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# Optimum Harvest Time for High Quality Seed Production of Sweet and Super Sweet Corn Hybrids

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**ABSTRACT: The production of sweet (*su*) and super sweet corns (*sh2*) has been economically feasible in Korea in recent years. Major factors limiting super sweet corn production are low germination and low seedling vigor. Since seed quality is closely related to seed maturity, the optimum harvest time for the seed production of sweet and super sweet corns was studied and the quality of seeds with varying maturities was investigated in 2001 and 2002 cropping seasons. The parents of the sweet corn seeds were Hybrid Early Sunglow (♀) and 'Golden Cross Bantam 70' (♂) and those of super sweet corn were Xtrasweet 82 (♀) and 'Fortune' (♂). Seeds were harvested at 21, 28, 35, 42, 49, and 56 days after silking (DAS). As the seeds developed, seed weight of sweet corn increased and the seed moisture content decreased faster than that of super sweet corn. Germination rates of sweet corn seeds harvested 21 and 28 DAS at 25 °C and emergence rates in the cold soil test were significantly lower than those of seeds harvested after 42 DAS in both years. Although the germination rates of super sweet corn seeds with varying maturities showed similar patterns as sweet corn seeds at 25 °C, the emergence rate of super sweet corn seeds in cold soil test continuously increased with seed maturity. This suggests that seed quality of super sweet corn should be tested in a cold soil test to estimate field emergence. As the seeds developed, leakage of total sugars and electrolytes from the both sweet and super sweet corn seeds decreased up to 42 or 49 DAS. The α-amylase activities of both sweet and super sweet corn seeds increased with seed maturity from 21 to 35 or 49 DAS depending on genotype and year. The optimum harvest time for the seed production of sweet corn was 42 DAS and 49 DAS for super sweet corn considering emergence rate and plumule dry weight in the cold soil test, leakage of sugars and electrolytes from the seeds, and α-amylase activity.**

***Keywords***: sweet corn, super sweet corn, harvest time of seeds, cold soil test, germination rate, emergence rate, sugar leakage, electrolyte leakage, α-amylase activity

Before the introduction of modern corn hybrids in Korea, local varieties of flint and waxy corns were grown for food. Fully developed seeds were harvested, after drying they were ground and mixed with rice or made into corn porridge and noodle. In contrast, fresh corn was harvested before the kernels became hard and they were roasted, boiled, or steamed to have as a snack.

In Korea, the commercial production of traditional sweet corn (*sugary, su*) started in the early 1970s and super sweet corn (*shrunken-2, sh2*) in 1990s. At the present time, waxy corn is widely grown for fresh corn and sweet and super sweet corns share about 7% of the fresh corn market. The fresh market sweet corn industry in the United States had a shift from the traditional sweet corn to super sweet corn in the 1990's (Juvik *et al.*, 1993).

Seeds of super sweet corn have 2 ~ 3-folds more sugar content over sweet corn at the "roasting ear" stage (Lee *et al.*, 1987a; Lee *et al.*, 1999; Seo *et al.*, 2002) and maintain higher sugar levels for longer periods after harvest (Lee *et al*, 1987b) mainly due to a slower conversion of sugars to starch. Since the quality of sweet corn is closely related to sugar content, super sweet corn allows for additional time to transport and store with superior quality and reduces the need for refrigeration after harvest (Alexander, 1988). The problems of super sweet corn production are low field emergence rate, poor seedling growth, and high seed price. In Korea, the field emergence rate of the super sweet corn hybrids ranged from 79.9 to 98.2 % depending on the hybrids under the black plastic mulch at the optimum planting time (Seo *et al.*, 2002). However, under the suboptimal temperature and excessive soil moisture conditions at the early planting emergence rate of super sweet corn hybrids was extremely low (Young *et al*, 1997) Therefore, farmers plant 2 or 3 seeds in a hill and remove extra plants at the 3-leaf stage to maintain an optimum plant population. This practice requires more seed expenses and labor, thus it causes an increase in production cost.

The poor seed quality of super sweet corn was mainly due to low starch accumulation (Young *et al.*, 1997), infection of microorganisms during the drying, storage, and germination (Parera & Cantliffe, 1991), deterioration under the improper storage conditions (Chang & Sung, 1998), mechanical damages (Hartz & Caprile, 1995), and imbibition injuries (Wann, 1986).

Seed maturity is, also, one of the most important factors governing seed quality. A maximum seed dry weight of super

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sweet corn was achieved at 43 to 47 DAS and the germination rate was closely related to dry matter accumulation in seeds (Churchill & Andrew, 1984; Lee, 2000; Wilson & Trawatha, 1991). Harvesting immature corn seeds resulted in increased seed damages, and reduced seed viability, seedling vigor, and yield (Knitte & Burris, 1976; Styer *et al.,* 1980). Also, the low seed germination rate and seedling vigor of the immature seeds might be related to the increased leakage of metabolites (Wilson & Trawatha, 1991) in super sweet corn and reduced $\alpha$-amylase activity in dent corn hybrids (Lee *et al.,* 2002). However, the effects of a late harvest on the germination and seedling vigor are not well documented. Styer *et al* (1980) reported that the late harvested seeds of dent corn reduced root growth, although the germination rate and shoot growth were not adversely affected Also, the decreased emergence rate of late harvested dent corn seeds in a cold soil test might be due to a lower $\alpha$-amylase activity (Lee *et al.,* 2002). However, information is not available on the seed production of sweet and super sweet corn hybrids under Korean environmental conditions.

Therefore, the optimum seed maturity of sweet corn and super sweet corn hybrids was determined in terms of emergence rate and seedling growth in a cold soil test rather than germination rate in a paper towel test at 25 °C. Also, seed weight and moisture content, leakage of sugars and electrolytes, and $\alpha$-amylase activity were investigated to characterize the quality of seeds with varying maturities.

## MATERIALS AND METHODS

### Plant materials

The study was conducted during the 2001 and 2002 growing seasons at Gyeongsan, Korea. Since commercial inbred lines of sweet and super sweet corn (*Zea mays* L.) hybrids were not available in Korea, two rows of female and one row of male commercial F1 hybrids with similar maturity developed in the United States were planted alternately to make hybrid seeds with natural pollination. The parents of sweet corn hybrid were Hybrid Early Sunglow (♀) and Golden Cross Bantam 70 (♂) and those of super sweet corn were Xtrasweet 82 (♀) and Fortune (♂). Sweet and super sweet corns were grown in separate fields to prevent cross pollination, and the tassels of female plants were removed before pollen shedding.

Before planting, 180-65-124 kg ha$^{-1}$ of N-P-K were applied and incorporated into the soil by tractor-driven rotary hoes. Soil was mulched with 0.03 mm black polyethylene film and then two seeds were planted through the film at the 25 cm apart in 60 cm wide rows on 19 April 2001 and 20 April 2002. At the 3-leaf stage extra plants were thinned out to leave one plant per hill.

The silking date was tagged to each plant and ears were harvested from 21 to 49 DAS in 2001 and from 21 to 56 DAS in 2002 at the 7-day intervals. The ears were dried in an air-forced drier at 35°C in 2001 and in a green house in 2002. Seeds were hand-shelled and stored in a freezer at -12 until they were used in various experiments.

### Seed weight and Moisture content

Seed weight was the average of randomly selected 100 dry seeds with three replications. Moisture content of seeds with varying maturities was calculated with the following formula; Moisture content (%) = [(fresh weight – dry weight) / dry weight] × 100. Dry weight was measured after drying in an oven at 105°C for 48 hours.

### Germination at 25 °C and Emergence in the cold soil test

For the germination test, 30 seeds were planted on six layers of moist paper towel in a 32 × 24 × 8 cm plastic tray and allowed to germinate in a growth chamber (HB-301LP, Hanbaeck Scientific Co., Korea) at 25 ± 0.1 °C for 7 days in the dark with three replications. To estimate the field emergence potential of the seeds, the cold soil test was conducted in soil where corn was planted the previous year at 70% of soil moisture. Then, 30 seeds were planted at the 2 cm depth and allowed to emerge in the above mentioned growth chamber at 10 ± 0.1 for 7 days followed by 25 ± 0.1 for 7 days The germination and emergence rates were measured according to AOSA (1990).

### Leakage of sugars and Electrolytes from seeds

To measure the leakage of total sugars from the seeds, 20 seeds were soaked in 20 mL distilled water at 25 °C for 24 hours. The leachate was filtered through a Whatman #42 filter paper. Then, 10 mL of 0.2% Anthrone reagent in 98% sulfuric acid was added slowly to 5 mL of the leachate, mixed well, immediately heated in boiling water for 7.5 minutes, cooled in ice water, and left at room temperature for 15 minutes as in the method employed by Lee *et al.* (1995). Absorbance of the sample solutions was measured at 630 nm in a spectrophotometer (UVIKON Spectrophotometer, Kontron, Italy) and the total sugars were calculated as a glucose equivalent.

To measure the leakage of electrolytes, 25 seeds were soaked in 75 mL of triple distilled water at 20 °C for 24 hours. The electrical conductivity (EC) of the seed soaking solution was measured using an EC meter (MC126 Conductivity Meter, Switzerland) according to the AOSA (1990).

### α-amylase activity

The α-amylase activity of the seeds was measured by the method designed by Reiss (1994). Three seeds were soaked in distilled water at 25 °C for 7 days, dipped in liquid nitrogen, and ground in a mortar with a pestle. The ground samples were mixed in 10 mM cold citric acid-sodium citrate buffer solution and centrifuged for 20 minutes at 20,000 g to remove the starch grains, cell walls, mitochondria, and nuclei. One milliliter of the supernatant and 2 mL of the soluble starch buffer solution (0.05% starch in 0.05 M citric acid-sodium citrate buffer solution) were mixed for 20 minutes. Then, the α-amylase activity reaction was stopped by adding 7 mL of 1 N HCl to the supernatant and buffer solution mixture. One milliliter of iodine solution (5 g KI and 0.35 g $KIO_3$ in 1,000 mL of 2 mM NaOH) was added to the mixture to develop a blue color. Absorbance of the sample solutions was measured at 595 nm in the spectrophotometer (UVIKON Spectrophotometer, Kontron, Italy). The α-amylase activity was expressed as the percentage of starch lost.

### Statistical analysis

Experiment design was a randomized complete block design with three replications in each corn type. Statistical significance of treatment effects was determined using SPSS Standard Version (2000). Germination and emergence rates data were analyzed after arcsin transformation.

## RESULTS AND DISCUSSION

### Seed weight

Seed development of sweet and super sweet corn in 2001 and 2002 is shown in Fig. 1. Seed weight of sweet corn was significantly greater than that of super sweet corn at the comparable stages of development in both years. The seed weight of sweet corn increased from 21 to 49 DAS in both years and it was higher in 2002 compared to 2001 at the comparable stages of seed development. However, the seed weight of super sweet corn increased from 21 to 28 DAS and a little thereafter in both years. Similar results were also reported by Churchill & Andrew (1984), Lee (2000), and Willson & Trawatha (1991).

In 2001, the leaf senescence of sweet corn initiated at 35 DAS and that of super sweet corn did at 42 DAS. All leaves dried out at 49 DAS after heavy rain and both corn types were harvested. At harvest time some seeds in super sweet corn ears were infected with fungi and viviparous sprouting was occurred after a few days of continuous raining. However, in 2002 leaf senescence proceeded slowly and the last harvest was made at 56 DAS.

In Korea, sweet corn and super sweet corns produce silks between middle of June and early July depending on planting time and would be harvested at late July and early August. Korea locates in Monsoon region and two thirds of the annual precipitation occurs during the June, July and August. High temperature and humidity at the ripening stage may cause infection of diseases in leaves and ears of corn, and preharvest sprouting. Therefore, to produce hybrid seeds of sweet corn and super sweet corns, the seed production area and optimum planting time should be studied to obtain high quality seeds by avoiding raining at the ripening stage.

### Seed moisture content

The seed moisture content of sweet and super sweet corns decreased continuously until the last harvest in both years

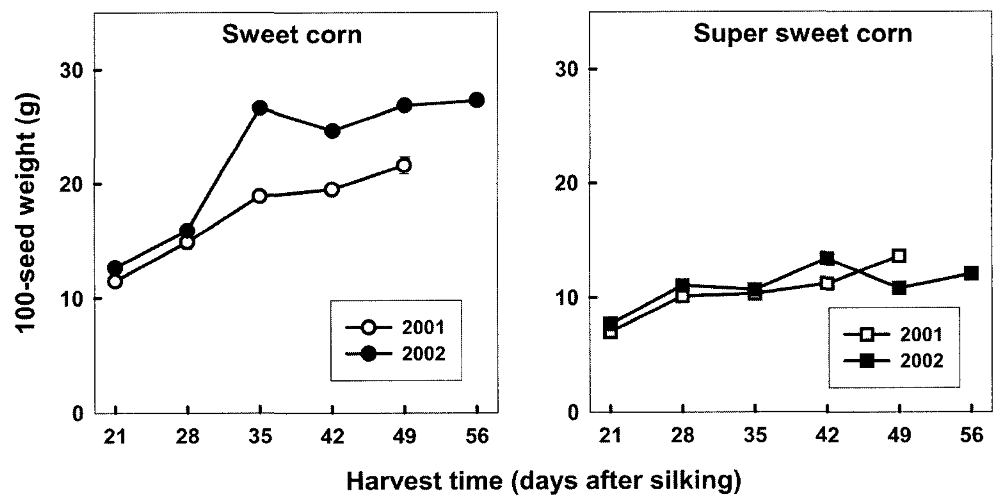


**Fig. 1.** Changes in 100-seed weight of sweet and super sweet corn seeds with different maturities Vertical line bars indicate standard error

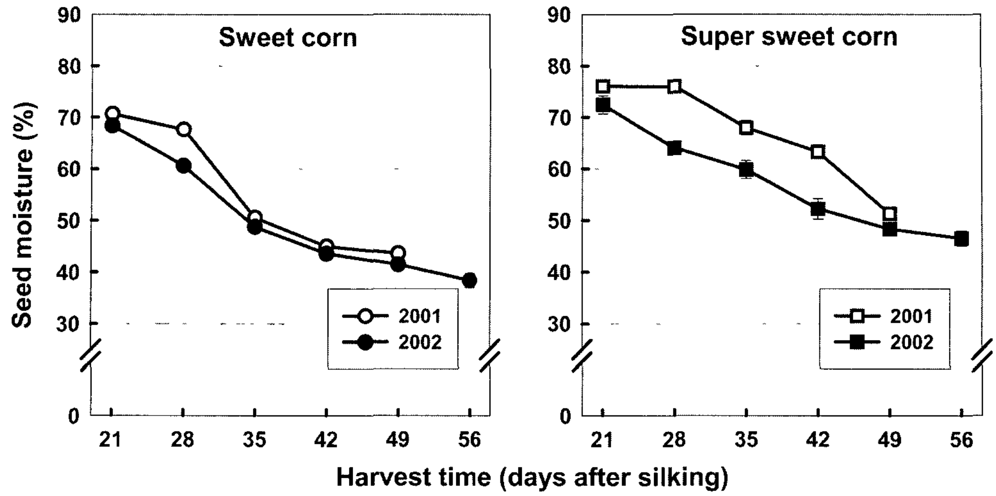


**Fig. 2.** Changes in moisture content of sweet and super sweet corn seeds with different maturities Vertical line bars indicate standard error

(Fig. 2). At 21 DAS the seed moisture content of sweet corn was about 5% higher than that of super sweet corn in both years and decreased faster than that of super sweet corn. At 49 DAS, the seed moisture content of sweet corn was 41 ~ 43 % and that of super sweet corn was about 49 ~ 51 %. At the physiological maturity, the seed moisture content of sweet corn was about 50 % (Bennet *et al*, 1988), that of super sweet corn was 50 ~ 55% (Wilson & Trawatha, 1991, Churchill & Andrew, 1984), and that of dent corn was 30 % (Lee *et al*, 2002) Thus, seed moisture content seems to be closely related to the starch accumulation in seeds of different corn types. Churchill & Andrew (1984) reported that the moisture content of super sweet corn seeds reduced to about 30 % by 60 ~ 67 DAS without further benefits for seed quality in the field. However, in Korea a delayed seed harvest beyond the optimum harvest time may cause preharvest seed sprouting or infection of fungi on seeds during the hot, rainy season without an increase in seed weight.

### Germination at 25 °C and Emergence in the cold soil test

Germination rate of seeds in paper towel test at 25 °C and emergence rate in the cold soil test are shown in Fig. 3. The emergence rate of both sweet and super sweet corns in the cold soil test was much lower compared to the germination rate in the paper towel test at 25 °C in both years at any comparable seed maturity, especially in immature seeds.

The germination rates of sweet corn in the paper towel test at 25 °C and emergence rate in the cold soil test showed similar patterns. The germination rate at 25 °C and emergence

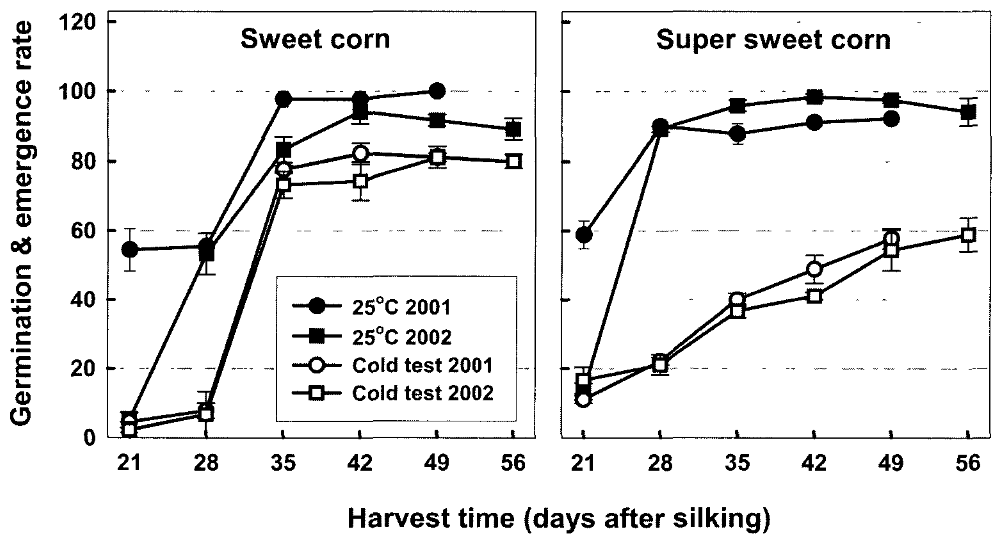


**Fig. 3.** Changes in germination rate of sweet and super sweet corn seeds with different maturities in a wetted paper towel and emergence rate in a cold soil test (10 °C for 7 days followed by 25 °C for 7 days). Vertical line bars indicate standard error.

rate in cold soil test of sweet corn seeds harvested at 21 and 28 DAS was significantly lower compared to seeds harvested at 35 to 49 DAS in both years.

However, the germination rate of super sweet corn seeds in the paper towel at 25 showed different patterns from the emergence rate in cold soil test. In the paper towel test at 25 °C the germination rate of super sweet corn seeds harvested at 21 DAS was 18.0% in 2001 and 58.9% in 2002 and they were much lower compared to seeds harvested between 28 and 49 DAS. In contrast, the emergence rates of super sweet corn seeds harvested at 21 DAS were about 11% in 2001 and 17% in 2002, but it increased gradually as the harvest time delayed until the last harvest in both years. These results imply that the germination test at the optimal germination conditions may be useful to estimate field emergence of sweet corn seeds, while super sweet corn seeds should be tested in cold soil test to estimate field emergence.

### Plumule weight

The plumule dry weight of sweet corn and super sweet corns at the end of cold soil test in 2001 is shown in Fig. 4. It increased from 21 to 42 DAS in sweet corn and to 49 DAS in super sweet corn. The plumule dry weight was positively correlated to the seed weight in both genotypes (Fig. 5).

Therefore, the optimum harvest time for the seed production of sweet corn seems to be 42 DAS and 49 DAS for super sweet corn considering seed emergence rate and plu-

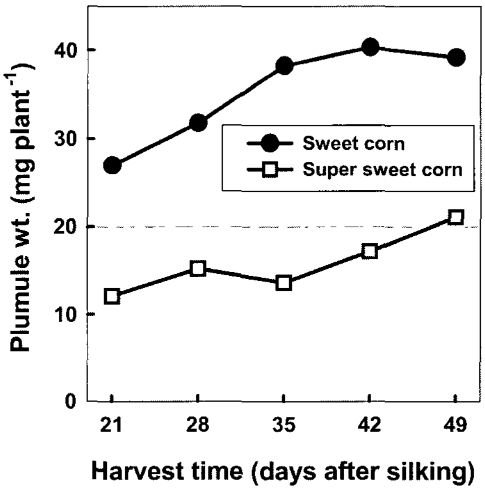


**Fig. 4.** Changes in plumule dry weight of sweet and super sweet corn seeds with different maturities in a cold soil test in 2001.

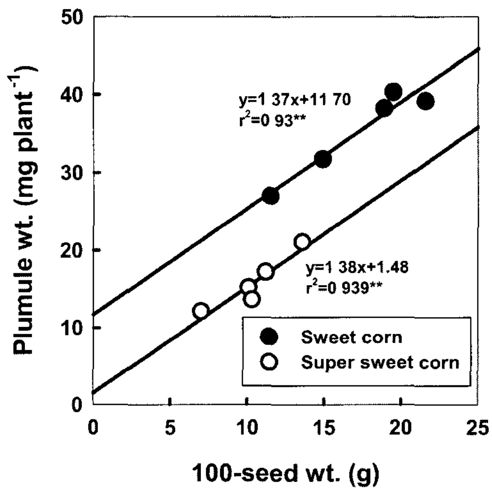


**Fig. 5.** Relationship between 100-seed weight and plumule dry weight of sweet and super sweet corn seeds in 2001

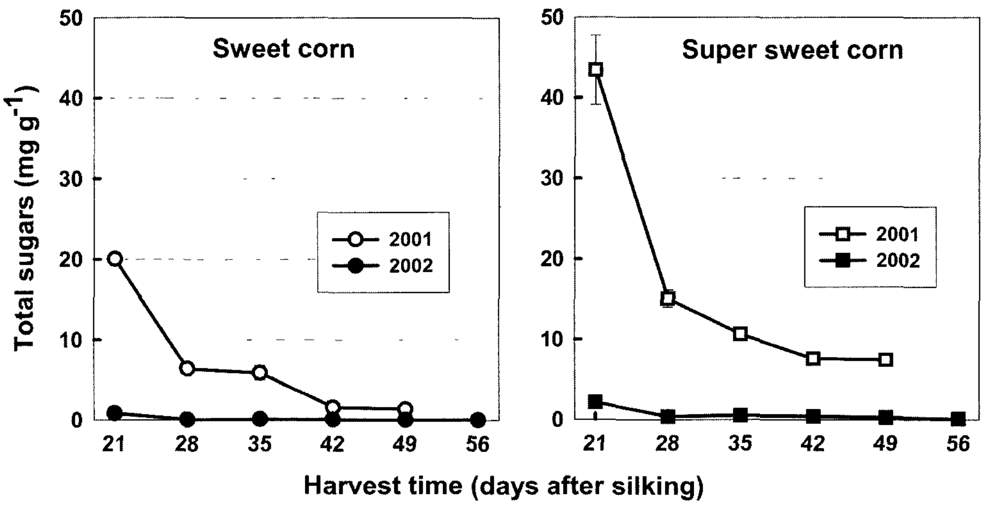


**Fig. 6.** Changes in leakage of total sugars from sweet and super sweet corn seeds with different maturities in soaking water. Ears were dried in an air-forced drier at 35 °C in 2001 and in a green hourse in 2002. Vertical line bars indicate standard error.

mule growth in the cold soil test. Similar results were reported by Churchill & Andrew (1984), Styer *et al.* (1980), and Wilson & Trawatha (1991). However, Bennett *et al.* (1988) reported that the germination rate of sweet corn and super sweet corn increased from 16 to 28 DAS and then decreased with maturity, although the shoot dry weight increased up to 42 DAS. These different results might come from the different genotypes and the varying environments during the ripening stages of corn.

### Leakage of sugars and Electrolytes

**Leakage of sugars:** Leakage of total sugars from the seeds with varying maturities is shown in Fig. 6. In 2001, super sweet corn seeds leaked more sugars than sweet corn seeds at the comparable harvest time. The amounts of sugars leaked from the seeds decreased very quickly from 21 to 28 DAS and then slowly up to 42 DAS with seed maturity in both corn types. Sweet corn seeds leaked very little at 42 and 49 DAS, while super sweet corn seeds did considerable amounts of sugars at the same seed maturity. Similar results were reported on inbred and hybrid seeds of dent corn with varying maturities (Lee *et al.*, 2002).

However, in 2002 both sweet corn and super sweet corn seeds did not leak significant amounts of sugars regardless of seed maturity. Why sugar leakage is so different between two years? In 2001, seeds were dried in an air-forced drier at 35 °C, so sugar was maintained in seeds, while in 2002 seeds were dried in a green house, so most sugars must be transformed into starch and respired during the drying (Miller & Brooks, 1832).

**Leakage of electrolytes:** Leakage of electrolytes from the seeds with varying maturities is shown in Fig. 7. Leakage of electrolytes form seeds to soaking solution (leachate) was measured as electrical conductivity (EC). EC of super sweet corn leachate was higher compared to that of sweet corn seeds at the comparable harvest time. Wann (1986) also reported similar results. As seed maturity advances, the EC of sweet corn leachate decreased rapidly from 21 to 35 DAS and leveled off, while that of super sweet corn seeds decreased from 21 to 49 DAS continuously. Wilson & Trawatha (1991) reported that EC of super sweet corn leachate reduced from 22 to about 70 DAS and leveled off with further seed maturity (Fig. 7).

### α-amylase activity

The α-amylase activity of seeds with varying maturities is shown in Fig. 8. The α-amylase activity of super sweet corn was significantly higher than that of sweet corn and also similar results were reported by Lee & Seo (2004), Seo *et al.* (2003), and Young *et al.* (1997). The α-amylase activity of germinating corn seeds differed depending on corn type, tissue of seeds, and time course of germination (Young *et al.*, 1997). At the radicle and coleoptile emergence stages the α-amylase activity of super sweet corn in scuttelum was significantly higher than that of sweet corn seeds and became similar at the leaf emergence stage However, in endosperm significant amounts of the α-amylase activity initiated from the coleoptile emergence stage and the α-amylase activity of super sweet corn was slightly lower than that of sweet corn. At the leaf emergence stage the α-amylase activity of super sweet corn was much lower than that of sweet corn due to fast depletion of starch in super sweet corn seeds. In this experiment the α-amylase activity of whole seeds was mea-

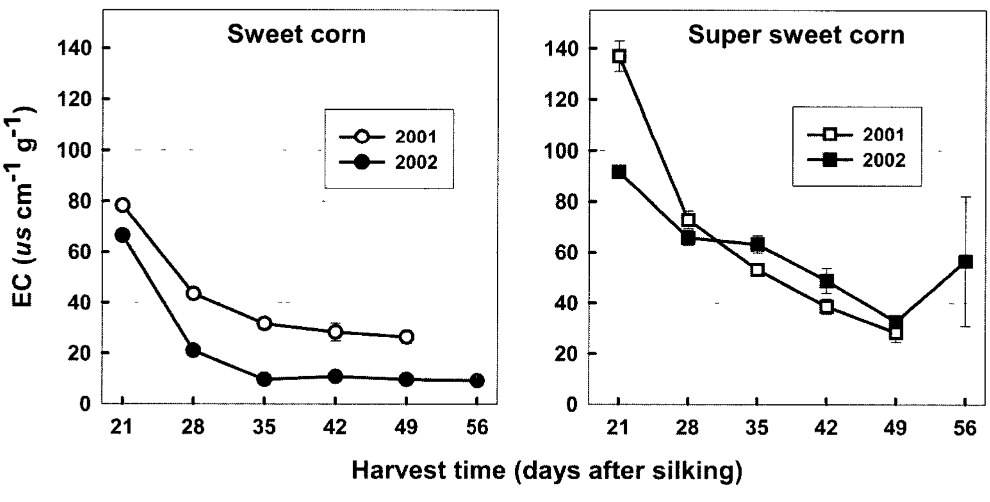


**Fig. 7.** Changes in electrical conductivity (EC) of seed soaking solutions of sweet and super sweet corns. Ears were dried in an air-forced drier at 35 °C in 2001 and in a green house in 2002 Vertical line bars indicate standard error.

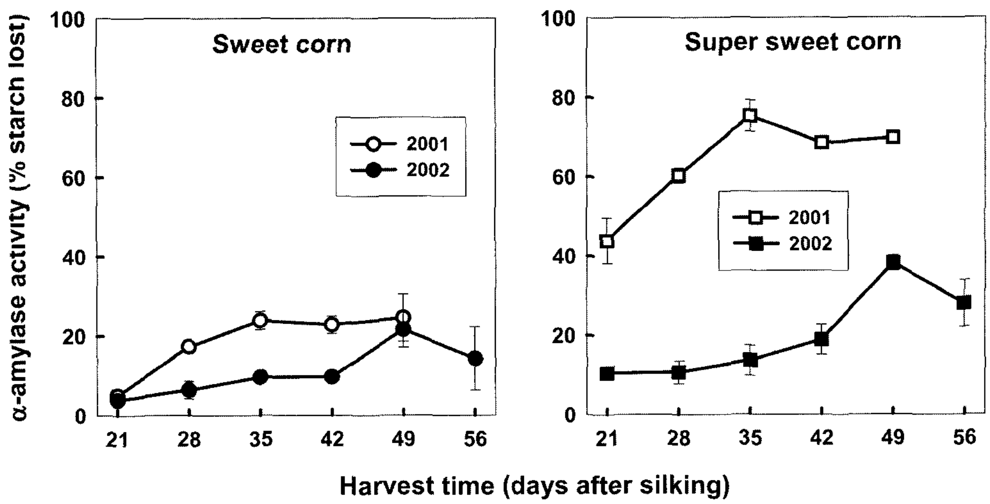


**Fig. 8.** Changes in α-amylase activity of sweet and super sweet corn seeds with different maturities. Ears were dried in an air-forced drier at 35 °C in 2001 and in a green house in 2002. Vertical line bars indicate standard error

sured at the coleoptile emergence stage, thus, the α-amylase activity of super sweet corn might be higher than that of sweet corn.

The α-amylase activities of both sweet and super sweet corns increased from 21 to 35 DAS, and then leveled off in 2001, while they increased from 21 to 49 DAS and decreased at 56 DAS in 2002. Similar patterns of α-amylase activity with varying seed maturities were also observed in dent corn inbred lines (Lee *et al*, 2002).

## CONCLUSION

Germination and emergence rates of sweet and super sweet corns with different seed maturities varied depending on the germinating temperature regimes (Fig. 3). Since the result of the cold soil test represents the field emergence potential of corn, optimum harvest time of seeds should be determined by the emergence rate in the cold soil test rather than the germination rate conducted under the optimum conditions such as moisten paper towel at 25 °C.

In this experiment the optimum harvest time for seed production of sweet corn was 42 DAS and 49 DAS for super sweet corn considering emergence rate (Fig. 3) and plumule growth of seedlings in cold soil test (Fig. 4). A delayed harvest beyond the optimum harvest time may be damaged by the wild animals, preharvest sprouting, and infections of fungi in seeds during the hot, rainy season in Korea. However, in areas where the weather conditions are mild, seeds may be harvested late to save drying expenses (Churchill & Andrew, 1984).

Seeds harvested at the optimum maturity showed high seed weight (Fig. 1), reduced leakage of sugars (Fig. 6) and electrolytes (Fig. 7) when soaked in water, and a higher α-amylase activity (Fig 8). These excellent seed qualities support the higher emergence rate and plumule growth of sweet corn and super sweet corn seeds in the cold soil test, thus the seed will perform well even under the unfavorable environments such as earlier planting in the field (Willson *et al.*, 1992).

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