests were carried out according to the standard germination method, using four replications of 100 seeds per seed lot (ISTA, 2010). The results obtained in each laboratory were averaged, and these values were treated as replications, giving four replications for unfractionated seeds and three for the fractionated ones. In all cases the seeds were rolled between three layers of crepe filter paper moistened with 1.4-1.7 cm^3/g water. Illumination was provided for at least 8 hours, at a day/night temperature of 30/20°C or a constant 25°C (ISTA, 2010), with a relative humidity of 70%. The seedlings were evaluated on the 6th-7th day, depending on their state of development, and classified as normal, abnormal or dead. In addition to the germination tests, the Complex Stressing Vigor Test (ISTA, 1995) was also carried out in Martonvásár. The protocol for germination (BP-R) was the same as that used in the germination tests. In the first step 200 seeds were soaked in 0.15% sodium hypochlorite (NaClO) at 25°C for 48 h, followed by a further 48 h of soaking at 5°C in the same chemical. Both low temperature and hypoxia cause severe stress. Finally, without rinsing, eight lots of 25 seeds were germinated as described above at 25°C with constant illumination for 96 h. The seed imbibed the moisture required for germination during the 4-day soaking period. A further 96 h of germination under warmer conditions was thus sufficient for seedling development. The shoot and root length of the five most vigorous seedlings from each roll were recorded and averaged, and the shoot and root fresh weight of all the seedlings in each roll were determined, after removing the seed.

For the seed of four of the hybrids (PR39R20, PR35Y65, PR38H67, PR39G83) the germination tests were repeated a year after harvesting. The seed samples were stored undressed in 3-layered paper bags under farm conditions in the seed plant. The storage facility had a concrete base and metal walls and roof. The storage temperature was never lower than 10ºC in winter or higher than 25ºC in summer and the relative humidity ranged from 50-60%.

Correlation analysis was performed on the results

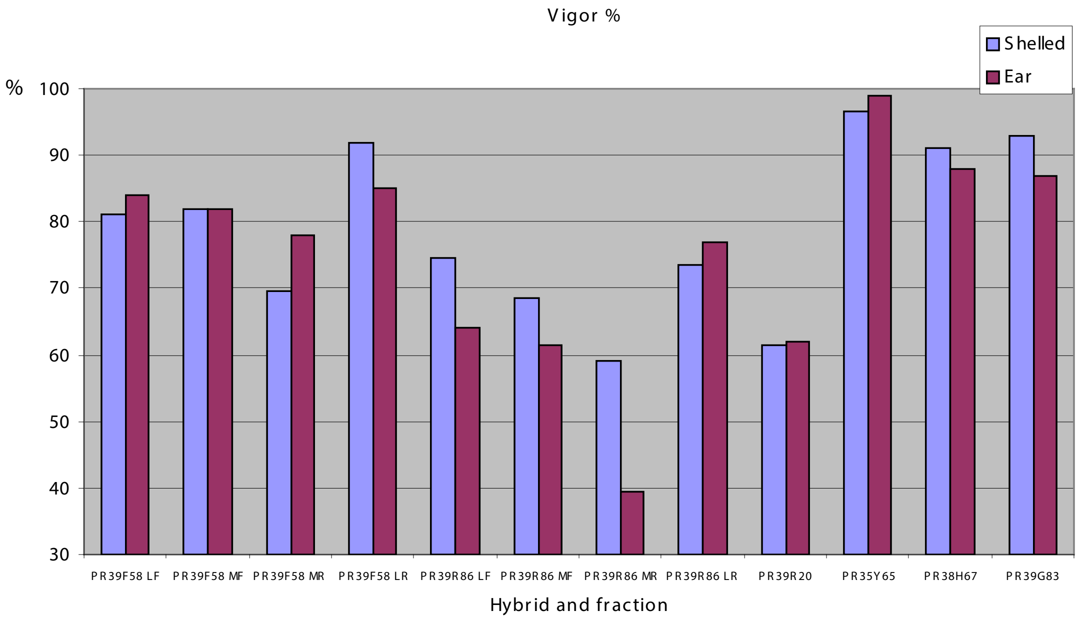

Figure 1 - Effect of shelled or ear harvesting on the vigor of the seed of Pioneer maize hybrids.
$LSD_{5\%}$ = 8.32 (for PR39F58 MR ear, and PR39R86 LF shelled); $LSD_{0.1\%}$ = 13.96 (for PR39R86 MR, shelled)

obtained in the individual laboratories, and analysis of variance between the treatments. As the data were not normally distributed, a χ^2 test was applied. Significant differences between the treatments were detected using the LSD test (MSTAT-C program).

Results and Discussion

The germination percentage of both the shelled and whole ear samples exceeded the minimum (90%) laid down in the ISTA standard (ISTA, 2010). The germination percentage of seed from the eight hybrids tested was unaffected by the harvesting method or the drying method. The statistical analysis showed that the seed of two hybrids (PR35Y65, PR39R20) had significant differences in germination (Table 2), suggesting that some hybrids have better tolerance of shelled harvesting than others. Prior to harvesting, scoring data were collected for 10×100 randomly chosen plants on each plot. These two hybrids did not differ from the mean for the other hybrids in terms of weather conditions, nutrient supplies, plant health status, ear number, seed-setting or grain moisture at harvest.

After a year of storage germination tests were repeated on the seed of four of the hybrids. The results indicated that for three of the four hybrids the germination ability declined by 1.5–1.6% in both treatments, while the number of abnormal seeds rose by 1.5–5.0% (Table 2). The germination percentage of seed harvested as whole ears from hybrid PR38H67 was approximately 6% less compared to germination immediately after harvesting, primarily due to a higher number of abnormal seedlings (5.25%). The loss of germination ability was smaller for shelled seed than for whole ear harvesting for all the hybrids.

Statistical analysis on the seed fractions of two randomly chosen hybrids (PR39F58, PR39R86) revealed no significant differences for any of the fractions. It should be noted that for these two varieties there was also no significant difference between the treatments for unfractionated seed.

The analysis indicated that the LF fraction had the greatest germination vigor after both shelled and ear harvesting. The germination of the LR fraction was only slightly poorer. For one hybrid, harvesting on the ear gave considerably better results, while for the other seeds from shelled harvesting had slightly better germination. No significant difference was observed for the MF fraction, though the germination of seeds from whole ear harvesting tended to surpass that of the shelled group. Germination was poorest (though still above the minimum laid down in the standard) for the MR fraction, with better results for both hybrids when whole ears were harvested.

In all the seedling examinations, a larger number of abnormal seedlings were found in lots from shelled harvesting, though the difference (2.00-2.69%) was only significant for hybrids PR35Y65, PR39F58 MR, PR39R86 LR and PR39R86 LF (Table 2). This suggests that a slightly larger number of kernels were damaged during mechanical shelling at harvest. It is also worth noting that the proportion of abnormal seedlings was about 1–3% higher for the round fractions and lower for the flat fractions. In the vigor tests (Figure 1) the germination of seed harvested on the ear was superior to that of seed from shelled harvesting in the case of the MR fraction of hybrid PR39F58, and for this fraction the vigor was significantly better

Table 3 - Effect of shelled or ear harvesting on the fresh shoot weight (SW) and root weight (RW) of the seed of Pioneer maize hybrids, 2010.

Hybrid	Fraction	Harvesting method	SW g/25 plants	RW g/25 plants
PR39F58	LF	Shelled	4.38	3.01
PR39F58	LF	Ear	6.3**	4.8***
PR39F58	MF	Shelled	3.76	2.51
PR39F58	MF	Ear	–	–
PR39F58	MR	Shelled	3.175	2.35
PR39F58	MR	Ear	4.82**	4.65***
PR39F58	LR	Shelled	6.37	4.5
PR39F58	LR	Ear	6.58	5.1
PR39R86	LF	Shelled	5.61*	2.9*
PR39R86	LF	Ear	4.35	2.28
PR39R86	MF	Shelled	3.9	2.25
PR39R86	MF	Ear	3.46	1.57
PR 39R86	MR	Shelled	3.37**	2.31**
PR39R86	MR	Ear	2.27	1.34
PR39R86	LR	Shelled	5.76	3.06
PR39R86	LR	Ear	6.06	4.06**
			*$LSD_{5\%}$ = 1.21	**$LSD_{5\%}$ = 0.62
			**$LSD_{1\%}$ = 1.44	**$LSD_{1\%}$ = 0.83
				***$LSD_{0.1\%}$ = 1.37

–: no kernels in the fraction

in terms of both fresh root and shoot weight (Table 3). In the case of the PR39R86 hybrid, on the other hand, greater vigor and heavier fresh root and shoot weights were recorded after shelled harvesting for two of the fractions (LF, MR) (Figure 1, Table 3).

In the vigor tests there was a reduction in vigor in both harvesting methods after the kernels were stored for a year (Table 4). The seed vigor showed that some hybrids are extremely tolerant to shelled harvesting, while others are less so. This is an important criterion for seed, especially under the extreme climate conditions often observed in Hungary. The contradictory data suggest that the genotypes may respond differently to harvesting methods, seed moisture content at harvesting and the artificial stress factors exerted during processing (Figure 1). The work is being continued with a larger number of hybrids, and the combined results of three years will shortly be published.

Conclusions

The results obtained for the Pioneer hybrids included in the large-plot experiments led to the conclusion that, in the majority of cases, the two different harvesting methods tested did not have a significant effect on seed germination. The farm size plots (5-10 ha) were located on fields used for seed production, thus enabling the results to be translated directly into seed production practice.

Among the eight hybrids tested, PR39R20 and PR35Y65 proved to be the most sensitive, as the germination ability of seed harvested shelled was significantly lower than that of seed harvested on the ear. Before introducing shelled harvesting into practice, it would be advisable to carry out small-plot experiments to determine which hybrids are able to tolerate shelled harvesting in seed production.

As reported by George et al (2003), who examined the germination of sweet corn seed fractions after manual and mechanical harvesting and processing, it was found in the present work that mechanical processing reduced the germination of the larger seed fractions, which also suffered greater injury.

The question of trueness to variety cannot be ignored when discussing the shelled harvesting of seed production fields, as this method does not allow ear selection for the elimination of alien or diseased ears, which is one of the major advantages of harvesting whole ears. If economic aspects are also considered (faster, cheaper harvesting and drying, minimization of kernel loss in the seed processing plant), however, it may be that, if the hybrid maize seed obtained from shelled harvesting satisfies all the quality criteria, seed producers should be allowed to harvest the seed shelled in certain cases. At present this technique is not authorized for seed production in Hungary.

Table 4 - Effect of shelled or ear harvesting on the vigor of the seed of Pioneer maize hybrids, 2010.

Hybrid	Harvesting method	At harvesting	A year later
PR38H67	Ear	88	81.5
PR38H67	Shelled	91	85.5
PR39R20	Ear	62	48
PR39R20	Shelled	61.5	51.5
PR35Y65	Ear	99	94.5
PR35Y65	Shelled	96.5	89
PR39G83	Ear	87	89.5
PR39G83	Shelled	93	96
		$LSD_{5\%}$ = 8.32	$LSD_{5\%}$ = 8.48

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References

Anderson JD, Gupta K, 1986. Nucleotide alterations during seed deterioration, pp xx-xx. In: Physiology of Seed Deterioration. McDonald MB, Nelson CJ eds. Crop Sci Soc of Am Spec Publ 11

Berzy T, Marton LC, Fehér C, 1996. A frakcionálás hatása a hibridkukorica (*Zea mays* L.) vetőmag életerejére és szemtermésére. (Effect of fractionisation on the seed vigor and yield elements of some Mv maize hybrids.) Növénytermelés 45: 19-26

Borba CS, Andreoli C, de Andrade RV., de Azevedo JT, de Oliveira AC, 1998. Effect of drying delay on physiological quality of corn seeds. Pesquisa Agropecuaria Brasiliera, 33: 105-108.

Bruggink H, Kraak HL, Bekendam J, 1991. Some factors affecting maize (*Zea mays* L.) cold test results. Seed Science & Technology 15: 729-740

Burris JS, 1975. The effect of drying temperatures on corn seed quality. Can J of Plant Sci 64: 487-496

Eisele C, 1981. Die Kalibrierung von Maissaatgut aus der Sicht der Aufbereitung und Vermarktung. Mais 2: 6-7

Fiala F, 1973. Der Einfluss der Saatgutqualität bei Mais auf der Feldaufgang und Ertrag, pp. 98-117. Jahrbuch 1972 der Bundesanstalt für Pflanzenbau und Samenprüfung in Wien

Gáspár S, 1980. A csírázás környezeti szabályozása. (Environmental regulation of germination), pp. 164-180. In: A magbiológia alapjai. (Scientific Background of Seed Biology). Szabó LG ed. Akadémiai Kiadó, Budapest

George DL, Gupta ML, Tay D, Parvata IGMA, 2003. Influence of planting date, method of handling and seed size on supersweet corn seed quality. Seed Science & Technology 31: 351-366

Germ H, 1966. Qualitätsprobleme beim Saatgut. Der Földerungsdienst 14: 43-48.

Herter U. Burris JS, 1989a. Effect of drying rate and temperature on drying injury in corn seed. Can J Plant Sci 69: 763-774

Herter U, Burris JS, 1989b. Changes in moisture, temperature and quality of corn seed during high-temperature drying. Can J Plant Sci 69: 749-761

Hope HJ, Maamari R, 1994. Measurements of maize cold tolerance during germination. Seed Science & Technology 22: 69-77

ISTA, 1995. Complex Stressing Vigour Test (CSVT). Handbook of Vigour Test Methods), 3rd Edition, International Seed Testing Association, Zurich

ISTA, 2010. The Germination Test, International Rules for Seed Testing, International Seed Testing Association, Basserdorf, Switzerland. Edition 2010/1. ISBN: 13-978-3-906549-60-6

Loeffler NL, Meier JL, Burris JS, 1985. Comparison of two cold test procedures for use in drying studies. Seed Science & Technology 13: 653-658

Mounsey K, Moowrer K, Ghaffarzadeh M, 2002. Combine Harvest of Seed Fields - Lasting Alternative (Possibilities, Quality Concerns, and Improved Technologies), pp. 51-53. Agronomy Services

Navratil RJ, Burris JS, 1984. The effect of drying temperature on corn seed quality. Can J Plant Sci 64: 481-496

Nijenstein JH, 1985. Effects of some factors influencing cold test germination of maize. Seed Science & Technology 14: 313-326

Odiemah M, 1991. Relation of seed testing traits to grain yield of maize hybrids under different environments. Seed Science & Technology 19: 25-32

Pásztor K, 1962. Különböző frakciójú magvakkal végzett összehasonlító kísérletek eredményei. (Results of comparative experiments on various seed fractions.) Kukoricatermesztési kísérletek (Maize Production Experiments 1958-1960). Akadémiai Kiadó, Budapest

Seyedin N, Burris JS, Flynn TE, 1984. Physiological studies on the effects of drying temperatures on corn seed quality. Can J Plant Sci 64: 497-504

Shieh WJ, McDonald MB, 1982. The influence of seed size, shape and treatment on inbred seed corn quality. Seed Science & Technology 10: 307-313

Thielebein M, 1958. Kornform und Saatgutwert von Mais. Mitteilungen der DLG 47: 1261-1263

Varga P, Berzy T, Anda A, 2012. Morzsoltan betakarított hibridkukorica (*Zea mays* L.) vetőmag előzetes vizsgálati eredményei (Preliminary results of shelled harvested mais seed) Növénytermelés 61(1): 1-18

Woltz J, TeKrony DM, Egli DB, 2006. Corn seed germination and vigor following freezing during seed development. Crop Sci 46: 1526-1535