

Vacuum Cooling and Storage Temperature Influence the Quality of Stored Mung Bean Sprouts

Jennifer R. DeEll¹ and Clément Vigneault

Agriculture and Agri-Food Canada, Horticultural Research and Development Centre, 430 Boul. Gouin, Saint-Jean-sur-Richelieu, Québec J3B 3E6, Canada

Frédérique Favre

Etablissement National d'Enseignement Supérieur Agronomique de Dijon, 21 Boul. Olivier de Serre, 21800 Quétigny, France

Timothy J. Rennie and Shahrokh Khanizadeh

Agriculture and Agri-Food Canada, Horticultural Research and Development Centre, 430 Boul. Gouin, Saint-Jean-sur-Richelieu, Québec J3B 3E6, Canada

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Abstract. The objective of this research was to evaluate the effects of vacuum cooling and temperature on the quality and storage life of mung bean sprouts (*Vigna radiata* L. Wilczek). Sprouts in micro-perforated bags were either not pre-cooled or vacuum cooled to 9, 6, or 3 °C, and stored for 7 days at 1, 3, or 6 °C. Vacuum-cooled bean sprouts lost more weight than sprouts not pre-cooled, and the weight loss was greater when the sprouts were cooled to lower temperatures. However, the total loss never exceeded 5% and no apparent signs of shrivel were observed. Vacuum cooling resulted in greater product freshness after 4 days of storage, but the effect was nonsignificant after 7 days. Storage temperature had greater influence on bean sprout quality than did cooling temperature, with greater freshness and whiter hypocotyls at the lower temperatures. However, blackening of cotyledons increased as the storage temperature decreased.

Bean sprouts are highly perishable and thus have an inherently short shelf-life. Sprouts remain in salable condition at 0 °C and 95% to 100% relative humidity (RH) for 7–9 d, while exposure to 20 °C for 30 min each day can reduce this storage-life by half (Hardenburg et al., 1986). Sprouts stored at 0, 2.5, 5, or 10 °C reach the lower limit of marketability after 8.5, 5.5, 4.5, and 2.5 d, respectively (Lipton et al., 1981). This rapid quality loss at relatively modest temperatures emphasizes the critical need for immediate cooling of bean sprouts. Varoquaux et al. (1996) showed that freshly harvested bean sprouts have a respiration rate of $\approx 1 \text{ mmol O}_2 \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$ at 10 °C, and that the rate is very dependent on temperature (10-fold increase for every 16.5 °C).

Vacuum cooling, which is achieved by evaporation of water from the product at very low air pressure, is one of the methods used for rapid cooling of horticultural crops (Mitchell, 1992; Thompson et al., 1998). Vegetables that have high surface : mass ratios and release water easily are the most suited to this method.

Vacuum cooling is used commercially in some areas to pre-cool bean sprouts; the sprouts are washed with water at room temperature, packaged in waxed cardboard boxes containing 13.5 kg of product, and then vacuum-cooled to ≈ 9 °C. However, little information exists in the literature on the benefits or the optimum cooling temperature. Therefore, the objective of this research was to evaluate the effects of vacuum cooling and temperature on the quality and storage life of fresh bean sprouts.

Plant material. Mung bean sprouts were provided by a local producer in Montréal. The sprouts were washed twice with water at ≈ 20 °C and then packaged in waxed cardboard boxes containing 13.5 kg of product. Transport to the laboratory took 40–45 min, during which time the sprouts were at ambient temperature (≈ 24 °C). They were then divided into samples of 500 ± 5 g and sealed in commercially available Ziploc™ bags with micro-perforations (Dow Brands Canada, Paris, Ont.).

Vacuum cooling. Samples were vacuum-cooled to 9, 6, or 3 °C using a laboratory-scale freeze-dryer (model Y1, series 77-003; Lysoan Co., Lachute, Québec). To monitor the internal temperature of the sprouts during cooling, one thermocouple (type T) was placed into one sprout within the center of each bag. Samples were cooled until the average temperature of the thermocouples reached the desired temperature (9, 6, or 3 °C). Additional control samples were not vacuum-cooled, but were placed directly into storage at the appropriate temperature.

Storage treatments. After vacuum cooling, three bags that had been cooled to each temperature (9, 6, or 3 °C) and three bags not pre-cooled were stored at either 1 or 6 °C for 7 d. RH within the bags was maintained at $>95\%$. In a second experiment, an additional storage temperature of 3 °C was used. Samples were vacuum-cooled in the same manner, and three bags that had been cooled to each temperature (9, 6, or 3 °C) and three bags not pre-cooled were stored at 1, 3, or 6 °C for 7 d. Each group of three bags was held separately in a $400 \times 600 \times 146$ -mm vented plastic container, and the containers were stacked in the appropriate cold room in the dark.

Quality analyses. The quality of the bean sprouts was evaluated before and after vacuum cooling, and then after 1, 4, and 7 d of storage. Overall freshness was evaluated using a scale of 1 to 5, while cotyledon and hypocotyl color were evaluated using 1 to 4 scales (Table 1). Weight loss was also determined, and reported

Table 1. Rating scales used for measuring bean sprout freshness, cotyledon color, and hypocotyl color.

Freshness		
5	Excellent	Overall appearance excellent; hypocotyls white and crisp; cotyledons green-yellow; no major defects
4	Good	Overall appearance good; some radicles showing signs of browning at the tips; some cotyledons showing signs of blackening; few defects; acceptable crispness of hypocotyls
3	Acceptable	Appearance at the limit of being acceptable; hypocotyls flaccid, tips of radicles brown and dry, some with brown streaks throughout; cotyledons dark; several defects
2	Unacceptable	No freshness; hypocotyls with dark streaks and brown grooves; cotyledons brown or black
1	Poor	Musty odor; hypocotyls brown, dry or slimy (decayed), many grooves; cotyledons black
Cotyledon color		
4	Excellent	Most clear and green
3	Good	Some beginning to darken
2	Unacceptable	Many brown or black
1	Poor	Most black
Hypocotyl color		
4	Excellent	Most white
3	Good	Some with brown spots developing
2	Unacceptable	Many with streaks of brown
1	Poor	Most brown

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¹To whom reprint requests should be addressed. E-mail address: deellj@em.agr.ca

as a percentage of the original sample weight. No free water accumulated in the bags during storage.

Statistical analyses. A completely randomized design with three replicates per treatment was used in both experiments. In Expt. 1, there were six combinations of vacuum cooling (9, 6, or 3 °C) and storage (1 or 6 °C) temperatures, while in Expt. 2 there were nine combinations of vacuum cooling (9, 6, or 3 °C) and storage (1, 3, or 6 °C) temperatures. Data were analyzed using the General Linear Models Procedure of SAS (SAS Institute, 1988), and the least squares means used to compare the adjusted means using the paired *t* test. For Expt. 2, regression analyses were also performed to determine the effect of storage temperature on bean sprout freshness, cotyledon color, and hypocotyl color.

Results and Discussion

During vacuum cooling, the temperature of the sprouts remained relatively constant for ≈6 min during the first phase, as the pressure inside the vacuum cooler was reduced (Fig. 1). Once the chamber pressure reached the point at which water began to evaporate, the temperature of the sprouts began to decrease rapidly. The time required to vacuum-cool the bean sprouts to 9, 6, or 3 °C was ≈9, 10, and 12 min, respectively.

Weight loss was greater in vacuum-cooled sprouts, and the final precooling temperature affected the loss (Table 2). In both experiments, weight loss was greater as the sprouts were cooled to lower temperatures, although ≈75% of the total loss due to vacuum cooling occurred before the sprouts reached 9 °C. Weight loss during vacuum cooling (mean = 3.2%) was greater than that during subsequent storage for 7 d (mean = 0.9%). Barger (1963) reported that moisture loss during vacuum cooling was ≈1% per 6 °C. However, this loss generally occurs equally from all parts of the product, and thus wilting is not apparent for most products unless the loss exceeds 5% (Hardenburg et al., 1986). From 2% to 4% moisture loss is common during vacuum cooling, and this level can cause noticeable wilting in some leafy vegetables (Thompson et al., 1998). No apparent signs of shrivel were observed in the bean sprouts, regardless of the final precooling and storage temperatures. Sprouts held in storage at 3 °C lost slightly more weight than did those held at 1 or 6 °C (Table 2).

Vacuum cooling had no immediate effects on the freshness of bean sprouts or on cotyledon and hypocotyl color; these characteristics were excellent immediately after cooling (freshness ≈5, cotyledon color ≈4, and hypocotyl color ≈4). However, after 4 d of storage the freshness of vacuum-cooled sprouts, regardless of the final precooling temperature, was greater than that of those placed immediately into cold storage (Table 3). Similarly, the hypocotyls of vacuum-cooled bean sprouts, regardless of the final precooling temperature, tended to discolor less after 4 d of storage than those not vacuum-cooled (Table 3). These

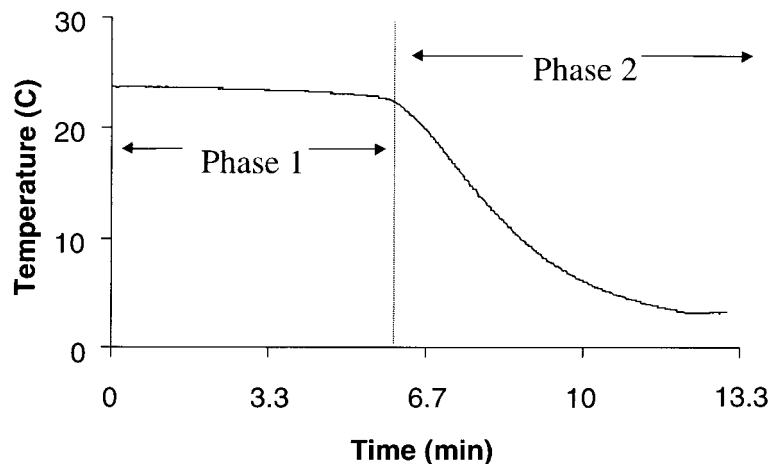


Fig. 1. Temperature of bean sprouts during vacuum cooling to 3 °C. Values are averages of readings from four thermocouples placed in separate bags (example from Expt. 1, Rep 2).

Table 2. Main effects of vacuum cooling and storage temperature on weight loss of bean sprouts after cooling and subsequent storage for 7 d.

Vacuum temp (°C)	Expt. 1 Weight loss (%) after:		Expt. 2 Weight loss (%) after:	
	Cooling	Storage	Cooling	Storage
None	---	1.01 c ^a	---	1.55 d
3	3.35 a	4.18 a	3.76 a	4.75 a
6	3.30 a	4.10 a	3.46 b	4.38 b
9	2.68 b	3.54 b	2.77 c	3.63 c
	***	***	***	***
Storage temp (°C)				
1	---	3.25	---	3.39 b
3	---	---	---	3.82 a
6	---	3.17	---	3.52 b
		NS		*

^aMean separation within columns and treatments by least square means.

ns, *, *** Differences nonsignificant or significant at $P \leq 0.05$ or 0.001, respectively.

Interaction (vacuum cooling \times storage temperature) nonsignificant at $P \leq 0.05$.

Table 3. Main effect of vacuum cooling on the freshness, cotyledon color, and hypocotyl color of bean sprouts after storage for 4 d.

Vacuum cooled to (°C)	Freshness (1–5)		Cotyledon color (1–4)		Hypocotyl color (1–4)	
	Expt. 1	Expt. 2	Expt. 1	Expt. 2	Expt. 1	Expt. 2
No vacuum	3.8	3.8 b ^a	3.5	3.9	3.0	3.1 b
3	4.1	4.4 a	3.1	3.7	3.3	3.6 a
6	4.3	4.3 a	3.4	3.9	3.3	3.4 a
9	4.2	4.4 a	3.3	3.8	3.2	3.5 a
	NS	*	NS	NS	NS	*

^aMean separation within columns and treatments by least square means.

ns, * Differences nonsignificant or significant at $P \leq 0.05$, respectively. Data averaged over storage temperatures within each cooling temperature, as the effect of storage temperature was nonsignificant at $P \leq 0.05$.

trends in freshness and hypocotyl color were noted in Expt. 1 but were not significant at $P \leq 0.05$. Fewer samples were used in Expt. 1 (3 °C storage temperature added for Expt. 2), which may explain the lack of significance. Vacuum cooling had no significant effect on cotyledon color in either experiment (Table 3).

After 7 d of storage, differences in bean sprout freshness and hypocotyl color were no longer significant (freshness = 2.6 and 2.8, hypocotyl color = 2.2 and 2.5, for noncooled and vacuum-cooled sprouts, respectively). The interaction of vacuum cooling (final cooling temperature) and storage temperature was not significant (data not presented).

Bean sprout freshness was better maintained (Fig. 2 A and D), and the hypocotyls remained whiter (Fig. 2 C and F) during storage at 1 °C than at 3 or 6 °C. Cotyledon color was better retained at 6 °C than at 1 °C (Fig. 2 B and E). Blackening of cotyledons increased as the storage temperature decreased. Mung bean plants are chilling sensitive (Raison and Chapman, 1976), and thus the darkening of the cotyledons at the lower storage temperatures may have been a symptom of chilling injury. However, Lipton et al. (1981) did not observe such darkening in the cotyledons of mung bean sprouts held at 0 °C for 7 d, but they noted that not all lots of sprouts behaved similarly.

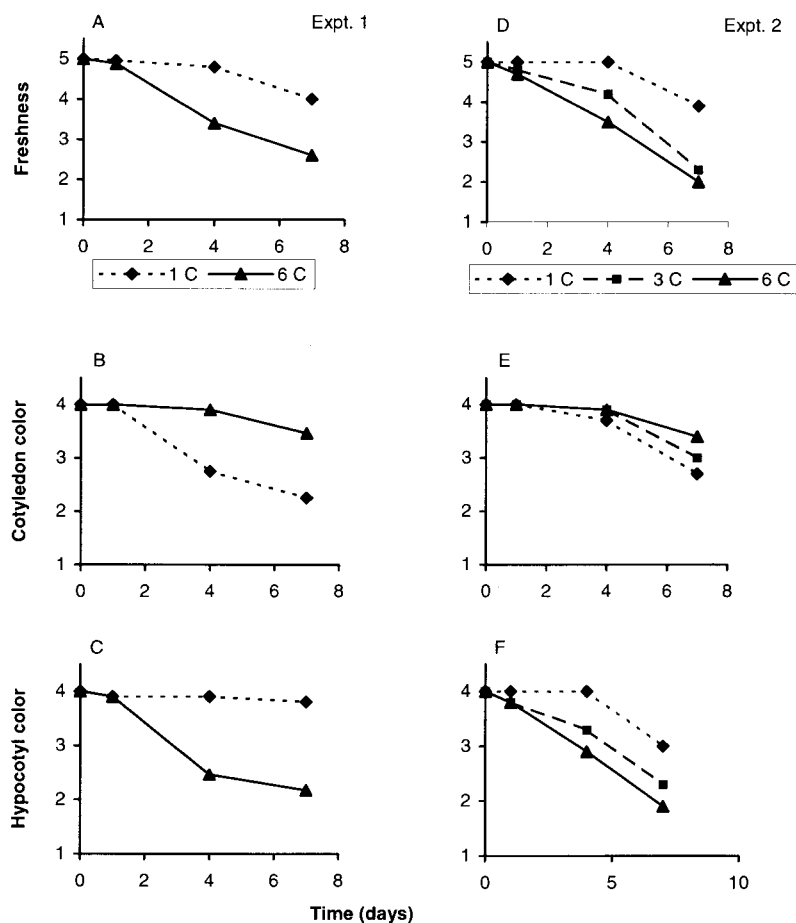


Fig. 2. Effects of storage temperature on freshness (1 = poor, 5 = excellent), cotyledon color (1 = poor, 4 = excellent) and hypocotyl color (1 = poor, 4 = excellent) of bean sprouts during storage for 7 d at 1 or 3 °C for Expt. 1 (A–C), and 1, 3, or 6 °C for Expt. 2 (D–F). Differences in all three parameters were significant at $P \leq 0.001$ on days 4 and 7 for both experiments (except for cotyledon color in which the difference was significant on day 4 in Expt. 2 at $P \leq 0.05$), while freshness and hypocotyl color were significant at $P \leq 0.05$ and 0.01, respectively, on day 1 in Expt. 2. Plotted data points are averaged over cooling temperatures within each storage temperature.

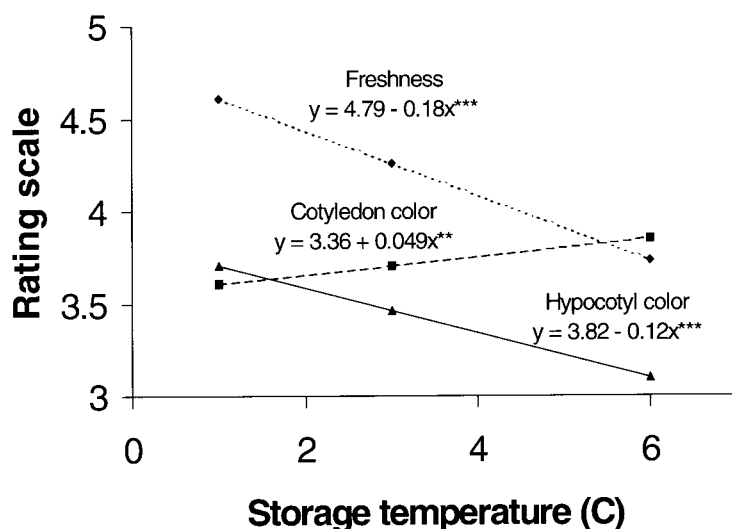


Fig. 3. Effects of storage temperature (°C) on bean sprout freshness, cotyledon color, and hypocotyl color. The r^2 values for freshness and hypocotyl color were significant at $P \leq 0.001$, while that for cotyledon color at $P \leq 0.01$. Rating scale values represent average scores on days 1, 4, and 7 for each storage temperature.

Data for bean sprout freshness, cotyledon color, and hypocotyl color as a function of storage temperature were analyzed using regression analyses (Fig. 3). Freshness and hypocotyl color retention decreased, while color retention increased in the cotyledons, as storage temperature increased. A 5 °C lower storage temperature maintained between one-half and one rating unit higher score for freshness and hypocotyl color over 7 d, while cotyledon color was reduced within a half rating unit.

In summary, vacuum-cooled bean sprouts lost more weight than did sprouts not pre-cooled, and the weight loss was greater when sprouts were cooled to lower temperatures. However, the total weight loss never exceeded 5% and no apparent signs of shrivel were observed. The use of vacuum cooling also resulted in greater product freshness after 4 d of storage, although the final precooling temperature had no effect. Storage temperature had greater influence on bean sprout quality than did cooling temperature, with greater freshness and whiter hypocotyl color at the lower temperatures. Cotyledons, however, darkened at the lower storage temperatures. Bean sprouts are highly perishable, and therefore a storage temperature of 1 °C is recommended even though the cotyledons may eventually become black.

These results suggest that vacuum cooling can lengthen the shelf-life of bean sprouts, although the final precooling temperature had little effect. Any subsequent room cooling in commercial operations would probably be slower than in this study; therefore, more research is needed to determine if final precooling temperature influences sprout quality under commercial conditions.

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