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Research Report

Changes in Quality and Vigour of Cucumber and Paprika Transplants as Affected by Storage Temperature under Dark Conditions

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Abstract: Cucumber and paprika transplants were stored at 9, 12, 15, and 18°C under dark conditions for 15 days and then grown in a greenhouse for 14 days after transplanting. To determine the effects of low storage temperature and long-term continuous darkness on the quality and vigour of transplants, we investigated the quality of transplants during storage and the growth of stored transplants after transplanting. In cucumber transplants, decreasing storage temperature reduced stem elongation and decrease in SPAD value. The quality of cucumber transplants stored at 9°C was well preserved during storage, but they did not survive after transplanting due to chilling damage. Growth and development after transplanting were significantly greater when cucumber transplants were stored at 12°C. In paprika transplants, the quality of transplants did not significantly differ before and after storage. After transplanting, there was no significant difference in the survival rate and growth, but the number of flower buds was greater in the paprika transplants stored at lower temperatures (9 and 12°C). These results indicate that the responses of transplants to the conditions of low temperature and darkness differed between cucumber and paprika, and storage temperature in darkness must be controlled carefully considering species-specific responses to reduce quality deterioration during storage and improve the recovery of transplants after transplanting.

Additional key words: chilling, chlorophyll degradation, seedling, stem elongation, storability

Introduction

Transplant production using plugs has been widely used in vegetable crops because it has several advantages. Transplants can be produced more uniformly and their growth can be controlled more easily, improving the overall quality by using plug-type production system. High-quality transplant production affects the success of final crop quality and yield.

Transplant storage is necessary for coordinating the supply of transplants with variable demand (Sato et al., 2004). Transplant production has seasonal market demand, and millions of transplants should be intensively produced during a narrow window of time at a planting season (Justus and Kubota, 2010). Additionally, delays in transplanting have frequently occurred due to labour shortages and bad weather conditions. Holding the transplants for several weeks is useful for transplant producers because extending the production time for a certain volume of transplants can distribute and reduce labour. Farmers also can adjust crop scheduling and labour management by storing the transplants prior to transplanting (Kubota et al., 2002).

For successful transplant storage, the growth and development of transplants must be suppressed but their quality must be maintained. Lowering temperature during dark storage is the most common and easiest method for maintaining transplant quality. Many researchers have reported that low temperature can reduce the deterioration of transplant quality during dark storage due to decreases in the carbo-

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hydrate contents of transplants (Kaczperski and Armitage, 1992; Sato et al., 1999). The deterioration of transplants quality such as succulent elongation, chlorophyll degradation, and dry weight loss were also found when the transplants were stored in darkness (Kubota and Kroggel, 2006). Additionally, it has been suggested that the interruption of photosynthesis combined with low temperature stress affects physiological changes of transplants during low temperature storage (Ning et al., 2006; Ding et al, 2011). However, the responses of transplants to low storage temperature under dark condition may differ among species, and the conditions of low temperature storage need to be evaluated considering species-specific responses.

The objectives of this study were to investigate changes in the quality of cucumber and paprika transplants at different temperatures during storage in darkness and to examine the effect of storage temperature on vigour of transplants after transplanting them to production sites.

Materials and Methods

Plant materials

We used cucumber (*Cucumis sativus* L. cv. Cool) and paprika (*Capsicum annuum* L. cv. Special) transplants supplied by Poseung Agricultural Association Cooperation (N 36.6°, E 127.1°; Pyeongtaek, Korea) and Hoban Agricultural Association Cooperation (N 37.5°, E 127.4°; Chuncheon, Korea), respectively. Cucumber and paprika transplants were cultivated conventionally using 40-cell trays filled with a commercial substrate mix in greenhouses for 30 and 40 days, respectively.

Storage conditions

Cucumber and paprika transplants in 40-cell trays were input in cardboard boxes commonly used for transplant shipping and the boxes were placed in four dark chambers set at 9, 12, 15, and 18°C for 15 days. During storage, transplants were not irrigated and the relative humidity was maintained at $\geq$ 80%.

Measurement of transplant quality before and after dark storage

Transplants from each treatment were sampled just before the start of storage and after 15 days of storage. We sampled plants from each treatment and measured plant height, number of leaves, and fresh and dry weights of shoot and root. Root/Shoot ratio was calculated with dry weights of shoot and root. To determine the chlorophyll content of transplants before and after storage, the SPAD value was measured using a chlorophyll meter (SPAD-502; Minolta Co. Ltd., Osaka, Japan).

Greenhouse cultivation after storage

After storage under dark conditions, the transplants were cultivated for 14 days in the greenhouse at the experimental field, Seoul National University, Suwon (E 127.0°, N 37.3°). Plants were transplanted into a plastic pot (Ø 10 cm) with a commercial substrate mix and irrigated with tap water once a day.

Assessment of transplant growth after transplanting

To evaluate the recovery of transplants from low temperature storage stress, we examined survival rate and growth of the stored transplants after transplanting to a greenhouse. Plant height; numbers of internodes, leaves, and flowers; SPAD value; leaf area; and fresh and dry weights of shoot and root were measured 14 days after transplanting.

Statistical analysis

The experimental data were analysed using SAS statistical software (SAS Institute Inc., Cary, NC, USA). Duncan's multiple range tests ($p \leq 0.05$) were performed to determine if a significant difference was observed among the treatments subjected to various temperatures during dark storage.

Results and discussion

Quality of cucumber and paprika transplants after dark storage

Plant height of cucumber transplants increased with increasing storage temperature (Fig. 1). Plant height is regarded as one of the more important morphologic characteristics with respect to the quality of transplants because growers prefer strong-looking transplants with shorter internodes rather than elongated transplants (Kubota and Kroggel, 2006). SPAD values of cucumber transplants after storage were lower than those before storage at all storage temperatures. Decreases in chlorophyll content were more pronounced at the high storage temperatures. Chlorophyll is susceptible to degradation under dark condition; therefore, etiolation is often observed during dark storage (Toivonen and Sweeney, 1998; Ding et al., 2011). The number of leaves and the fresh weight of cucumber transplants increased during storage, while the dry weight remained almost unchanged (Table 1). Succulent stem elongation during storage contributed to increases in fresh weight. Kubota et al. (2002) observed that the fresh weight of stem after dark storage increased by 20% compared to that before storage. Root/shoot ratio in the cucumber transplants stored at 9°C was much higher than that in the non-stored cucumber transplants. Kubota et al. (1997) reported that carbohydrate composition in plant organs was changed due to an altered pattern of carbohydrate allocation at low temperature. Source/sink relationship was affected by low temperature, which was generally related to the effects on root/shoot relationship (Hällgren and Öquist, 1990). It indicated that more carbohydrates can be partitioned into roots during storage at low temperature in cucumber transplants.

Paprika transplants showed little elongation and chlorophyll degradation rates after storage (Fig. 2). Many researchers have reported that lowering the temperature slows metabolic processes such as respiration and chlorophyll degradation, and significantly decreases quality deterioration of transplants during storage (Heins et al., 1995; Sato et al., 1999; Kubota et al., 2002). In paprika, however, there was no significant

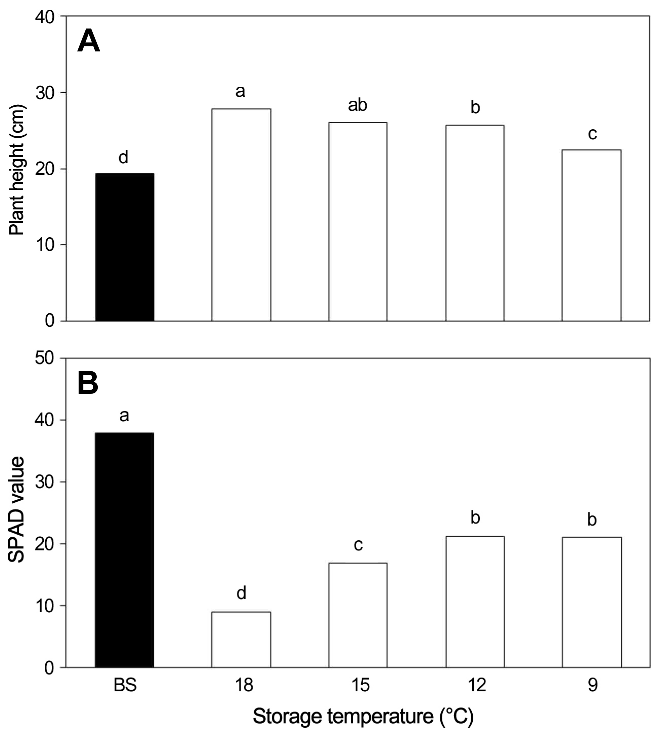

Fig. 1. Plant height and SPAD value of cucumber transplants as affected by temperature during 15 days of dark storage. BS = before storage. Means in columns with different letters are significantly different based on Duncan's multiple range tests at $p \leq 0.05$.

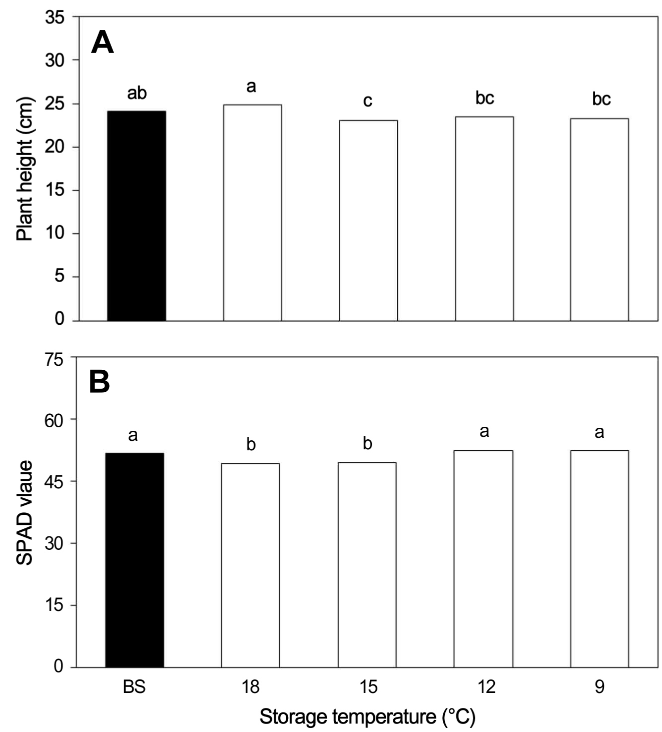

Fig. 2. Plant height and SPAD value of paprika transplants as affected by temperature during 15 days of dark storage. BS = before storage. Means in columns with different letters are significantly different based on Duncan's multiple range tests at $p \leq 0.05$.

Table 1. Number of leaves, fresh weight, and dry weight of cucumber transplants as affected by temperature during 15 days of dark storage.

Storage temperature (°C)	No. of leaves (/plant)	Fresh weight (g/plant)		Dry weight (g/plant)		Root/Shoot
		Shoot	Root	Shoot	Root	
Before storage	4.0 b[z]	08.75 c	3.69 b	0.87 a	0.20 ab	0.23 bc
18	4.9 a	11.09 a	4.23 ab	0.87 a	0.20 ab	0.24 bc
15	4.3 b	10.68 ab	4.10 ab	0.83 ab	0.17 b	0.21 c
12	4.2 b	09.84 bc	4.40 a	0.76 ab	0.20 ab	0.26 b
9	4.0 b	09.46 c	4.26 ab	0.72 b	0.25 a	0.34 a

[z]Means in columns with different letters are significantly different based on Duncan's multiple range tests at $p \leq 0.05$.

relationship between storage temperature and stem elongation/chlorophyll degradation of transplants. The number of leaves decreased with decreasing storage temperature, and root/shoot ratio in paprika transplant increased after storage (Table 2). Paprika transplants stored at 9 and 12°C had significant decreases in the number of leaves due to wilting and leaf senescence from chilling injury. Maintaining the number of leaves during storage is important to keep the photosynthetic surface area of transplants after transplanting (Justus and Kubota, 2010).

Growth of stored cucumber and paprika transplants after transplanting

Fourteen days after transplanting, cucumber transplants stored at 9°C for 15 days did not survive, although the deterioration of quality during storage was low (Table 3). Prolonged exposure to low temperatures during storage may have deleterious effects on the growth of transplants after transplanting. Cucumber transplants stored at 12°C showed the highest growth after transplanting. Lower consumption of carbohydrate at 12°C than at 15 and 18°C due to dark respiration during storage may affect the growth of cucumber transplants after transplanting. When cucumber transplants were stored at 18°C, the SPAD value decreased from 37.9 to 8.9 (Fig. 1); however, the chlorophyll contents were almost fully recovered after transplanting (Table 3).

All paprika transplants survived after transplanting, and no significant difference was observed in the growth of transplants stored at different temperatures (Table 4). However, the number of flower buds was significantly greater in paprika transplants stored at 9 and 12°C. Kubota et al. (1997) and Sato et al. (1999) reported that high storage temperatures, especially in darkness, reduced carbohydrate contents of transplants. Carbohydrate contents allocated to flower organs in transplants stored at higher temperatures (15 and 18°C) may be smaller than those in transplants stored at lower temperatures (9 and 12°C), and it may cause a delay in flower development.

These results indicate that it is important not only to reduce the quality deterioration during storage, but also to preserve the vigour of transplants and ensure regrowth after transplanting for successful transplant storage. In the present experiment, we determined not to compare the growth after transplanting of non-stored from the stored transplants. It was because that the non-stored transplants should be cultivated at the exactly same environment

Table 2. Number of leaves, fresh weight, and dry weight of paprika transplants as affected by temperature during 15 days of dark storage.

Storage temperature (°C)	No. of leaves (/plant)	Fresh weight (g/plant)		Dry weight (g/plant)		Root/Shoot
		Shoot	Root	Shoot	Root	
Before storage	11.8 a[z]	8.67 ab	4.34 c	1.14 a	0.36 b	0.32 b
18	12.0 a	9.28 a	6.71 a	1.03 b	0.42 ab	0.41 a
15	11.3 ab	8.31 b	6.61 a	0.93 b	0.39 ab	0.42 a
12	10.8 b	8.29 b	5.96 ab	1.02 b	0.42 ab	0.41 a
9	10.8 b	7.98 b	5.36 bc	1.00 b	0.44 a	0.44 a

[z]Means in columns with different letters are significantly different based on Duncan's multiple range tests at $p \leq 0.05$.

Table 3. Survival rate, plant height, number of leaves and flowers, SPAD value, leaf area, fresh and dry weight of cucumber transplants 14 days after transplanting.

Storage temperature (°C)	Survival rate (%)	Plant height (cm)	No. of leaves (/plant)	No. of flowers (/plant)	SPAD value	Leaf area (cm^2/plant)	Fresh weight (g)		Dry weight (g)	
							Shoot	Root	Shoot	Root
18	90	41.3 b[z]	9.6 b	5.1 b	30.7 a	341.1 c	13.62 c	2.41 b	1.05 c	0.13 b
15	100	52.6 b	9.9 b	7.4 a	32.0 a	579.1 b	22.74 b	3.09 b	1.59 b	0.15 b
12	90	64.3 a	11.2 a	8.1 a	32.0 a	765.3 a	30.34 a	5.13 a	1.99 a	0.24 a
9	0	ND[y]	ND	ND	ND	ND	ND	ND	ND	ND

[z]Means in columns with different letters are significantly different based on Duncan's multiple range tests at $p \leq 0.05$.
[y]No data available because all the plants did not survive 14 days after transplanting.

Table 4. Survival rate, plant height, number of leaves and flower buds, SPAD value, leaf area, fresh and dry weight of paprika transplants 14 days after transplanting.

Storage temperature (°C)	Survival rate (%)	Plant height (cm)	No. of leaves (/plant)	No. of flower buds (/plant)	SPAD value	Leaf area (cm^2/plant)	Fresh weight (g)		Dry weight (g)	
							Shoot	Root	Shoot	Root
18	100	31.2 a[z]	29.5 a	12.4 b	55.1 a	499.1 a	25.09 ab	12.83 a	2.94 a	1.01 a
15	100	29.4 b	27.1 a	12.0 b	55.4 a	470.8 a	22.58 b	12.66 a	2.63 b	0.98 a
12	100	32.7 a	29.1 a	17.3 a	56.3 a	508.2 a	25.68 a	13.13 a	3.08 a	0.98 a
9	100	32.6 a	28.6 a	15.1 a	53.7 a	525.2 a	24.56 ab	12.48 a	2.95 a	0.94 a

[z]Means in columns with different letters are significantly different based on Duncan's multiple range tests at $p \leq 0.05$.

conditions of the stored transplants that were sown and cultivated 15 days earlier, which was not possible to achieve under natural conditions using a plastic greenhouse. Therefore, further study will be required to compare the growth of non-stored and stored transplants after transplanting using the same age transplants cultivated under controlled environment conditions.

In conclusion, cucumber and paprika transplants responded differently to the conditions of low temperature and darkness, with paprika transplants showing better tolerance against low temperature and darkness during storage. In both species, control of storage temperature could reduce the deterioration of quality during storage and improve the recovery of transplants after transplanting to some extent. Our studies suggest that environmental conditions including temperature during storage should be controlled carefully considering species-specific responses of transplants in order to maintain the quality of transplants during storage and to preserve the vigour of transplants after transplanting.

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