Hortic. Environ. Biotechnol.
DOI 10.1007/s13580-016-0158-x

ISSN (print) : 2211-3452
ISSN (online) : 2211-3460

Research Report

Proper Period and Temperature for Transportation of Cucumber and Tomato Transplants

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Received June 20, 2016 / Revised August 11, 2016 / Accepted August 15, 2016

Abstract. With an increased demand for high-quality transplants, vegetable growers have begun to purchase grafted transplants from specialized propagators. These are often shipped over long distances, but improper transport conditions can deteriorate transplant quality. To determine the appropriate period and temperature for transporting grafted transplants, we stored cucumber and tomato transplants in darkness at 6, 9, 12, 15, and 18°C for 3, 6, 9, 12, and 15 days, and subsequently cultivated these in a greenhouse for 15 days. We investigated the changes in plant height and SPAD value during storage, as well as the early growth of the stored transplants during subsequent cultivation. Increasing temperature during storage promoted stem elongation in both transplant species, with cucumber transplants showing greater stem elongation than tomato transplants. SPAD values of cucumber and tomato transplants tended to decrease with increasing storage temperature, declining even further with extended storage period. The cucumber transplants stored for 3 days and the tomato transplants stored for 6 days, showed no decrease in percent survival and no delay of growth after transplanting compared with non-stored transplants. From these results, we suggest that the appropriate temperature for transporting cucumber and tomato transplants in darkness is 6°C, and the appropriate period of storage in darkness are 3 and 6 days for cucumber and tomato transplants, respectively. Controlling transportation conditions can avoid the deterioration of transplant quality during transport and the delay of early growth after transplanting.

***Additional key words*:** dark storage, grafted transplants, low temperature, quality deterioration, shipping

Introduction

In recent years, most vegetable growers have purchased plug transplants for cultivation in greenhouses and fields. Since the success of final crop production is largely affected by transplant quality, vegetable growers demand high-quality transplants, often from distant suppliers. However, there are risks associated with the deterioration of transplant quality during transport and delayed growth and development after transplanting. In particular, high-quality grafted transplants are often shipped over long distances within the country or abroad as their producers are still limited in many countries (Kubota and Kroggel, 2006).

It is critical to transport vegetable transplants in appropriate conditions to maintain their quality and vigor. It has been reported that transportation in darkness causes the deterioration of transplant qualities such as stem elongation, chlorophyll degradation, and consumption of assimilates (Kubota et al., 2002; Sato et al., 2004). Kubota et al. (2004) reported that a low temperature could reduce this deterioration of quality and the associated negative effects on early growth and yield of tomato transplants. However, Kwack and Chun (2015) confirmed that long-term exposure to low temperature adversely affected the vigor of stored transplants after transplanting. The transport distance is a limiting factor for propagators to reach more customers and also for growers when choosing possible transplant sources (Kubota and Kroggel, 2006). When transplants are shipped long distances, growers are forced to hold them under adverse environmental conditions for days (Cantliffe, 1993). In addition, plant species differ in their abilities to withstand adverse conditions for long-distance transportation. Therefore, it is important to analyze the factors affecting the transportability of transplants, and determining the optimum transportation conditions can improve the transportability of transplants. However, there is a little information on the effect of transportation conditions on the quality and subsequent growth of vegetable transplants.

In this study, we stored grafted cucumber and tomato

transplants at five different air temperature conditions for five different durations, up to a maximum of 15 days, and determined the optimum conditions for transportation in order to avoid their quality deterioration and delay of early growth.

Materials and Methods

The grafted cucumber and tomato transplants used in this study cultivated conventionally by a commercial seedling supplier (Poseung Agricultural Association Cooperation, Pyeongtaek, Korea). For grafted cucumber transplants, 'Eunseong Bakdadagi' (*Cucumis sativus* L.; Seminis Vegetable Seeds Inc., Seoul, Korea) and 'Heukjong' (*Cucurbita ficifolia* L.; Seminis Vegetable Seeds Inc., Seoul, Korea) seedlings grown for 15 days after sowing were used as scions and rootstocks, respectively, and were cultivated for 25 days after grafting. Grafted tomato (*Solanum lycopersicum* L.) transplants were cultivated for 23 days after grafting 'SV0339TG' seedlings (Dongbu Farm Hungnong Co., LTD., Seoul, Korea; scions grown for 31 days after sowing) onto 'High Power' seedlings (Fineness Seed Co., LTD., Gwangju, Korea; rootstocks grown for 33 days after sowing).

The grafted transplants in 40-cell trays were placed into cardboard boxes commonly used for transportation. Boxes were placed in five dark chambers (Hanbaek Scientific Technology, Bucheon, Korea) set at 6, 9, 12, 15, and 18°C for 3, 6, 9, 12, and 15 days. Grafted transplants were not watered during storage, and the relative humidity was maintained at ≥ 80%. Ten transplants from each treatment were randomly sampled just before the start of storage and after 3, 6, 9, 12, and 15 days of storage. The height of each sampled transplant was measured using a caliper, and SPAD value was measured using a chlorophyll meter (SPAD-502,

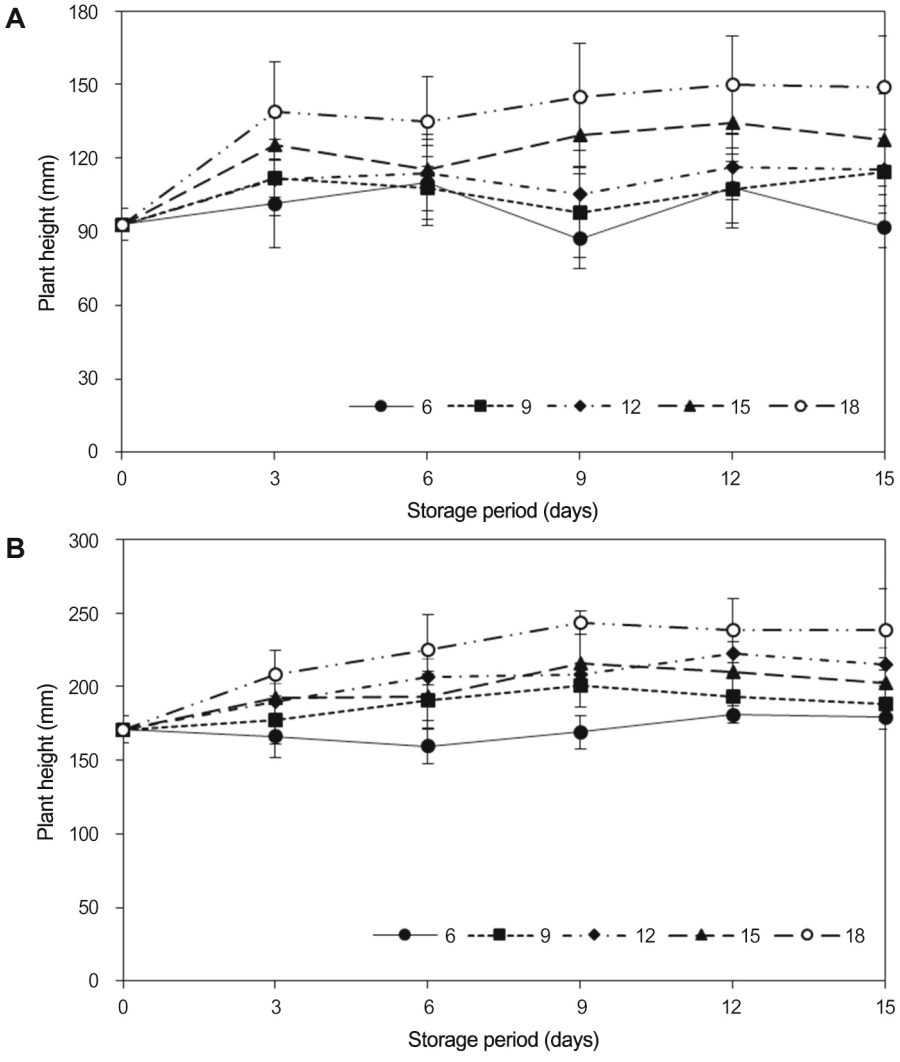

Fig. 1. Changes in plant height of grafted cucumber (A) and tomato (B) transplants affected by different storage temperatures for 15 days of storage. Error bars represent the standard error of the mean (n = 10).

Minolta Co. Ltd., Osaka, Japan).

Sampled transplants from each treatment at each storage time-point were planted into plastic pots (Ø 10 cm) with a commercial substrate mix (Plant World, Nongwoo Bio Co., LTD, Suwon, Korea) and cultivated for 15 days in a greenhouse located at the experimental field of Seoul National University, Suwon, Korea. To investigate the effects of transportation temperature and period on the vigor of stored transplants after transplanting, we examined the percent survival and growth parameters of stored transplants after transplanting them in a greenhouse. For grafted cucumber transplants, plant height, number of leaves and female flowers, SPAD value, leaf area, and fresh and dry weights of the shoot and root were measured 15 days after planting. For grafted tomato transplants, plant height, number of leaves, internodes, and trusses; SPAD value; leaf area; and fresh and dry weights of the shoot and root were measured.

Experimental data were analyzed using SAS statistical software (SAS Institute Inc., Cary, NC, USA). Duncan's multiple range test ($P \leq 0.05$) and Dunnett's test ($P \leq 0.05$) were used to determine significant differences between treatments.

Results and Discussion

In both cucumber and tomato transplants, plant height increased with increasing storage temperature (Fig. 1). The stems of the cucumber transplants were rapidly elongated at all storage temperatures in the first 3 days of storage, after which no further stem elongation was observed. In the tomato transplants, plant height increased slowly until 9 days in storage, with a smaller increase compared to that in the cucumber transplants.

During storage, cucumber and tomato transplants' SPAD values decreased with increasing storage temperature (Fig. 2),

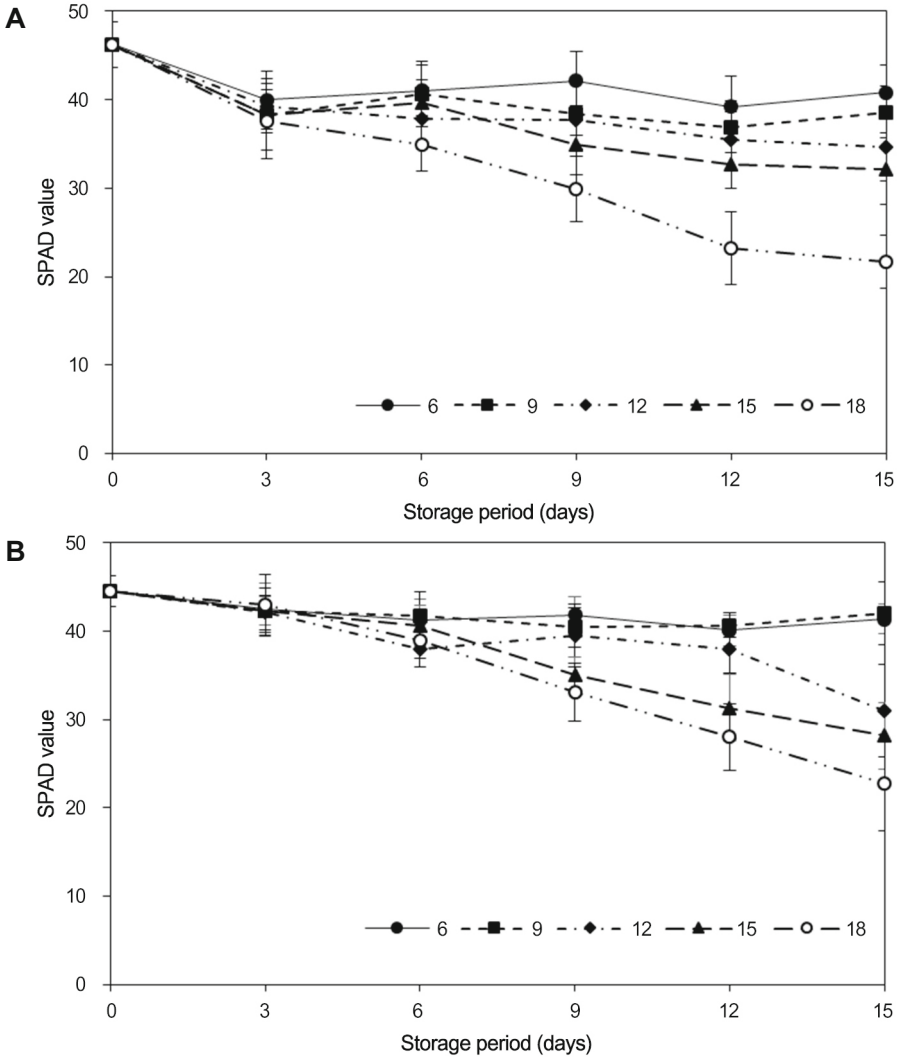

Fig. 2. Changes in SPAD value of grafted cucumber (A) and tomato (B) transplants affected by different storage temperatures for 15 days of storage. Error bars represent the standard error of the mean (n = 10).

Table 1. Effects of storage period and temperature on percent survival and growth of grafted cucumber transplants grown for 15 days after transplanting

Storage period (day)	Storage temp. (°C)	% survival	Plant height (cm)	No. of leaves (/plant)	SPAD value	Leaf area (cm^2/plant)	Dry weight (g/plant)		Soot/root ratio	No. of female flowers (/plant)
							Shoot	Root		
Non-stored		100	36.8	7.4	45.3	624	3.08	0.40	8.1	5.5
3	6	100	38.6 ab[z]	8.0 a*	43.0 a	600 a	2.97 a	0.28 a*	10.9 a*	6.8 a
	9	100	36.8 ab	7.9 a*	43.1 a	612 a	2.98 a	0.31 a	10.0 a	7.3 a
	12	100	39.3 ab	7.4 ab	41.8 ab*	600 a	3.04 a	0.35 a	9.5 a	6.3 ab
	15	100	41.9 a*[y]	7.5 ab	42.3 ab	644 a	3.28 a	0.31 a	11.2 a*	7.4 a*
	18	100	33.5 b	7.0 b	39.5 b*	459 b*	2.17 b*	0.26 a*	8.9 a	5.0 b
6	6	100	13.8 b*	4.0 b*	51.3 a	237 c*	1.99 a*	0.16 b*	13.4 a*	1.4 c*
	9	88	13.4 b*	6.1 a	45.5 b	334 bc*	2.12 a*	0.17 ab*	13.4 a*	2.7 bc*
	12	88	26.1 a	6.6 a	44.4 b	462 ab*	2.58 a	0.26 ab*	11.7 ab	5.0 ab
	15	100	33.4 a	7.8 a	43.2 b	535 a*	2.60 a	0.25 ab*	10.5 ab	7.0 ab
	18	88	33.5 a	7.6 a	42.2 b	494 a*	2.41 a*	0.27 a*	09.3 b	6.4 a
9	6	0	n.a.[x]	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	9	50	8.3*	3.5*	50.9	120*	0.96*	0.08*	12.7*	0.8*
	12	88	30.1	7.3	41.5	446*	1.93*	0.27*	7.7	5.4
	15	75	31.2	7.3	46.4	415*	1.86*	0.24*	7.9	6.8
	18	88	33.2	7.4	46.1	451*	1.84*	0.21*	10.1	5.6
12	6	0	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	9	0	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	12	75	22.3*	5.7*	40.6	282*	1.13*	0.15*	9.5	5.0
	15	75	27.8*	6.7	40.0*	354*	1.24*	0.12*	11.4*	6.3
	18	75	29.7*	6.7	42.0	301*	1.10*	0.08*	14.7*	3.7
15	6	0	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	9	0	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	12	38	25.0*	6.7	40.4	354*	1.30*	0.07*	18.1*	4.0
	15	25	33.8	8.0	41.4	451*	1.54*	0.08*	18.5*	7.0
	18	0	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

[z]Means with different letters are significantly different according to Duncan's multiple range tests at $p \leq 0.05$.
[y]Means with a single asterisk (*) are significantly different from the non-stored control according to Dunnett's test at $p \leq 0.05$.
[x]No data available because none of the plants survived 15 days after transplanting.

but not during the first 3 days of storage. After 3 days of storage, higher storage temperature induced greater degradation of chlorophyll in both transplants. When the grafted cucumber and tomato transplants were stored at 18°C for 15 days, SPAD values reduced by 53 and 49%, respectively, compared with those of non-stored transplants. Little chlorophyll degradation was observed in tomato transplants stored for 15 days at 6 and 9°C.

Storage in darkness resulted in succulent elongation of the stem, etiolation of the leaves, and a decrease in carbohydrates caused by dark respiration (Kaczperski and Armitage, 1992; Sato et al., 1999). It has been reported that low temperature can prevent the deterioration of transplant quality during dark storage (Heins et al., 1992; Cushman et al., 1998); our results concurred with these reports. Kwack and Chun (2015) reported that the change in transplant quality during dark storage differed between plant species, indeed, we observed more severe stem elongation with a more rapid decrease in SPAD value in cucumber transplants than tomato transplants.

When the cucumber transplants were stored for 3 days, 100% of plants in all temperature treatments survived after transplanting (Table 1). There were no significant differences in the growth of transplants stored at 6, 9, 12, or 15°C for 3 days compared with non-stored transplants; however, storage at 18°C for 3 days slightly reduced growth 15 days after transplanting. When cucumber transplants were stored for 6 days, growth was severely decreased when stored at temperatures lower than 10°C. In the cucumber transplants stored at 12, 15, and 18°C for 6 days, plant height, number of leaves, SPAD value, and number of female flowers were similar to those of non-stored transplants; however, leaf area and root

Table 2. Effects of storage period and temperature on percent survival and growth of grafted tomato transplants grown for 15 days after transplanting

Storage period (day)	Storage temp. (°C)	% survival	Plant height (cm)	No. of leaves (/plant)	SPAD value	Leaf area (cm^2/plant)	Dry weight (g/plant)		Soot/root ratio	No. of trusses (/plant)
							Shoot	Root		
Non-stored		100	41.6	11	43.5	535	2.60	0.49	5.3	1.3
3	6	100	39.4 ab[z]	12 a	41.3 b*	478 a	2.67 a	0.53 a	5.1 bc	1.3 a
	9	100	38.7 b	12 a	42.6 ab	454 a	2.71 a	0.59 a	4.7 c	1.1 a
	12	100	37.9 b*[y]	12 a	40.9 b*	409 a*	2.42 a	0.45 a	5.4 bc	1.1 a
	15	100	44.9 a*	12 a	43.9 a	496 a	3.12 a*	0.53 a	5.9 ab	1.1 a
	18	100	42.6 ab	12 a*	42.9 ab	517 a	3.31 a	0.53 a	6.2 a*	1.1 a
6	6	100	47.2 a	13 a	43.8 ab	567 a	3.67 a*	0.60 a*	6.1 a	1.4 a
	9	100	36.9 bc	10 b	41.5 bc	372 b*	2.13 b	0.41 ab	5.3 a	1.3 a
	12	100	35.8 c	10 b*	42.3 bc	354 b*	1.97 b	0.33 b*	6.0 a	1.1 a
	15	100	43.1 abc	11 ab	40.7 c*	514 a	2.95 ab	0.50 ab	6.1 a	1.3 a
	18	100	44.7 ab*	13 a*	45.1 a	523 a	3.22 ab	0.54 a	5.9 a	1.7 a
9	6	86	31.0 c*	10 b	43.5 ab	323 a*	2.16 a	0.43 a	5.3 a	1.3 b
	9	86	34.1 bc	10 b	42.1 ab	365 a*	2.81 a	0.46 a	6.4 a	1.5 b
	12	86	43.1 ab	13 a	42.0 ab	470 a	2.87 a	0.42 a	6.7 a*	1.7 ab
	15	100	39.4 abc	10 b*	40.7 b*	379 a*	2.21 a	0.43 a	5.6 a	1.4 b
	18	100	44.8 a	13 a*	44.0 a	486 a	2.98 a	0.47 a	6.5 a*	2.1 a*
12	6	71	34.6 bc*	12 a	38.3 bc*	360 ab*	2.11 ab	0.44 ab	5.2 a	1.4 b
	9	71	27.8 c*	9 b*	42.5 a	283 b*	1.48 b*	0.31 b	5.3 a	1.2 b
	12	86	43.5 a	11 ab	42.9 a	423 a*	2.85 a	0.58 a	5.0 a	2.0 a*
	15	100	31.0 c*	9 b*	37.9 c*	281 b*	1.56 b*	0.33 ab*	4.8 a	1.1 b
	18	86	39.6 ab*	12 a	41.0 ab*	375 ab*	2.43 ab	0.46 ab	5.5 a	2.0 a*
15	6	57	40.5 a	13 a*	45.0 a	425 a*	3.86 a	0.62 a*	6.2 a	1.8 a
	9	57	37.0 a	11 a	43.0 ab	334 a*	2.12 b	0.42 ab	5.8 a	1.8 a
	12	57	34.6 a*	11 a	39.6 b*	299 a*	1.68 b*	0.31 b*	5.4 a	1.8 a
	15	71	35.1 a*	12 a	41.1 ab	315 a*	1.58 b*	0.32 b*	5.1 a	1.8 a
	18	71	36.8 a*	14 a*	40.8 b*	322 a*	1.89 b*	0.27 b*	7.1 a*	2.0 a*

[z]Means with different letters are significantly different according to Duncan's multiple range tests at $p \leq 0.05$.
[y]Means with a single asterisk (*) are significantly different from the non-stored control according to Dunnett's test at $p \leq 0.05$.

dry weight were lower. Cucumber transplants stored at 6°C for more than 6 days did not survive after transplanting, and when stored for 9 days or more days, growth was greatly delayed compared to non-stored transplants.

Growth of tomato transplants stored for up to 6 days was not delayed compared with non-stored transplants, and 100% of plants survived in all temperature treatments (Table 2). Although the leaf area of the transplants stored at 12 and 15°C for 6 days was lower than that of non-stored transplants, there were no significant differences in shoot dry weight. Percent survival after transplanting of tomato transplants stored for 9 days slightly decreased in low storage temperatures (6, 9, and 12°C). When stored for 12 and 15 days, most of the stored transplants showed lower percent survival and growth compared with non-stored transplants.

Results showed that high temperature and prolonged storage in darkness reduced the survival and early growth of transplants after transplanting. Risse et al. (1979) and Heins et al. (1992) showed that transplants stored at high temperatures showed retarded growth after transplanting because of a loss of photosynthetic ability during dark storage. Kozai et al. (1996) reported that degradation of chloroplast components such as chlorophyll reduced the photosynthetic ability in transplants exposed to prolonged darkness. Transportation at low temperatures reduced the deterioration of cucumber and tomato transplant quality; however, survival and growth after transplanting were adversely affected by prolonged exposure to low temperatures. Transplant vigor might be reduced because of chilling stress experienced during storage at low temperatures (Kwack and Chun, 2015). We also found that exposure to 6°C for more than 3 and 6 days could induce chilling stress in cucumber and tomato transplants, respectively, and that chilling-stressed transplants were unable to recover after transplanting. Sato and Okada (2014) assumed that,

when photosynthesis is limited, carbohydrates consumption was caused by the synthesis of cell wall or other components related to stem elongation. Stem elongation during transport was more marked in cucumber than in tomato transplants; therefore, high carbohydrate consumption may induce a more severe reduction in vigor of stored cucumber transplants.

Transportation conditions should be controlled giving consideration to the distance traveled and plant species. The results of this study suggest that grafted cucumber transplants can be transported in darkness for 3 days, and tomato transplants for 6 days, when the transport temperature is maintained at 6°C. If other factors including light, vibration, and packing materials during transport are appropriately controlled, the transportability of vegetable transplants will improve, which would enable grafted vegetable transplant markets to expand locally and internationally.

Acknowledgements: This study was supported by the Advanced Production Technology Development Program (Project No. 312034-04-3-HD050) of the Korea Institute of Planning and Evaluation for Technology in Food, Agriculture, Forestry, and Fisheries.

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