by 2 dominant genes (Table 3), more definitive studies on the inheritance of turnip mosaic resistance is needed.

We have not addressed the issue of strain specificity of *P. parasitica* and TuMV. Whether the resistance identified in this study is strain-specific is not known. In order to fully deploy host resistance in controlling downy mildew and turnip mosaic in Chinese cabbage, a comprehensive disease screening program involving a range of pathotypes is needed.

The relationship between cotyledon resistance and adult plant resistance to *P. parasitica* needs to be evaluated in downy mildew-infested areas. If seedling resistance expressed as reduced sporulation is also present in the adult plant then a significant reduction of epidemic spread may be effected.

Table 3. Genetical analysis of turnip mosaic resistance derived from a cross between PHW64710, homozygous resistant and PHW64708, susceptible Chinese cabbage plant.

Generation	No. of plants		Expected[z] ratio	χ^2	P
	Resistant	Susceptible			
F_1	23	0			
F_2	71	3	15 : 1	0.61	0.5–0.3
F_1xP_1	50	0			
F_1xP_2	18	11	3 : 1	2.59	0.2–0.1

[z]Based on a dominant digenic model.

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Prediction of Sweet Corn Field Emergence by Conductivity and Cold Tests

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Abstract. **Field-emergence trials and laboratory seed-quality tests were conducted on 45 seed lots of 13 sweet corn (*Zea mays* L.) hybrids. Results from standard laboratory germination tests were not correlated with field emergence in 4 field trials. Cold tests conducted in sterile sand and on rolled towels were correlated highly with field emergence. Electrolyte leakage tests conducted on individual seeds with the ASA-610 Automatic Seed Analyzer were superior to bulk-seed measurements with a conductivity meter. By combining the seedling-growth cold test (total seedling dry weight) with the Automatic Seed Analyzer test, multiple correlation values with field emergence ranged from 0.70 to 0.80.**

The use of high-quality seed is essential for improving stand establishment in vegetable crops. Planting vigorous seed should result in more uniform emergence and higher yields over a wide range of environmental conditions. Vigor selection can be accomplished either on individual seeds or on bulk seed lots. Levengood et al. (11) developed a method (using an early model seed analyzer, MSS-110) to remove individual seeds of low vigor based on the electrical current level in the testa after a brief imbibition period. Field emergence, plant vigor, and yields were improved by planting only the top-grade seed. Later research (13, 14, 19) using the ASA-610 Automatic Seed Analyzer showed that this instrument could be used to predict germination and to detect changes in seed viability. These later studies concentrated on correlation with laboratory tests rather than field emergence. Until routine selection of individual seeds with high seed vigor becomes feasible, growers must rely on better tests to predict the overall performance of seed lots under field conditions. The inaccuracy of the standard laboratory germination procedure to test seed vigor (8, 16, 17) has led to extensive research for more reliable vigor tests (9).

Seed-quality testing in sweet corn has involved mainly the cold test (12). In the standard cold test, seeds are exposed to cold temperatures (10°C) in the presence of soil pathogens for an established period (7 days) and then transferred to temperatures favorable for growth. Burris and Navratil (2) have shown for field corn that cold tests on sterile substrates were comparable to those involving soil. They concluded that the main response

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of the seed was to the temperature stress during imbibition. Elimination of soil from the cold test would make it easier to standardize results among seed-testing laboratories. The cold test alone, however, is not a reliable predictor of field emergence (15).

The objectives of our study were to: 1) examine the response of several seed lots to cold tests on sterile substrates; 2) determine if conductivity tests currently used for peas would be suitable tests for sweet corn seed vigor; and 3) evaluate the possibility of combining the above tests to achieve a better assessment of sweet corn field-emergence potential.

Materials and Methods

Seeds of 45 lots from 13 cultivars of sweet corn were supplied by vegetable-processing companies in Minnesota. Seeds were stored in a controlled storage facility at 3° to 4°C and 40% to 50% relative humidity. No adjustments were made for moisture since all seed samples measured with a Motomco moisture meter ranged from 7.0% to 9.0% (wet weight basis). All tests were conducted within a period of one year.

Field tests. Data were collected for field emergence from 4 separate trials (Table 1). For each seed lot, a total of 100 seeds in each 1980 trial and 200 seeds in each 1981 trial was planted about 3 cm deep in a randomized complete-block design with 4 replications. Final stand counts were recorded 3 weeks after planting. The plots were seeded with a cone planter at Waseca and by hand at Anoka and Chanhassen due to the lack of an available cone planter. The method of planting was not expected to influence seed damage or the stand at 3 weeks. No herbicide, fertilizer, or irrigation were applied.

Laboratory germination. Laboratory germination tests were conducted at 25°C on 25.4 × 38.1 cm standard weight germination paper towels according to standard procedures (10); 4 replicates of 50 seeds each were tested.

Cold tests. A sterile-sand cold test was conducted as a randomized complete block design with 4 replicates of 50 seeds each. Water was mixed mechanically with sand to obtain uniform moisture before steam sterilization. Plastic flats were filled with 3.8 cm of firmly compacted sand and seeded with the radicle end of each seed oriented downward. Seeds were covered with 2.5 cm of firmly pressed sand. The flats were placed in polyethylene bags to retain soil moisture at about 70% saturation and incubated at 10°C in the dark. After 6 days, the polyethylene was removed and the temperature was increased to 25° to 27°C. Emergence was determined for 6 consecutive days with color-coded toothpicks. The emergence index (EI) and the seed quality index (SQI) were calculated according to the formulas developed by Silbernagel (18). The EI is a formula weighted for the speed of germination and the SQI is the EI adjusted for the number of healthy vigorous seedlings. The total number of seedlings emerged and the percentage of healthy vigorous seedlings were determined. A healthy vigorous seedling was defined as having a shoot height of at least half the average height in the test and free from defects, such as coiling.

In a 2nd study, the seedling-growth test described by the Association of Official Seed Analysts (1) was modified for use as a cold test. From each seed lot, 4 replicates of 50 seeds each were used. Seeds were oriented with the embryo side up and the radicle pointed to the bottom of the towel. They were rolled between 3 layers of 35.5 × 63.0 cm standard-weight germination towels and incubated in an upright position in a polyethylene bag inside a metal container. The samples were incubated at 10°C for 4 days followed by an additional 4 days at 25°. The number of normal and abnormal seedlings and dead seeds was determined. Total seedling dry weight was obtained after removal of the kernels by weighing the combined roots and shoots from normal seedlings and the average weight per normal seedling was determined.

Conductivity tests. Since our preliminary tests showed that commercial seed treatments could increase the electrolyte content of the leachate, all seeds were rinsed for 10–15 sec in deionized water, blotted to remove free water, and air-dried prior to testing. A conductivity bridge (Barnstead PM-70CB) was used to measure the leachate obtained by soaking samples of 10 seeds in 50 ml deionized water at 24° to 25°C for 24 hr. The final volume of water was adjusted to 50 ml before conductivity measurements were undertaken to avoid uneven concentration of leachates due to differences in seed imbibition. Four replicates of each seed lot were evaluated. The conductivity measurements were expressed in micromhos. A seed-weight correction was made to determine if initial seed size affected electrolyte leakage.

Electrical conductivity of individual seeds was measured with the ASA 610 Automatic Seed Analyzer (Agro Sciences, Inc.). Seeds were placed in trays containing 100 individual cells which had been equilibrated with deionized water and checked for purity (i.e., all cells had current values below 8 microamps at a scale select position of 3). After a 24-hr soak period at 25°C, seeds with ionic leachates producing an electrical current of 190 microamps or more (based on a series of preliminary tests) at a scale select position of 3 were considered nonvigorous seed. The number of seeds producing current levels less than this partition

Table 1. Descriptive details of 4 field trials at which 45 seed lots of sweet corn were evaluated for emergence.

Trial	Minnesota location	Planting date	Soil type	Soil temp[z] (°C)	Total precip[y] (cm)	Avg days to 50% emergence
1	Waseca	Sept. 17, 1980	Webster clay loam	14	8.6	17
2	Anoka	Sept. 16, 1980	Mucky peat	12	1.3	18
3	Waseca	Apr. 25, 1981	Webster clay loam	14	6.9	17
4	Chanhassen	Apr. 16, 1981	Mucky peat	---	5.1	20

[z]Average daily maximum temperature, for the duration of the test period at 10-cm depth; data not available for Chanhassen.
[y]Total precipitation for duration of the test period.

was determined and used to predict emergence. Four replicates of 100 seeds from each lot were tested.

Results and Discussion

The mean emergence of the sweet corn seed lots varied from 49% to 77% depending on the location. The correlations among the 4 field trials were highly significant and ranged from 0.69 to 0.84. A wide range in field emergence was found among the samples but it was not due to such artificial processes as accelerated aging or radiation. The poor seed vigor naturally present in some seed lots could have been due to improper harvesting and handling, poor storage conditions, or other factors reported to reduce seed quality (9). These seed lots, typical of those available commercially, were evaluated by the standard laboratory germination test, but the relationship between field emergence and standard laboratory germination was very low at all 4 locations (Table 2). This indicates that, without further testing, a grower would have little basis for making critical decisions concerning the purchase of seed, rates of seeding, or planting date to achieve the best possible stand.

The cold tests were conducted on a sterile sand medium to avoid the problems in standardizing a cold test which used infected soil. Both the sterile-sand cold test and the seedling-growth cold test were superior to the standard laboratory germination test in predicting field emergence (Table 2).

For emergence in the sterile-sand cold test, several indices of vigor were calculated. The EI and SQI calculations were time-consuming and failed to improve correlations with field data over simple counts of the number of healthy vigorous seedlings present. Emergence rates could be more important in evaluating seed quality when tests are conducted in heavy soils where emergence is more difficult. However, since the EI requires daily coding of emergence, it may be too time-consuming for routine seed-quality testing.

The seedling-growth cold test conducted on rolled germination paper towels in the absence of soil may be a more practical test for measuring the effect of cold stress on germination because it requires less time to perform and less space for cold incubation than the sterile-sand cold test or other tests with soil (3, 4). One disadvantage is the time-consuming nature of seedling dry-weight determination. Earlier research with sweet corn (3, 4) found that cold tests in rolled germination paper towels only gave high correlations to midsummer plantings and that cold tests with nonsterile soil were better emergence predictors superior for earlier plantings. The data reported here reflect much higher correlations with early-seasons field emergence; however, the cold test conducted in this study differed from those of previous studies in that dry weights of normal seedlings were used. Since the highest correlations with field emergence were generally with the total seedling dry weight (Table 2), derived from only normal seedlings and their weight, it is recommended for evaluating cold-test results on rolled germination paper towels.

The conductivity tests also were good indicators of field emergence (Table 2). Adjusting the bulk conductivity test for seed weight did not improve the correlation with the field emergence, suggesting that seed size failed to influence the amount of electrolyte leakage. This conclusion is consistent with other studies (20). Other factors which have been shown to cause variability in conductivity (5, 20)—including seed moisture and soak water source—were not considered to be problems in this study since distilled water was used and all seeds were held in uniform storage conditions for one month or longer before the tests were conducted. This length of storage likely minimized seed-moisture variability. It is possible that some of the variability in the results reported here are genetic (given the large number of varieties), related to seed provenance or seed handling (6). Regardless of the cause, increased leachate conductivity was probably due to the loss of ability to reorganize cellular membranes rapidly and completely (12).

The ASA-610, which measures the current (expressed as micromhos) of the leachates from individual seeds, gave higher correlations with field performance than did bulk-seed conduc-

Table 2. Relationship ("r" value) between field emergence and laboratory data for 45 seed lots of sweet corn.[z]

	Field emergence (%)				
	1980		1981		Overall
Seed test	Waseca	Anoka	Waseca	Chanhassen	avg
Standard lab germination	0.15	0.18	0.09	0.20	0.18
Sterile-sand cold test					
1) Total emergence (%)	0.55	0.55	0.50	0.38	0.49
2) Healthy vigorous seedlings (%)	0.62	062	0.65	0.51	0.62
3) Emergence index (%)	0.62	0.54	0.55	0.44	0.58
4) Seed quality index (%)	0.59	0.64	0.60	0.50	0.61
Seedling-growth cold test					
1) Normal seedlings (%)	0.54	0.53	0.56	0.38	0.48
2) Weight per seedling (mg)	0.53	0.55	0.58	0.46	0.56
3) Total seedling dry wt (g)	0.59	0.61	0.64	0.46	0.62
Bulk Conductivity test					
1) Micromhos	−0.49	−0.57	−0.42	−0.61	−0.58
2) Micromhos/g	−0.54	−0.52	−0.39	−0.64	−0.57
ASA-610 seed analyzer (%)	0.51	0.63	0.48	0.68	0.64
ASA-610 + seedling dry wt	0.70	0.79	0.72	0.75	0.80

[z]Absolute values above 0.28, significant at the 5% level; above 0.37, significant at the 1% level (n = 45).

tivity tests (Table 2). The correlation between the 2 tests was highly significant ($r = -0.86$). The principal advantage of the ASA-610 over other leachate tests is that readings on individual seeds are obtained. With this information, one can distinguish more easily among seed lots having a large number of mediocre seeds and those having a few extremely poor seeds.

The predicted germination obtained with the ASA-610 is based on a critical current level selected by the operator. Seed leachates producing current levels higher than this critical value (the partition) are indicative of membrane damage and the seed is considered nongerminable. By basing the selection of a partition on known field performance as in this study, the ASA-610 can be used as a vigor test as well as a germination test. If the conducitivity of the leachate is less than the partition, cellular membranes are more intact and the seed is considered more vigorous. Degeneration of cellular membranes is one of the initial steps in the loss of seed quality noted by Delouche and Baskin (7). The ASA-610, therefore, is capable of measuring changes that occur early in the loss of seed vigor. Since it is a rapid, simple, and objective test which correlates well with field performance, the ASA-610 has potential as a standard test for seed vigor in sweet corn.

The ASA-610 and seedling-growth cold tests (total seedling dry weight) were both correlated with field emergence. Multiple regression analyses combining these tests seemed desirable for 2 reasons: 1) since the 2 tests were not correlated with each other ($r = 0.24$), they were probably measuring 2 separate aspects of seed quality; and 2) a location effect was observed in which the conductivity test was a better indication of field performance on both peat sites, while the cold tests gave greater correlations with the clay-loam site. Without further understanding of this location effect, it is not possible to select the best test for a specific site. The correlation values obtained from combining these 2 tests ($r = 0.70$ to 0.80) lie within the range obtained from retesting the seed samples at different field sites ($r = 0.69$ to 0.84).

The rolled-towel cold test and the ASA-610 test are good vigor tests for sweet corn because they are inexpensive, can be standardized easily and conducted without extensive training, and are correlated highly with field emergence. The coefficients of determination (R^2) for the regression equations including the above 2 tests ranged from 0.49 to 0.64 depending on the field site. Further tests are being conducted to improve the accuracy of prediction for sweet corn emergence.

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