ENHANCED SWEET CORN PROPAGATION: STUDIES ON TRANSPLANTING FEASIBILITY AND SEED PRIMING

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Summary
Sweet corn hybrids with high-sugar genotypes (sh²) has inherent problem of low seed emergence and stand in the field. This study was conducted to determine the effect of seed size, tray cell size and growing media components on sweet corn transplant transplanting. Other objectives were to evaluate the effect of priming sweet corn seeds on germination in the field. Bio-priming with Trichoderma and Bacillus, osmo-priming with KNO₃, and hydro-priming with H₂O have been tested. The results indicated that transplanting sweet corn is feasible with high quality transplants from seeds that germinate well in disease-free environment. Large sweet corn seeds, large tray cells, and vermiculite-based growing media proved to gave higher germination percentages. While same factors did not show pronounced effect on seedling performance in terms of root and shoot length and fresh weight. In the priming experiment, the bio-priming treatment showed the highest germination of seeds percentage among other priming treatments and the control. Sweet corn seeds treated with Bacillus megaterium germinated 50% higher than seeds treated with Trichoderma spp. as bio-control agents. Aspergillus niger, and Penicillium represented 65% of pathogens responsible for failure of sweet corn seed germination. The results of this study demonstrated the feasibility of enhanced sweet corn seed propagation through transplanting and seed priming to improve emergence and field stand.

key words: sweet corn, transplanting, seed size, tray cell size, seed priming, bio-priming, Bacillus megaterium, Trichoderma spp.

INTRODUCTION
Sweet corn (Zea mays L.) for fresh market, freezing and canning is an important commodity in many countries and becoming increasingly popular between consumers. However, sweet corn seeds germinate slowly and exhibit poor seedling vigor (Wolf et al. 1997). Poor germination is particular problem with early spring planting in cold soils. Seed priming, bio-priming, prehydration, coating and various fungicides treatments may
improve the stand establishment of sweet corn (Bennett et al. 1991, 1992). Poor germination in sweet corn has been attributed to low seed vigor and susceptibility to seed and soilborne diseases. Injuries during imbibition has been identified as a major contributing factor to poor stand establishment in sweet corn resulting in increased leakage of electrolytes and carbohydrates (Schmidt & Tracy 1988, Wann 1986). The resulting leakage of electrolytes can stimulate pathogenic soilborne fungi. Also, low carbohydrate levels in seed adversely affect germination vigor (Styer & Cantliffe 1983, 1984).

1. Transplanting
On the other hand, transplanting provides optimal environmental conditions for seed germination and avoids planting seeds in disease-contaminated soil. Sweet corn has been transplanted experimentally in an attempt to improve stands and hasten maturity (Menasha & Tignor 2004, Menasha 2005, Di Benedetto et al. 2006, Miller 1972, Rattin et al. 2006, Wyatt & Mullins 1989). Similar attempts have been reported in field corn (Khehra et al. 1990, Pendleton & Egli 1969). Conversely, transplanting sweet corn remains a questionable practice because it increases production costs and often stunts plant development. Transplanting sweet corn is feasible because transplant technologies enable large-scale transplant production with minimal labor. However, little information is available on factors affecting transplanting such as seed quality, transplanting methods, growing media components and environmental conditions.

Since growers of fresh market sweet corn are interested in the earliest possible maturity for optimal prices, the approach of transplanting has been used. Transplanting sweet corn decreased time to harvest by 1 to 3 weeks depending the transplant age (Miller 1972, Wyatt & Mullins 1989). The effects on yield and mature plant characteristics have varied, depending on age of transplants and time of transplanting (Waters et al. 1990). Significant increase in stand counts and earliness were achieved through transplanting as compared with direct seeding (Dunwell et al. 1993). However, transplant produced a greater percentage of smaller, lower quality ears than did direct seeded plants which may nullify the benefits of improved stands obtained through transplanting (Welbaum et al. 2001). Corn does not transplant well because pruned roots do not branch and root replacement is generally poor compared with other crops such as tomato and cabbage. So, the inability of corn roots to regenerate after transplanting resulted in stunted plants that produced a greater percentage of cull ears (Welbaum et al. 2001). Further research on transplant production and planting should probably focus on the characteristics of root development and handling practices to protect roots from damage (Waters et al. 1990). Plug trays that minimize trauma to sweet corn roots may improve transplant field performance (Menasha & Tignor 2004, Menasha 2005, Rattin et al. 2006, Welbaum et al. 2001).

1.1. The effect of seed size
The development of the plant that emerges from a seed is influenced by the health and vigor of that seed.
Seeds size is one of the most important characters of seed quality of a crop. Seed size and shape is controlled by the genetics of the parent plant (Voigt et al. 1966), but also influenced by environmental conditions during plant development and grain fill. Stresses such as high temperature, low soil moisture, or low fertility can reduce seed size. In corn placement of the seed on the ear also affects both size and shape. The sequential development of the corn ear from the base to the top causes a range in seed maturity and filling period, and affects the seed ability to compete for available photosynthate and space on the cob. Large-round seeds usually come from the base of the ear, flats from the center, and small round seed from the tip. Large seeds have advantage over small seeds because of the stock of nutrients at the disposal of the embryo (Giles 1990, Styer & Cantliffe 1984, Wann 1980).

In sweet corn, Cameron et al. (1962) found that seed size of hybrid varieties affect total percentage of germination, size of young plants, percentage of ear shoots which silk early and the number of ears ready for early market. Sweet corn seed size was shown consistently to influence early seedling dry weight (Bennett et al. 1988). In field corn, the relation between seed size and emergence, growth and yield has been extensively studied. There was a significant positive correlation between seed size (as indicated by 1000-seed weight) and plant vigor parameters under low temperature (Gubbels 1974). Seed size effect on field corn performance has shown a tendency for small seed classes to produce smaller plants than those from large size classes (Hicks et al. 1976). Also, in field corn initial plant size was larger when grown from large seed, but relative differences in plant size became smaller as the crop matured and there were no significant yield effect (Hawkins & Cooper 1979). On the other hand, seed size was not significant on maize seedling emergence and growth but significantly increased seedling height (large seed has taller seedlings as compared to small seed). Seed size did not influence seedling dry weight and number of leaves (Molatudi & Mariga 2009). Similar results have been achieved by Hunter and Kannenberg (1972). The same trend for the relationship between seed size and emergence, seedling growth and yield was found in broad array of plants including cabbage (Shanmuganathan & Benjamin 1992), broccoli (Heather & Sieczka 1991), tomato (Halsey 1969), onion (Gamiely et al. 1990), pea (Pyke & Hedley 1983).

1.2. The effect of tray cell size

Transplants are produced in a number of various sized containers or cells. Varying container size alters the rooting volume of the plants, which can greatly affect plant growth. Container size is important to transplant producers as they seek to optimize production space while transplant consumers are interested in container size as it relates to optimum post-transplant performance. A trend among many commercial transplants produces is toward more cells per tray (smaller containers) which increases the number of plants produced while reducing the need to develop more transplant production space and decreases propagation cost per plant. A major effect of
decreased container size is that it increases root restricting conditions (NeSmith & Duval 1998).

Plants undergo many physiological and morphological changes in response to reduced rooting volume. Plant development can be influenced by container size. Root restriction and container size can affect root and shoot growth, biomass accumulation, photosynthesis, leaf chlorophyll content, flowering and yield. The delicate balance between roots and shoots can be upset when the root system is restricted in a small rooting volume. Transplants with relatively large root systems generally suffer less post-planting shock and thus come into production earlier than plants with small root systems. Container grown plants in general have different root morphology than field seeded crops. These alterations in root morphology may be more pronounced with small container size and could predispose plants to drought stress since a significant reservoir of soil water resources goes unexplored. When root restricted seedlings are planted in the field they are often unable to compensate for evaporation even if they are well watered after transplanting (NeSmith & Duval 1998).

Shoot growth is greatly impacted by varying container size and root restriction. Similarly as rooting volume decreased, less leaf area is produced. The reduction in leaf area was due to both smaller and fewer leaves per plant. Reduced plant biomass under root restricting conditions could possibly be due to a lower photosynthetic rate. The flowering period was reduced due to increased root restriction in various species. Many morphological and physiological responses of plants to varying container sizes and root restricting conditions have been reported (Hall 1989, Maynard et al. 1996, Ruff et al. 1987). However, of most concern to the end user of the transplant is the post-planting performance of the seedling and of particular concern is crop yield resulting from transplants grown in different container sizes. Varying transplant container size has shown mixed results on harvested yield which have not been thoroughly explained (Cantliffe 1993, NeSmith & Duval 1998). In sweet corn, a greater percent germination was observed for seeds sown in the 49 ml/cell trays compared to the 19 ml/cell trays (Dunwell et al. 1993). Increased cell volume before transplanting significantly increased root surface area, average diameter, root volume, and shoot biomass after transplanting (Menasha & Tignor 2004, Menasha 2005). Similar results were obtained by Di Benedetto et al. (2006).

1.3. The effect of growing media
The transplant production process involves optimizing the many factors that govern both seedling production and post-plant performance (NeSmith & Duval 1998). Among these, perhaps the most important is the type of growing medium used. Due to the relatively shallow depth and limited volume of the container, growing media must be amended to provide the appropriate physical and chemical properties necessary for plant growth. Successful nursery production of container grown plants is largely dependent on these chemical and physical properties of the grown medium. An ideal medium should be free of dis-
eases and weed, light enough to facilitate handling and shipping. The media should also be well drained and yet retain sufficient water to reduce the frequency of watering. Other parameters to consider include cost, availability, and stability over time. Selection of the proper media components is crucial to the successful production of transplants.

Peat is a very common organic component in nursery mixes. Peat is usually included in a mix to increase the water-holding capacity or to decrease the weight. In the last few years, coconut coir has been considered as a substitute for natural peat in growing media (Arenas et al. 2002). The particular structure of coconut fibers and their physical and chemical properties make them suitable for container media purposes. Coconut fiber has high water holding capacity and has been traditionally used to improve the physical and chemical properties of soils. Coconut coir has been tested as a horticultural medium for several ornamental crops with acceptable results. However, little work has been done with coconut coir as a medium component in vegetables transplant production. The relationship between transplant growth and coconut fiber should be investigated further (Arenas et al. 2002).

Both sand and vermiculite are some of the most commonly used amendments for the production of vegetable transplants. Medium and coarse sand particles provide optimum adjustments in media texture. Although sand is generally the least expensive of all inorganic amendments it is also the heaviest which may result in prohibitive transportation costs. On the other hand, vermiculite has a very high water holding capacity and aid in aeration and drainage. Vermiculite has excellent exchange and buffering capacities as well as the ability to supply potassium and magnesium. Although vermiculite is less durable than sand, its chemical and physical properties are very desirable for growing media. The time of in strawberry flowering was earlier in sand media than in media containing peat (Tehranifar et al. 2007). Tomato performed better when the sand content was proportionally higher in the growing medium mixture (Abo-Rezq et al. 2009).

2. Biological seed treatments and seed priming

Biological seed treatments for control of seed and seedling diseases offer the grower an alternative to chemical fungicides. A wide variety of microorganisms are currently used as seed treatments. The most intensively studied include bacteria of the genera Pseudomonas, Enterobacter, Erwinia, Bacillus; the fungi Trichoderma and Gliocladium; and the actinomycete Streptomyces (Callan et al. 1997, Lazarovits & Nowak 1997, Mathre et al. 1999). Bacterial antagonism, responsible for biological control may operate by antibiosis, competition or parasitism. Parasitism relies on lytic enzymes for the degradation of cell walls of pathogenic fungi (Chet et al. 1990). Trichoderma spp. are common inhabitants of the rhizosphere and are well recognized as biological agents of soilborne pathogens. A considerable amount of research has focused on the mycoparastic nature of Trichoderma and its contribution to plant health (Howell 2003). The application
of *Trichoderma* to the soil as a biological agent not only resulted in reduced disease severity but also enhanced plant growth. The potential of *Trichoderma* species as biocontrol agents of plant diseases was first recognized in early 1930s (Weindling 1932). The mechanisms employed by *Trichoderma* species to affect disease control includes mycoparasitism and antibiotic (toxin) production, competition through rhizosphere competence, production of enzymes such as chitinases and glucanases responsible for the suppression of plant pathogen by destroying cell wall integrity, induction of defense response in plant such as peroxidase activity (Harman 2000, Harman et al. 2008, Howell 2003). The biological seed treatments have been reported as an effective seed protection method in sweet corn using *Trichoderma* (Bjorkman et al. 1998, Bjorkman 2004, Harman et al. 1989, Parera & Cantliffe 1990), *Pseudomonas* (Callan et al. 1990, Callan et al. 1991, Cantliffe & Bieniek 1988, Mathre et al. 1995), *Gliocladium* (Hartz & Caprile 1995).

Seed priming is composed of a controlled moisturization period that does not allow radical emergence followed by a dry down period. Priming treatment promotes early germinative metabolic processes that result in a rapid and uniform emergence rate in the field. Sugars, salts, polyethylene glycol, or manitol are used to create soaking solutions with osmotic potentials that provide control of initial imbibition rates (Bennett et al. 1992, Taylor & Harman 1990, Taylor et al. 1998). Several biochemical changes are occurring during priming (Khan 1992). Protein synthesis increases substantially during and following priming. Metabolic enzymes involved in storage reserve mobilization have been shown to increase, including α-amylase, malate dehydrogenase, and isocitrate lyase. Also, there is some evidence to suggest that cell wall properties of the seed cover change during priming (Hartmann et al. 1997, Varier et al. 2010). Basra et al. (1988) suggested that osmotic priming of maize seeds induced changes in embryo phospholipids and the benefits associated with osmo-priming may be at least partly due to an increased potential for ATP accumulation.

Several priming treatments have been tested in sweet corn including presoaking hydration (Bennett & Waters 1987 a,b, Gerber & Caplan 1989, Bennett et al. 1988, Gubbels 1975, Sabota et al. 1987), polyethylene glycol (PEG 8000) (Bennett & Waters 1987a,b, El-Saifi et al. 2010, Murray 1990); polymers (Sabota et al. 1987); mineral salts (El-Saifi et al. 2010); organic solvents (Hung et al. 1992), $\text{H}_2\text{O}_2$ (Gubbels 1975), sodium hypochlorite (Hartz & Caprile 1995, Parera & Cantliffe 1991) with varying results.

The objective of this investigation was to study the enhancement of sweet corn propagation through determine the effect of different seed priming techniques on seed emergence and stand establishment in the field. Besides, study the effects of seed size, tray cell size and growing media on germination and the growth performance of sweet corn transplants under the greenhouse condition.
MATERIALS AND METHODS

Germination experiment
This experiment was carried out at the transplants production greenhouse at the experimental farm of department of Horticulture, Faculty of Agriculture, Suez Canal University, Ismailia, Egypt on the spring season of 2011. Eight treatments have been established as follows:
Two different sweet corn seed size:
- Large seeds (diameter >0.6 cm.) (100 seeds weight = 11 gram).
- Small seeds (diameter <0.6 cm.) (100 seeds weight = 7 gram).
Two different seedling tray cell sizes:
- Large cells (58 cm²).
- Small cells (18 cm²).
Two different growing media mixture:
- Coconut fiber with vermiculite (2:1 v/v).
- Coconut fiber with sand (2:1 v/v).
Two replications were utilized each including 8 styrofoam trays with 84 seeds in large cell size treatments and 209 seeds in small cell size treatments. The seeds were visually graded to large and small then each grade was sieved using 6 mm pores sieve. Sweet corn kernels of cultivar 277A (sh2) (Illinois Supersweet) were planted in the greenhouse on March 11, 2011. Early germination was recorded after 10 days of planting. Final germination was recorded when no more apparent germination was observed (approximately after 21 days). After germination evaluation, 10 seedlings from each treatment were collected randomly for more laboratory evaluation. Each seedling was cut at the point of growing media surface using sharp blade. Shoot length and shoot weight were recorded on the vegetative part of the seedling. The bottom part which includes root system and growing media was carefully washed using running tap water to completely remove the growing media surrounding the root system. Roots were air dried before root length and root weight were recorded. Then both shoot and root were placed in the oven under 70°C for 24 hours to allow for drying before dry weight of both were recorded. The experiment was statistically arranged in factorial design with three factors.

Seed priming experiment
A field experiment was conducted at the experimental farm of department of Horticulture, Faculty of Agriculture, Suez Canal University, Ismailia, Egypt to test the effect of bio-priming, hydro-priming and osmo-priming on the germination of sweet corn kernels of cultivar 277A (sh2) (Illinois Supersweet). The experiment was carried out in randomized complete block design with at least 4 replications (rows), each replicate was 10 m in length and 0.5 m in width containing approximately 35-40 seeds at a spacing of 25 cm within the row. The direction of rows was North-South and the seeds were cultivated directly on the third top of the slop ridges on the West direction. Experimental site soil texture was sandy (91% sand, 6% silt and 3% clay) with pH 8.27 and EC 0.47 ds·m⁻¹, Ca 0.8 meq·L⁻¹, Mg 0.6 meq·L⁻¹, K 0.3 meq·L⁻¹, Na 3.0 meq·L⁻¹, Bicarbonate 1.6 meq·L⁻¹, CL 3.0 meq·L⁻¹, and Sulfate 0.1 meq·L⁻¹. Before each planting, the soil of the experimental site was cleared, ploughed, harrowed and divided into rows. The experiment was conducted during the spring season of 2009 and was repeat-
ed in spring season of 2010 and 2011. Five treatments have been established as follows:
- Bio-priming with *Trichoderma*,
- Bio-priming with *Bacillus*,
- Osmo-priming with KNO$_3$ (5%),
- Hydro-priming with H$_2$O,
- Control (non-treated dry seeds).

For osmo- and hydro-priming treatments, sweet corn seeds were soaked in KNO$_3$ (5%) solution or in distilled water for 24 hours before planting. Seeds from all priming treatments and control were hand planted in rows in soil. Number of germinated seeds was recorded after 3 weeks of planting and when no more apparent germination was observed, percentage of germination was calculated as number of germinated seeds divided by the total number of planted seeds in each replicate.

**Microbial cultures and seed inoculation**

*Trichoderma* isolates were grown in molasses broth (molasses 30 g, yeast extract 5 g, distilled water 1000 ml) for 10 days at 27 ± 1°C. Subsequently broth cultures were homogenized using mixer grinder. The homogenized liquid cultures were formulated using talc as a carrier material (Talc: broth culture at 2:1 w/v) with 10 g of carboxyl methyl cellulose (CMC) per kilogram of carrier material as adhesive agent.

Pure isolates of *Bacillus megaterium* were kindly obtained from Department of Microbiology of Soil, Water and Environment Research Institute, Agriculture Research Center (ARC), Giza, Egypt. *Bacillus megaterium* were grown in Sperber’s broth (Sperber 1957), for 7 days at 27 ±1°C on a rotary shaker at 150 rpm. After incubation period bacterial cultures were formulated using talc as a carrier material (Talc: broth culture at 2:1 w/v) with 10 g CMC per kg carrier material as adhesive agent.

Seeds of sweet corn were first surface sterilized with sodium hypochlorite (1%), washed in distilled water and then were treated with talc based formulation of *Trichoderma* at 3 g·kg$^{-1}$ seeds ($\approx 6 \times 10^7$ cfu·g$^{-1}$) or 5 g·kg$^{-1}$ seeds ($\approx 8 \times 10^9$ cfu·g$^{-1}$) of *Bacillus megaterium* (Rudresh *et al.*, 2005).

**Isolation of the causal organism**

Non-germinated seeds were randomly collected from the experimental site from all treatments to evaluate the pathogenic fungi associated with seed decay. Seeds with damping-off symptoms were picked up on PDA plates and purified for pathogen isolation and identification. Pure cultures were identified according to the description of Gilman (1957), Barnett and Hunter (1972).

**Statistical analysis**

Data were statistically analyzed using ANOVA/MANOVA of Statistica 6 software (Statsoft 2001, Tulsa, Ok, USA) with mean values compared using Duncan’s multiple range with a significance level of at least $p \leq 0.05$.

**RESULTS**

**Transplanting feasibility experiment**

The main effect and interaction between media type, seed size and tray cell size on early and total seed germination of sweet corn are summarized in Table 1 and 2. The effect of each factor was different for early and final germination. Small sweet corn
kernels gave high early germination percentage while the large kernels provided the highest final and total germination percentage. In addition, the small tray cell size (18 cm$^3$) gave highest early germination compared to the large tray cell size (58 cm$^3$) which presented the highest final germination rate (Table 1). The growing mixture of coconut peat and sand promoted the early germination of seeds and accelerated the speed of germination since it granted higher early percentage of germination while the other growing mixture (coconut peat and vermiculite) gave the higher final percentage. The interaction between vermiculite based growing media with both large seed size and large tray cell size was associated with the highest percentage of final germination while the growing media with sand combined with large seed size and large tray cell size showed the lowest percentage of early and final germination (Table 2).

Table 1. The main effect of media type, seed size and tray cell size on early and total seed germination of sweet corn cv. 277A sh$_2$

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Early germination (%)</th>
<th>Final germination (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Media</td>
<td>Vermiculite</td>
<td>42.3</td>
</tr>
<tr>
<td></td>
<td>Sand</td>
<td>46.1</td>
</tr>
<tr>
<td>Seed size</td>
<td>Large seeds</td>
<td>41.3</td>
</tr>
<tr>
<td></td>
<td>Small seeds</td>
<td>47.1</td>
</tr>
<tr>
<td>Tray cell size</td>
<td>Large cells</td>
<td>42.2</td>
</tr>
<tr>
<td></td>
<td>Small cells</td>
<td>46.2</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>44.2</td>
</tr>
</tbody>
</table>

Table 2. The interaction between media type, seed size and tray cell size on early and total seed germination of sweet corn cv. 277A sh$_2$

<table>
<thead>
<tr>
<th>Media</th>
<th>Seed size</th>
<th>Tray cell size</th>
<th>Early germination (%)</th>
<th>Final germination (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vermiculite</td>
<td>Large seeds</td>
<td>Large cells</td>
<td>39.3</td>
<td>86.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Small cells</td>
<td>40.4</td>
<td>50.5</td>
</tr>
<tr>
<td></td>
<td>Small seeds</td>
<td>Large cells</td>
<td>47.6</td>
<td>48.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Small cells</td>
<td>41.9</td>
<td>48.5</td>
</tr>
<tr>
<td>Sand</td>
<td>Large seeds</td>
<td>Large cells</td>
<td>30.5</td>
<td>32.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Small cells</td>
<td>55.1</td>
<td>55.6</td>
</tr>
<tr>
<td></td>
<td>Small seeds</td>
<td>Large cells</td>
<td>51.3</td>
<td>51.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Small cells</td>
<td>47.5</td>
<td>49.5</td>
</tr>
</tbody>
</table>

The effect of these three factors on shoot and root length, shoot and root fresh weight of germinated seedlings are summarized in Table 3 and 4. Growing media with sand gave the higher shoot and root length and weight comparing with media with vermiculite. Although large seeds gave significantly higher root length, the shoot length and root length and weight did not affected statistically by the size of sweet corn seeds. Similar trend was observed with the tray cell size given that it did not significantly
affect these traits with the observation that small tray cell size tend to offer non-significantly higher root length and weight while large tray cell size have a tendency to give slightly higher shoot length and weight (Table 3).

Table 3. The main effect of media type, seed size and tray cell size on both shoot and root length and fresh weight of germinated seedlings of sweet corn cv. 277A sh2

<table>
<thead>
<tr>
<th>Treatments</th>
<th>RL 1</th>
<th>RFW 2</th>
<th>SL 3</th>
<th>SFW 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Media</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vermiculite</td>
<td>8.03a</td>
<td>0.94b</td>
<td>3.04b</td>
<td>0.35b</td>
</tr>
<tr>
<td>Sand</td>
<td>8.23a</td>
<td>1.13a</td>
<td>3.73a</td>
<td>0.50a</td>
</tr>
<tr>
<td>Seed size</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large seeds</td>
<td>9.17a</td>
<td>1.03a</td>
<td>3.36a</td>
<td>0.41a</td>
</tr>
<tr>
<td>Small seeds</td>
<td>7.09b</td>
<td>1.03a</td>
<td>3.40a</td>
<td>0.44a</td>
</tr>
<tr>
<td>Tray cell size</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large cells</td>
<td>8.02a</td>
<td>0.98a</td>
<td>3.47a</td>
<td>0.44a</td>
</tr>
<tr>
<td>Small cells</td>
<td>8.24a</td>
<td>1.08a</td>
<td>3.30a</td>
<td>0.42a</td>
</tr>
<tr>
<td>Mean</td>
<td>8.13</td>
<td>1.03</td>
<td>3.38</td>
<td>0.43</td>
</tr>
</tbody>
</table>

Note: 1RL = Root Length (cm); 2RFW = Root Fresh Weight (gram)  
3SL = Shoot Length (cm); 4SFW = Shoot Fresh Weight (gram)  
5Values followed by the same letter within a column are not significantly different at the 0.05% level of probability according to Duncan’s multiple range test

Table 4. The interaction effect between media type, seed size and tray cell size on shoot and root length, shoot and root fresh weight of sweet corn germinated seedlings cv. 277A sh

<table>
<thead>
<tr>
<th>Media</th>
<th>Seed size</th>
<th>Tray cell size</th>
<th>RL 1</th>
<th>RFW 2</th>
<th>SL 3</th>
<th>SFW 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vermiculite</td>
<td>Large seeds</td>
<td>Large cells</td>
<td>9.27a</td>
<td>0.97bc</td>
<td>2.72d</td>
<td>0.39cd</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Small cells</td>
<td>9.20a</td>
<td>0.91</td>
<td>3.67b</td>
<td>0.34d</td>
</tr>
<tr>
<td></td>
<td>Small seeds</td>
<td>Large cells</td>
<td>6.55b</td>
<td>0.88c</td>
<td>2.83d</td>
<td>0.34d</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Small cells</td>
<td>7.10b</td>
<td>0.98bc</td>
<td>2.92cd</td>
<td>0.34d</td>
</tr>
<tr>
<td>Sand</td>
<td>Large seeds</td>
<td>Large cells</td>
<td>9.13a</td>
<td>0.97bc</td>
<td>3.97b</td>
<td>0.45bc</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Small cells</td>
<td>9.07a</td>
<td>1.27a</td>
<td>3.09cb</td>
<td>0.46bc</td>
</tr>
<tr>
<td></td>
<td>Small seeds</td>
<td>Large cells</td>
<td>7.14b</td>
<td>1.09abc</td>
<td>4.36a</td>
<td>0.57a</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Small cells</td>
<td>7.58b</td>
<td>1.18ab</td>
<td>3.50cb</td>
<td>0.52ab</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
<td>8.13</td>
<td>1.03</td>
<td>3.38</td>
<td>0.48</td>
</tr>
</tbody>
</table>

Note: see Table 3

The interactions between the three factors are presented in Table 4. Even though there was no clear trend expressing the interaction between the three factors for studied traits, it can be noticed that the interaction between large sweet corn kernels and with either vermiculite or sand growing mixture regardless tray cell size gave better root length than the interaction between small seed size and both growing media types (Table 4). However, growing media mixture with sand interacted well with small seeds and large tray cells to give the highest significant shoot length and weight (Table 4).

Since the growth of the seedling to mature plant was correlated with the performance of both root and
shoot systems, the ratio of shoot/root is of considerable interest and is presented in Table 5 for length, fresh and dry weight. Growing media with sand and large tray cell size tend to give higher ratio for length and fresh weight while sand with small tray cells showed the higher shoot/root ratio for dry weight (Table 5).

Table 5. The ratio of shoot/root for length, fresh and dry weight of sweet corn germinated seedlings cv. 277A sh

<table>
<thead>
<tr>
<th>Seed size</th>
<th>Media</th>
<th>Vermiculite</th>
<th>Sand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tray cell size</td>
<td>Large cells</td>
<td>Large cells</td>
</tr>
<tr>
<td>Large seeds</td>
<td>SL/RL1</td>
<td>0.38</td>
<td>0.40</td>
</tr>
<tr>
<td></td>
<td>SFW/RFW2</td>
<td>0.35</td>
<td>0.37</td>
</tr>
<tr>
<td>Small seeds</td>
<td>SL/RL</td>
<td>0.43</td>
<td>0.32</td>
</tr>
<tr>
<td></td>
<td>SFW/RFW</td>
<td>0.39</td>
<td>0.40</td>
</tr>
</tbody>
</table>

1SL/RL = Shoot Length/ Root Length (cm)
2SFW/RFW = Shoot Fresh Weight/ Root Fresh Weight (gram)

Seed priming experiment

Results of the sweet corn seed priming experiment are shown in Table 6 and Figure 1. Sweet corn bio-primed seeds with *Bacillus megaterium* showed the highest significant percentage of germination and number of germinated seeds and the increase was 55% over the control treatment in the germination percentage (Table 6). Sweet corn seeds that were bio-treated with isolates of *Trichoderma* ranked second in germination percentage although not significantly different than the control non-treated seeds (Table 6). Both sweet corn seeds osmo-primed with KNO₃ or hydro-primed showed poor germination performance resulted in germination percentages lower than the control non-treated dry seeds. Isolations of fungi from infected dead or non-germinated seeds showed that *Aspergillus niger* was the dominant fungus with 33.8% frequency followed by *Penicillium* spp with 31.1% (Fig. 1). Both *Aspergillus niger* and *Penicillium* spp. accounted for two thirds of the causal organisms while the rest of isolated fungi (*Rhizopus stolonifer, Alternaria* spp. and *Fusarium* spp.) accounted for 17.6, 10.8, and 6.7% of the causal organisms respectively (Fig. 1).

Table 6. The effect of seed priming of sweet corn cv. 277A sh₂ on germination percentage and number of germinated seeds

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Germination %</th>
<th>No. germinated seeds</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Bacillus megaterium</em></td>
<td>59.32a¹</td>
<td>88.98a</td>
</tr>
<tr>
<td><em>Trichoderma</em> spp</td>
<td>40.67b</td>
<td>61.0b</td>
</tr>
<tr>
<td>KNO₃</td>
<td>20.12c</td>
<td>30.18c</td>
</tr>
<tr>
<td>H₂O</td>
<td>17.56c</td>
<td>26.33c</td>
</tr>
<tr>
<td>Control</td>
<td>38.02b</td>
<td>57.02b</td>
</tr>
<tr>
<td>Mean</td>
<td>35.1</td>
<td>52.7</td>
</tr>
</tbody>
</table>

¹Values followed by the same letter within a column are not significantly different at the 0.05% level of probability according to Duncan’s multiple range test
DISCUSSION

Seed-borne and soil-borne fungi are the principal causes of sweet corn seed decay, and seedling blight, with stand reductions reaching 50% in localized areas. The most problematic fungi are *Fusarium*, *Rhizopus, Aspergillus* and *Penicillium*. The greatest damage from these pathogens occurs during the pre-emergence stage, causing poor germination of seeds or poor emergence of corn seedlings (Halfon-Meiri & Solil 1990). These fungi are common soil inhabitants in soils worldwide and have a broad host range. They survive between crops as dormant resting structures (oospores, sclerotia), in crop debris, saprophytically, and pathogenically on weeds and other hosts.

Beneficial bacteria and fungi provide promising alternatives or supplements to chemicals as seed treatments against soil borne pathogens. Beneficial fungi (*Trichoderma* spp.) and bacteria (*Bacillus* spp.) have been studied and selected for disease-suppressive properties. Bio-protectants are known to possess high degree of rhizosphere competence, and that protect seeds when added as a seed treatment. The present investigation confirms the earlier works in sweet corn (Bjorkman et al. 1998). It revealed that seed treatment with bio-agent strains improved seed germination and seedling stand over the control. Similar improvements of seed germination by bio-control means have been reported in maize (Mao et al. 1997). Beneficial bacteria and fungi increased synthesis of compounds which would have triggered the activity of specific enzymes that promoted early germination, such as α-amylase, which have brought an increase in availability of starch assimilation.

The efficacy of biological seed treatments can be affected by soil pH and iron concentration, moisture, temperature, and pathogen inoculums density (Callan et al. 1997). Efficacy can also be influenced by certain characteristics of the biological agent and of the seed treatment itself and these include the inoculum density on the bio-control agent on the seed, adjunct treatments such as priming, formulations and additives that enhance the activity and survival of the bio-control agent in the formulated product, crop and patho-

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**Fig.1.** Frequency of fungi isolated from non-germinated seeds of sweet corn cv. 277A sh2

<table>
<thead>
<tr>
<th>Fungi</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Aspergillus niger</em></td>
<td>33.8</td>
</tr>
<tr>
<td><em>Penicillium</em></td>
<td>17.6</td>
</tr>
<tr>
<td><em>Rhizopus stolonifer</em></td>
<td>10.8</td>
</tr>
<tr>
<td><em>Alternaria spp</em></td>
<td>6.7</td>
</tr>
<tr>
<td><em>Fusarium</em> spp</td>
<td>31.1</td>
</tr>
</tbody>
</table>

---
gen specificity of the biocontrol agent, and compatibility with other microbial inoculants or chemical fungicides (Callan et al. 1997).

The acidic nature of tomato seeds was suggested to be responsible for the relatively better protection of tomato by the more acid-tolerant Trichoderma than Enterobacter cloacae (Harman & Taylor 1988). Consequently, the sugary nature of sweet corn seeds may be responsible for the differences of biocontrol agents effectiveness against one pathogen than another. The array of pathogens isolated from the decayed and non-germinated sweet corn seeds may explain the difference observed between *Trichoderma* and *Bacillus* in our experiments due to the production of pathogen-specific antibiotics.

Bigger seed germination translates to healthy seedlings. If seed is large the emerging seedling has a larger food source depending on before it gets established. Maize seedlings from bigger seeds tend to emerge more successfully and are more vigorous both at the start of and throughout of their whole life (Boctes & Girardin 1994). Vigorous seedling are also, likely to be less affected by weeds and diseases. The larger seeds allow a better tolerance on unfavorable conditions also during early growth (Heather & Sieczka 1991). Taylor and Ten Broeck (1988) demonstrated that the amount of seedling emergence force expended increased linearly as seed size increased for an array of small- to large-seeded vegetable crops. However, an inverse relation existed between the capacity of seeds to use reserve materials and small-sized seeds were more efficient in using this reserve materials than large ones (Bremner et al. 1963, Taylor & Ten Broeck 1988). In our experiment the small seeds showed higher early germination than large seeds (Table 1) which can be explained by the rapid imbibition of moisture which accelerate both physiological and chemical process of germination. It is conceivable that smaller seeds require less water for germination, since they have less volume (Muchena & Grogan 1977). Roots of large seeds have much higher penetrating potential than those of small seeds which of great importance for the establishment of the plant and its competitive survival amongst other plants (Gelmond 1978).

Transplanting sweet corn was investigated as a method to improve stand establishment and hasten maturity. Transplanting sweet corn has been reported to produce significantly higher emergence percentage than direct seeded (Welbaum et al. 2001) and significantly reduced days required for emergence comparing to direct seeded (Water et al. 1990). It is obvious from the obtained results that the average final germination percentage was improved in the transplanting experiment (53%) compared to when seeds were directly cultivated in the field (35%). The superior germination percentage obtained when large sweet corn seeds were planted in large tray cells filled with vermiculite-based media in the transplanting experiment (86.9%) (Table 2) was much higher than the superior germination percentage obtained with *Bacillus*-treated seeds in priming experiment (59.3%) (Table 6). This may be justified by the numerous benefits of plug transplant-
Transplanting using plugs offers the ease of transplanting, improved plant survival, avoid of soilborne diseases (Durner et al. 2002, Ratten et al. 2006). In plug production system there is little likelihood of plugs becoming infected with soilborne pathogens. Plugs keep most root hairs that quickly absorb water and nutrients. This active root system allows more uniform and faster plant growth.

Transplants produced in speedling trays are largely dependent on the chemical and physical properties of the growing media and the selection of the proper media components is critical to the successful production of transplants. Vermiculite with its plate-like structure holds large quantities of water and positive charged nutrients like K, Mg, and Ca. This can be correlated to the higher final germination percentages associated with vermiculite-based growing media (Table 1). Sand is typically selected as a media component to improve the drainage. The coarse sand particles with loose texture allow faster penetrating potential and growth of roots which can explain the significantly higher root length, fresh weight (Table 3) associated with sweet corn seeds grown in sand compared to vermiculite. The better root system development with sand allowed for water and nutrients and nutrients absorption which reflected in significantly higher shoot length and fresh weight (Table 3) compared to the vermiculite.

Transplants grown in large tray-cell sizes generally are taller and have greater leaf area and shoot dry weight than those grown in small tray-cell sizes (Cantliffe 1993). Better seedling performance obtained when larger seedling containers were used may be partially due to beneficial effect arising from favorable physical properties of the planting media and availability of fertilizer since the amount of each was proportional to container size. Moreover, hormones synthesized in the root apex and reallocated to shoots would be reduced when the root growth was obstructed by the container base (Di Benedetto et al. 2006).

Plant responses to reduced soil volume have been reported for a wide range of crops (NeSmith & Duval 1998). On the other hand, higher production efficiency is obtained if multicell trays with the smaller cell volume are used. Container geometry can have a pronounced effect on seedling morphology. More narrow cells caused seedling height to decrease (Liptay & Edwards 1994). In this experiment small tray cells favor the root growth (length and weight) while large tray cells favor the shoot length and weight (Table 3). These conflicting results can be explained by the difference between both tray cell depths. The small cell are narrow and deep which promoted the root length while the large cell contained more media with high levels of aeration and water holding capacity that allowed for better growth of shoot (Table 3). Relation between plants growth and container size that affect levels of aeration and water availability is well documented (Milks et al. 1989, Bilderback & Fonteno 1987).

In conclusion, the results of this study suggested that transplanting can be an alternative method of sweet corn propagation compared with direct seeding. Plug cell trays filled with suitable growing media and the use of large sweet corn seeds would
produce better transplants. Bio-priming is suggested to enhance sweet corn low germination in contaminated soils and further improve seedling establishment. Additional research is needed to test other beneficial organisms combined with various chemical and physical seed treatments.

REFERENCES


Menasha S.R., Tignor M.E. 2004. Plug tray cell volume effects on sweet


**ROZMNAŻANIE SUPER SŁODKIEJ KUKURYDZY CUKROWEJ: BADANIA NAD KONDYCJONOWANIEM NASION ORAZ PRODUKCJĄ Z ROZSADY**

**Streszczenie**

Uprawa mieszańców kukurydzy cukrowej z genotypami o wysokiej zawartości cukru (sh2) jest utrudniona ze względu na słabe wschody nasion. Badania przeprowadzono w celu określenia wpływu wielkości nasion, wielkości komórek w paletach rozsadowych i komponentów podłoża uprawowego na młode rośliny kukurydzy cukrowej. Drugim celem badań była ocena wpływu kondycjonowania nasion kukurydzy cukrowej na kielkowanie nasion w polu. Zastosowano bio-priming przy użyciu grzybów Trichoderma i bakterii Bacillus, osmo-priming w roztworze KNO₃ oraz hydopriming w H₂O. Badania wykazały, że przesadzanie kukurydzy cukrowej jest możliwe pod warunkiem zastosowania wysokiej jakości rozsady uzyskanej z nasion dobrze kielkujących w wol-
nym od chorób środowiska. Duże nasiona, duże komórki w paletach rozsadowych oraz podłoża na bazie wermikulitu sprzyjały kielkowaniu nasion kukurydzy cukrowej. Natomiaż te same czynniki nie wykazały wyraźnego wpływu na wzrost sadzonek pod względem długości korzeni i pędów oraz świeżej masy. W doświadczeniu z kondycjonowaniem nasion traktowanie mikroorganizmami dało najwyższy procentowy udział kielkujących nasion w porównaniu do pozostałych zabiegów kondycjonowania i kombinacji kontrolnej. Nasiona traktowane bakteriami *Bacillus megaterium* kielkowały o 50% lepiej niż nasiona traktowane grzybami *Trichoderma* spp.

*Aspergillus niger* i *Penicillium* stanowiły 65% patogenów odpowiedzialnych za porażenie nasion kukurydzy cukrowej. Wyniki badań wykazały możliwość rozmnażania super słodkiej kukurydzy cukrowej z rozsady oraz wykorzystanie kondycjonowania nasion dla poprawy wschodów oraz obsady roślin na polu.