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Application of sucrose on tomato seedlings improves transplant quality, crop establishment, cold and dark hardiness

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Abstract: Transplant production is an important part of the vegetable production process. Therefore, improving transplant quality and resistance to adverse environmental conditions is important. Effects of sucrose solutions (0, 5, 10, 15, 20 and 25%), applied to the foliage of tomato (*Solanum lycopersicum* L.) cultivars Calj-N3 and Rio-Grande were studied. Treatments were applied to developing seedlings at every other irrigation for six weeks. Application of 25% sucrose increased fresh and dry weights of shoots, fresh weight of roots, and shoot and root dry weight percentages. Application of 25% sucrose led to a 13 and 18% higher survival to chilling temperature in 'Calj-N3' and 'Rio-Grande' tomato seedlings, respectively. The highest transplant survival percentages in darkness were found at 10% sucrose and higher. Seedlings sprayed with 15% sucrose solution had the highest transplant establishment in the field and flowering was approximately four to five days earlier. A 15% sucrose treatment is thus preferred.

1. Introduction

Transplanting vegetables has benefits over direct seeding. Transplanting increases crop season length, reduces expenses of vegetable production, and decreases the risk of chilling and other potential risks (Schrader, 2000).

Tomato (*Solanum lycopersicum* L.) is used for the fresh and processing market. In most open field tomato production areas use of transplants is beneficial because of a short growing season. Cool temperatures are an early season problem in some areas and they result in delays in production and economic loss (Shukry and El-Otaby, 2011). Strategies to increase tomato chilling resistance are necessary to produce quality transplants and increase stress resistance by appropriate treatments.

It was found that tomato seedlings are able to take up sugar solution applied to foliage; although up-take depends on environmental conditions (Berrie, 1960). Multiple applications of sugars to foliage on tomato in a dark room increases growth rate and especially when application is at fairly high temperatures (Went and Carter, 1948). Tomato plants treated with a 10% aqueous sucrose solution daily up to three days before transplanting, produced more adventitious roots (Smith and Zink, 1951). Application of 70 $g \cdot l^{-1}$ sucrose resulted in improved establishment in the field and shoot growth as a result of producing more adventitious roots (Percival and Fraser, 2005). In other investigations on non-vegetable plants such as young trees of silver birch, cherry, and red oak, applications of sugar ≤ 50 $g \cdot l^{-1}$ in water as a root drench significantly enhanced root vigor by week 12 (Percival, 2004). Sucrose injection to soybeans increased leaf area and pod numbers but suppressed photosynthesis (Abdin *et al.*, 1998).

There is very little information in the literature on the application of sucrose on transplants to improve chilling resistance and other transplant quality characteristics. The present study was undertaken to investigate effects of sucrose application on tomato transplants, as a commercially important vegetable established from transplants, and evaluate effects on increasing chilling resistance and other traits under field conditions. Foliar application was chosen because roots take up very little sugar, stems take it up mainly through wounds, but intact leaves absorb it readily; apparently through the whole surface (Went and Carter, 1948).

2. Materials and Methods

The study was carried out in a 200 m^2 area, at an altitude of 1810 m above sea level. The regional mean relative humidity was 46% and the mean monthly minimum and maximum temperatures during the growing season were 15.6 and 30.7 °C, respectively. Soil samples were analyzed prior to the start of the experiment. The loamy soil had an EC of 2.41 $mmhos \cdot m^{-1}$ and a pH of 7.6 (soil extract 1:2). The soil was plowed and disked to turn under existing plant

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material. Fertilization was according to soil test result and crop need to supply nutrient requirements for tomato production (Jones, 2007).

The tomato cultivars Calj-N3 and Rio-Grande were used. Seeds were sown in 300 ml plastic pots filled with peat and perlite (1:1 v:v) and irrigated every other day. Plantlets emerged after one week. Pots were irrigated with water for the first two weeks after sowing. Afterwards, they were fertigated with a complete NPK fertilizer as recommended by Papadopoulos (1991) for tomato transplant production. Greenhouse conditions for transplant production were 24±4°C and 45±5% relative humidity.

Seedling foliage was treated with six sucrose solutions (0, 5, 10, 15, 20 and 25% concentrations) starting two weeks after emergence. One drop of tween 20 was added to each solution to increase leaf surface absorption. Application covered all leaf surfaces at every other irrigation interval until seedlings were moved to the field at the sixth week after seed sowing. Leaves were washed using a mist system between each sucrose application.

For the field experiment, six-week-old seedlings were transplanted into the field at a 40×60 cm spacing in rows covered with black polyethylene mulch. Plots were fertigated through tape irrigation with starter fertilizer 10-10-10 NPK for the first week after transplanting to help stand establishment according to Masson *et al.* (1991). Cultural practices until the end of the experiment were carried out as described by Papadopoulos (1991). The field experiment was repeated in two subsequent years.

Seedlings at the end of the sixth week from seed sowing were divided into four groups. Group A was used to determine vegetative characteristics including leaf chlorophyll content (Saini *et al.*, 2001), transplant shoot and root fresh and dry weights, and shoot and root dry matter percentage. Group B was stored in darkness at 20°C for 96 h to determine effects of treatment on darkness survival. Group C was placed in an incubator at 0°C for 96 h to determine effects of sucrose on resistance to chilling. Group D was transplanted into the field to determine degree of field establishment, leaf number preceding first flower and the days from transplanting to first flower formation.

Group A, B and C experiments were arranged in a completely randomized design; group D (factors after transplanting into field) was arranged in a completely randomized block design over two years. All treatments consisted of six replicates of 10 plants. Data analysis was performed using the SPSS12 (SPSS Inc., Chicago, IL) computer software for Windows. If differences were significant, means were separated with least significant difference (LSD) test.

3. Results and Discussion

The effects of treatments on all measured traits were always significant except for leaf number, leaf chlorophyll content, fruit set percent and yield; for group D the effects of year and its interaction with treatments for all measured traits were not significant (data not shown).

Fresh and dry weights of shoots and roots, shoot and root dry matter percentage increased with increasing sucrose concentration in both cultivars (Table 1). The highest values were for the 25% sucrose concentration. Similar results in terms of increased dry matter of shoots and roots were found in seedlings of a non-vegetable plant, birch (*Betula pendula* Roth.), after a root drench application of sucrose and fructose (Percival and Fraser, 2005). Accordingly, it seems that sucrose could be absorbed by aerial and underground plant organs and used in metabolism for growth and development. Ritchie (1987) reported that root growth potential is not a physiological process. However, it integrates many important physiological processes in seedlings and has become a popular and useful indicator of seedling vigor.

Table 1 - Vegetative characteristics of two tomato cultivars, sprayed with aqueous sucrose solution for a 6-week transplant raising period

Tomato cultivar	Sucrose concentration (%)	Shoot fresh weight (g)	Shoot dry weight (g)	Shoot dry weight percentage	Root fresh weight (g)	Root dry weight (g)	Root dry weight percentage	Leaf number preceding the first flower	Days from transplanting to first flower
Calj-N3	0	4.25±0.20 e	0.33± 0.01 e	7.83±0.19 f	0.21±0.01 g	0.018±0.048 a	8.55±0.05 ef	9.67±0.33 a	27.33±0.88 a
	5	4.57±0.23 de	0.35±0.03 e	7.55±0.29 fg	0.24±0.02 ef	0.021±0.002 a	8.79±0.12 de	9.33±0.33 ab	26.33±0.33 b
	10	4.74±0.20 cd	0.52±0.02 c	10.89±0.15 cd	0.42±0.03 cd	0.037±0.002 a	8.86±0.12 cd	8.67±0.33 c	24.67±0.33 d
	15	4.72±0.24 cd	0.52±0.03 c	10.94±0.23 bcd	0.50±0.05 bc	0.046±0.005 a	9.27±0.11 ab	7.33±0.33 ef	23.33±0.33 ef
	20	5.02±0.04 c	0.59±0.01 b	11.73±0.31 ab	0.61±0.04 a	0.057±0.005 a	9.40±0.15 a	7.00±0.00 f	23.00±0.00 ef
	25	6.22± 0.15 a	0.74±0.02 a	11.97±0.18 a	0.64±0.02 a	0.060±0.003 a	9.36±0.07 ab	7.33±0.33 ef	22.67±0.33 f
Rio-Grande	0	3.24±0.19 g	0.22±0.02 f	6.70±0.26 h	0.11±0.01 h	0.008±0.001 b	7.52±0.19 h	9.67±0.33 a	27.33±0.33 a
	5	3.55±0.16 fg	0.24±0.03 f	6.84±0.49 gh	0.15±0.02 gh	0.012±0.002 ab	7.96±0.30 g	9.33±0.33 ab	25.67±0.33 bc
	10	3.84±0.16 f	0.38±0.02 de	10.00±0.26 e	0.31±0.03 e	0.026±0.002 a	8.26±0.09 f	9.00±0.00 bc	25.00±0.57 cd
	15	4.26±0.20 e	0.42±0.02 d	9.78±0.74 e	0.40±0.05 d	0.036±0.005 a	8.95±0.04 cd	8.00±0.00 d	23.67±0.33 e
	20	5.02±0.09 c	0.51±0.03 c	10.19±0.50 de	0.51±0.03 b	0.046±0.004 a	9.10±0.12 bc	7.67±0.33 de	23.33±0.33 ef
	25	5.54±0.19 b	0.62±0.02 b	11.15±0.58 bc	0.53±0.01 b	0.048±0.001 a	9.12±0.05 abc	7.33±0.33 ef	23.33±0.33 ef
LSD value		0.37	0.053	0.81	0.075	0.042	0.28	0.59	0.86

Data are mean ± s.e. of six replicates. Different letters indicate significant differences for each column at P≤ 0.05 by LSD test.

Any physiological problem affecting seedlings should show up as a decrease in the seedling's ability to produce roots. Thus, sucrose spray is an applicable method to increase root fresh weight and thereby increase transplant vigor.

Survival in dark

Tomato growers often purchase seedlings from distant transplant producers, risking deterioration of transplants during transportation. Transportation conditions, status of flower development at time of transport, planting conditions after transport, and unfavorable combinations of these conditions often result in flower abortion and delayed fruit development of the first truss (Kubota *et al.*, 2004). Low-temperature storage in darkness has been reported as a way to preserve seedling quality (Leskovar and Cantliffe, 1991; Kaczperski and Armitage, 1992; Kaczperski *et al.*, 1996). Nearly all plant food reserves are stored as starch or sugars. These are produced by photosynthesis and consumed by respiration to sustain plant growth and metabolism. Cold storage affects photosynthesis and respiration in two ways. First, absence of light interrupts photosynthesis, and second, low temperature decreases respiration rate. The net effect is that seedlings very slowly burn up their supply of reserve carbohydrates in storage (Ritchie, 1987). Therefore, survival in darkness and seedling quality are important for transplant transportation. Low temperature and dim light during transportation maintain transplant quality at an acceptable level (Kubota and Kroggel, 2006). Our results showed that by increasing sucrose concentration, survival of transplants in darkness was increased. The highest transplant survival percentage in darkness was found with 10% concentration of sucrose and was not cultivar dependent (Fig. 1). Kubota *et al*. (1997) reported reductions in levels of soluble sugars and starch in dark-stored broccoli (*Brassica oleracea* L. Botrytis 'Group Green Duke') plantlets. In spite of interruption of the supply of photosynthates in darkness, amounts of soluble sugars increase through degradation of starch in shoots (Sato *et al.*, 2004). Accordingly, it is concluded that foliar application of sugars can be used as an energy source for respiration in darkness with low, or no, decrease in transplant quality.

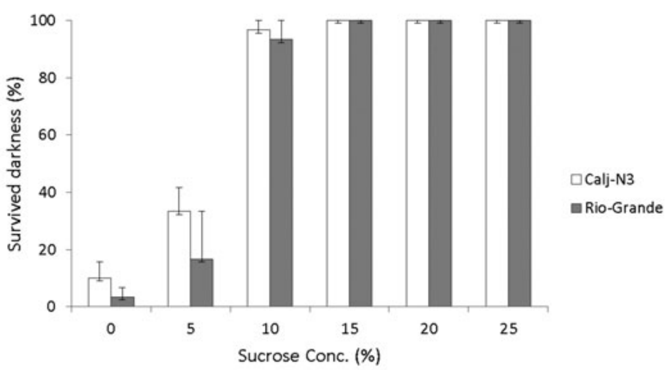

Fig. 1 - Effect of sucrose foliar spray on the percent of survived 'Calj-N3' and 'Rio-Grande' tomato transplants in darkness.

Chilling temperature survival

Seedling survival percentage increased as sucrose concentration increased in both cultivars (Fig. 2). Application of 25% sucrose solution produced the best survival in response to chilling. Compared to controls there was 13 and 18 times greater chilling resistance in 'Calj-N3' and 'Rio-Grande' seedlings, respectively. Since carbohydrate reserves undergo a net loss during low temperature storage and hardiness development requires an expenditure of metabolic energy (Ritchie, 1987), providing sucrose as an available source of energy through foliar application can help transplants survive low temperatures. Sucrose has been reported as a metabolite for stabilizing membranes in plant tissues during chilling (King *et al.*, 1988). Sugar is able to maintain dry mass of plantlets under a wider range of environmental conditions during low temperature storage (Kubota, 2005).

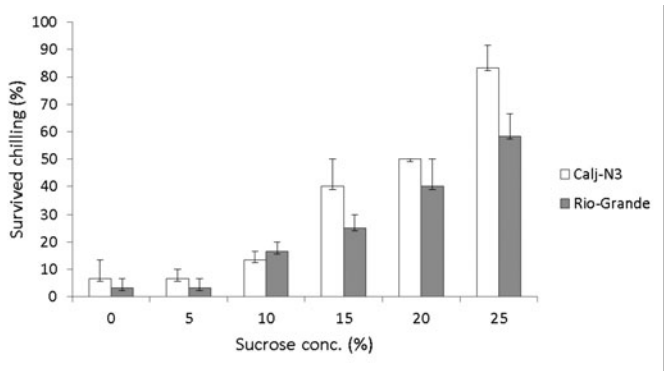

Fig. 2 - Effect of sucrose foliar spray on the percent of 'Calj-N3' and 'Rio-Grande' tomato cultivar transplants that survived chilling temperatures.

Leaf chlorophyll content

Leaf chlorophyll content was not different in cultivars due to treatment (data not shown). The same result was observed in birch (Percival and Fraser, 2005) where sugar feeding at 25 $g \cdot l^{-1}$ level had no significant effect on carotenoid and chlorophyll concentrations.

Field establishment efficacy

High transplant establishment percentage in the field results from quality transplants and successful transplanting. Tomato seedlings treated with 15 or 25% sucrose had the highest and similar transplant establishment rates (Fig. 3). This could be related to the greater root systems produced by those plants. Root growth is considered a useful indicator of seedling vigor (Ritchie, 1987).

Number of leaves and days to first flower

A standard indicator for flowering time is the number of leaves produced on the primary shoot before first flowers are initiated (Koornneef *et al.*, 1991). In tomato, the number of leaves produced before flowers is genetically controlled, but mediated by environmental conditions. Usually only from six to 11 leaves are required below the first inflorescence in tomato (Kinet and Peet, 1997), with

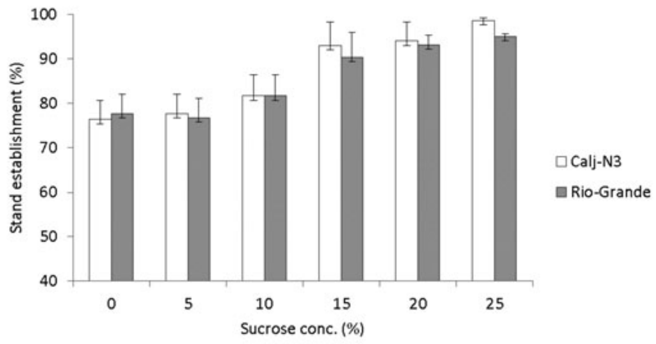

Fig. 3 - Effect of sucrose foliar spray on the percent of successful stand establishment of 'Calj-N3' and 'Rio-Grande' tomato cultivar transplants.

the lower number being found in an early crop. The 'Calj-N3' and 'Rio-Grande' seedlings treated with 15 and 20% sucrose solution, respectively, produced flowers sooner than other treatments (Table 1). In those concentrations there were fewer leaves than in the controls. It may be that sucrose application provides additional carbohydrates required for flower initiation. Flowering was observed to occur approximately four to five days earlier in cultivars treated with ≥15% sucrose (Table 1).

Fruit set percent and yield

Analysis of variance for both cultivars over two years did not show differences for fruit set percent and fruit yield (data not shown). It seems the effect of sucrose application on seedlings might not extend beyond flowering. Fruit set (and eventually yield) is affected by environmental factors and plant growth regulators during the fruit set period (Kinet and Peet, 1997).

4. Conclusions

Overall, transplant quality of horticultural crops is generally defined by physiological potentials (growth and developmental characteristics and photosynthetic ability), visual quality (color and morphology), genetic uniformity, and pathogen status (Kubota *et al.*, 2002). In the present study, in most cases the 15-25% sucrose treatment gave the best results. The main detracting factor for the 25% sucrose concentration was sticky leaf surfaces after application, which may attract insects. Washing leaves to remove stickiness and applying this amount of sugar is probably not economical. Therefore, the 15% level is recommended, which can be applied through overhead mist or irrigation system in commercial transplant production operations. Overhead irrigation systems wash excesses sucrose off leaves, reducing problems. The results from this investigation can be useful for transplant production companies and growers. Adverse environmental conditions do not always allow immediate transplanting into the field and sucrose-treated seedlings can be held for a few days, thus allowing flexibility in crop scheduling and labor management.

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