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Lowbush blueberry quality changes in response to prepacking delays and holding temperatures☆

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Abstract

The quality of stored wild lowbush blueberries (*Vaccinium angustifolium* Ait. and *V. myrtilloides* Michx.) was examined with different prepacking temperatures (5, 12, 19, and 26°C), delay times (3, 9, 21, and 45 h), and subsequent storage times (7, 14, and 21 d) at 0°C. All factors were considered both individually and in combination. Quality after storage was defined by changes in ten attributes: split berries, bloom, firmness, weight loss, moisture, soluble solids, titratable acids, pH, microbial counts, and marketable berries. We concluded that when there is minimal impact damage during packing and berries are stored at 0°C, cooling before packing is beneficial only when the delay time exceeds 21 h. Precooling creates severe condensation problems during the subsequent packing at ambient temperatures. Minimizing delays is the best option for maximizing fresh lowbush blueberry quality.

Keywords: *Vaccinium angustifolium*; Fresh quality factors

1. Introduction

Research to extend the shelf-life of lowbush blueberries is needed because growers have an interest in the fresh market. Previous studies established that minimal mechanical damage and storage at 0°C helps to maintain the quality of both highbush blueberries (*Vaccinium corymbosum* L.) (Cappellini et al., 1972; Ballinger et al., 1973, 1978) and lowbush blueberries (*V. angustifolium*) (Kender et al., 1966; Sanford et al., 1991). However, given these recommended conditions for handling, packing, storage, and distribution, the added benefits of lowering temperatures and

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minimizing prepacking delays immediately after harvest are less clear, particularly in the case of lowbush blueberries.

In comparison with berries that were not precooled, Ceponis and Cappellini (1979) demonstrated 39% less decay in highbush blueberries when they were precooled to 1.5°C and stored for 4 days at 1.5°C plus 3 days at 21°C. However, this advantage diminished to 18% less decay when the storage time at 1.5°C was increased to 10 days. Furthermore, the long delays of 48 h for the control berries to reach cold-storage temperatures, as reported by Ceponis and Cappellini (1979), may have inadvertently exaggerated the differences between the percent decay values for the control and test samples (Jackson and Sanford, 1989). Similarly, Hudson and Tietjen (1981) reported dramatic reductions in decay (60–80%) for berries that were precooled to 2°C and then held for 3 days at 10°C plus 24 h at 21°C. Again, however, the authors may have overestimated the benefit by not emphasizing the low total amount of decay (6.6–9.2%) in the stored control berries. This value is considerably less than the 20.9–66.0% decay in control berries reported by Ceponis and Cappellini (1979). Seen in this light, the 80% reduction in decay (from 6.6 to 1.2%) reported by Hudson and Tietjen (1981) may be of little practical significance (Jackson and Sanford, 1989). Thus, despite considerable effort in designing precooling systems for blueberries (Ferrell, 1984; Rohrbach et al., 1984), there is little evidence suggesting cooling before packing is consistently beneficial.

This study examines the effects of various postharvest holding temperatures and times on the quality of blueberries subsequently stored at 0°C. Since lowbush blueberries show little decay (defined as the presence of visible mould) during storage (Sanford et al., 1991), a broad spectrum of attributes was used to assess quality changes. This study also incorporated previous recommendations from other investigations (Sanford et al., 1989, 1991). Berries from diverse cultural locations were used, packing damage was minimized, washing was avoided, and storage conditions were maintained at 0°C.

2. Materials and methods

2.1. Pre-storage treatment

A 64-kg lot of wild lowbush blueberries was obtained from each of seven regional fresh lowbush blueberry packers, representing diverse cultural locations throughout Nova Scotia. Depending upon local practices, the berries were either hand-raked or machine-harvested and contained the usual amounts of foreign material associated with these harvesting methods. The berries were transported to Atlantic Food and Horticulture Centre at ambient temperature (19–26°C) within 2 h of picking.

Immediately upon arrival, each lot of berries was divided into four sub-samples. These were spread on shallow white foam trays two to three berries deep, and placed in either a 5, 12, 19 or 26°C temperature-controlled room at ambient relative humidity (70–80%). Room temperature was carefully monitored and periodic temperature checks were conducted using thermocouples inserted into random berries, ensuring that equilibration to the room environment was achieved in 2–3 h. After this time, the berries were returned to lugs and held in their respective rooms until required for packing. Care was taken to minimize handling damage during these transfer operations. Standard 500-ml moulded-pulp boxes were acclimatized to the storage conditions and the weight of each empty box was recorded.

After 3, 9, 21 and 45 h of storage (postharvest delay) at the respective temperatures, approximately 4 kg of berries were removed from the holding chambers and passed over a winnowing/inclined belt machine to remove the bulk of the leaves, berry clusters, squashed berries, and other unwanted material. The cleaned berries were dropped onto a moving, smooth, plastic-coated conveyor belt from a height of 53 cm, to simulate a minimum level of cumulative impact damage (Ballinger et al., 1973) and bruising that might reasonably be encountered in most commercial operations, and visually inspected to remove remaining foreign berries and debris. At the end of the conveyor belt, the berries from each time/temperature combination were collected into nine

standard 500-ml moulded-pulp boxes (≈ 300 g each) and over-wrapped with commercial microporous cellulose film (breather wrap). Each box of berries was weighed, and then all units were rapidly cooled by placing them in the direct path of the cold-air blast from the evaporator coils and fan in a 0°C room (ambient relative humidity measured by sling psychrometry ≈ 70–80%). The boxes were shelved in the same facility. These packing and storage conditions ensured minimal damage and optimum quality retention of the fresh product (Sanford et al., 1991).

2.1.1. Zero-time quality

Immediately upon arrival at the laboratory, a sample was collected from each blueberry lot. This sample was hand-cleaned to remove leaves, unripe and foreign berries, and other unwanted material. The remaining blueberries were then analysed as described below for the rest of the berries.

2.2. Post-storage analyses

At 7, 14 and 21 days after harvest, the following quality attributes of the berries were measured.

2.2.1. Weight loss

The three individual sample boxes of berries from each packing delay time/temperature combination were re-weighed, and the weight of the empty box was subtracted to calculate the weight loss (% w/w) of the fruit.

2.2.2. Defective berries

A 50-g sample (approximately 150–190 berries) was removed from one box taken at random from each packing delay time/temperature combination. Each berry was examined and classified as either split, decayed, or marketable (unblemished). These attributes were defined as follows: (1) split—any berry with a visible fracture in its outer skin; (2) decayed—any berry with visible mould growth; (3) marketable (unblemished)—neither of the above and without any additional visible defects such as outer skin wrinkling. The fruit from each class was weighed and calculated as a percentage of the total.

2.2.3. Microbial content

For each experimental treatment, a 25-g sample of blueberries was aseptically withdrawn from an unsampled box, representing approximately all levels of the contents. The sample was blended for 2 min in 225 g of 0.1% (w/v) sterile peptone water in a Colworth 400 Stomacher (Seward Laboratory, London, UK) to prepare a 10^{-1} dilution. A 10^{-4} dilution was also prepared and both dilutions were individually surfaced-plated on duplicate plates of appropriate agar media using a Spiral Plater (Spiral Systems, Bethesda, MD). General microbial counts were estimated on TSY agar (tryptic soy broth (Difco), 30 g; yeast extract, 5 g; agar, 20 g l^{-1}) and incubated aerobically at 30°C for 48 h. Lactic acid bacteria (LAB) was estimated on lactobacillus MRS agar (Difco), adjusted to pH 5.6, and incubated anaerobically at 30°C for 48 h. Yeast/mould was determined on oxytetracycline gentamycin yeast extract (OGY) agar (ICMSF, 1978) and incubated aerobically at 25°C for 5 days. The microbial counts reported for each sample are the highest count obtained from any one of the general or selective agar media used. Normally, this was the TSY agar count.

2.2.4. Bloom (epicuticular wax)

The contents of a full box of berries was carefully poured onto a standard-sized white plastic tray. Bloom was rated on a 0–5 scale (0 = no bloom, 5 = high bloom) against photographic standards by five trained assessors.

2.2.5. Fruit firmness

Fruit firmness was measured using an Accuforce II Digital Force Gauge, Model AF-100 (Ametek, Hunter Spring Division, Hatfield, PA) fitted with a modified compression head. A 30-g sample of berries was placed in a 36.4-mm diameter plastic cylinder and the berries compressed to a depth of 30 mm using a solid plastic piston (Sanford et al., 1991). The maximum force detected during compression was reported.

For each treatment combination, the leftover berries from the above analyses were combined and randomly divided for the following tests.

2.2.6. Soluble solids and titratable acids

Approximately 200 g of berries was squeezed through cheesecloth and the juice analysed for percent soluble solids using an Abbe Mark II refractometer (Reichart Scientific Instruments, Buffalo, NY), and for acidity by titrating a 50-ml sample against 0.5 N NaOH to pH 8.1 using a Mettler DL40RC automatic titrator (Mettler Instruments AG, Zurich, Switzerland). Titratable acids were expressed as g l^{-1} citric acid.

2.2.7. Moisture content

Fruit moisture was determined on a dry weight basis. A 10 ± 2-g sample of berries was dried to a constant weight at 60°C in a vacuum oven and the % moisture (w/w) calculated from the weight differential.

2.3. Statistical design and analysis

A split-plot design was used, where the seven individual lots (locations) of berries formed the replicates, the prepacking delay time and temperature combinations (4×4) formed the main blocks and the evaluation (storage duration) times (3) became the split-plot treatment. Handling and storage effects before packing were estimated through polynomial regression within an analysis of variance for each attribute. To stabilize variance, the angular transformation was performed on the percentage of split, decayed, and marketable berries and the resulting mean values back-transformed for presentation. All data were analysed statistically using Genstat 5 procedures (Genstat 5 Committee, 1993).

3. Results

The effects of prepacking temperatures (5, 12, 19 and 26°C), delay times (3, 9, 21 and 45 h), and subsequent storage times at 0°C (7, 14 and 21 days) were determined on ten quality attributes of lowbush blueberries (Tables 1 and 2). The percentage of marketable berries, the percentage of split berries, and fruit firmness responded to the interaction between temperature and delay time (Table 1). For most attributes, however, there was no interaction. Consequently, the effects of individual experimental treatments on the quality attributes added to the effects of the others over the entire range of experimental values. The polynomial regression analysis reports the linear or quadratic nature of each quantitative factor. Only the individual factor means are given in the tables; the significant interactions are given in Figs. 1–3. The storage means, for example, are averaged over a range of prepacking temperatures and delays. Thus the difference between the zero time and 7-day storage mean is much larger than that anticipated under ideal prepacking conditions.

Quality analysis of the unpacked, hand-cleaned blueberries shortly after harvest (zero-time values) showed that, on average, $> 85\%$ were marketable (Table 1). Most of the remaining berries were split due to over-ripeness, prevailing preharvest weather condition, or harvesting (raking) damage. Foreign berries, leaves, stems, and other material accounted for 0.5%. The microbial load on these harvest-fresh berries was low, comprised mainly of yeasts and gram negative bacilli. Mould contamination was low (< 100 cfu g^{-1}) and, under the conditions of minimal packing damage and storage at 0°C, translated into an unmeasurable amount of visible decay (mouldiness) in the stored product; hence decay was unimportant in this study and is not reported.

Prepacking temperature had a slight effect on the weight loss and pH of stored blueberries (Tables 1 and 2). Decreasing the temperature of the berries from 26 to 5°C within a short period after harvest (4–5 h) resulted in a weight loss of only 0.21% after storage for up to 21 days at 0°C, while the change in pH was similarly modest ($+0.06$ U). No changes were noted in bloom, soluble solids, titratable acids, or moisture content of the berries.

Prepacking delays also had little effect on weight loss in the stored berries (Table 1). An increase in delay time from 3 to 21 h resulted in no significant change, irrespective of the prepacking temperature, while a 45-h delay caused only a slight increase (about 0.2%). There was no effect of prepacking delays on bloom, soluble solids, titratable acids, pH, or percent moisture.

Table 1
Means of prepacking temperature, delay time, and storage duration at 0°C on the weight loss, marketable and split berries, microbial growth, firmness, and bloom in lowbush blueberries

Experimental factor	Weight loss (%)	Marketable berries (%)	Split berries (%)	Microbial counts (log_{10} g^{-1})	Firmness (N)	Bloom (0–5)[a]
Zero time values	–	85.5	14	4.57	46.4	2.7
Values after packing and storage						
Location						
Minimum	2.06	86.8	10.1	4.9	24.4	2.5
Maximum	2.7	89.9	13.1	5.99	32.1	2.9
Prepacking temperature (°C)						
5	2.26	89.4	10.6	5.21	29	2.7
12	2.39	88.5	11.4	5.29	28.6	2.7
19	2.38	87.7	12.2	5.39	26.1	2.7
26	2.47	87.8	12.1	5.4	26.3	2.6
SEM ($n = 84$, df = 90)	0.048	0.57	0.57	0.033	0.56	0.05
Significant effects[c]	L*	T × D[b]	T × D[b]	L***	T × D[b]	NS
Prepacking delay time (h)						
3	2.34	89	10.9	5.1	29.8	2.7
9	2.37	90.1	9.8	5.27	28.6	2.6
21	2.27	88.7	11.2	5.41	27.6	2.7
45	2.53	85.3	14.6	5.51	24	2.6
SEM ($n = 84$, df = 90)	0.048	0.57	0.57	0.033	0.56	0.5
Significant effects[c]	L*,Q**	T × D[b]	T × D[b]	L,Q***	T × D[b]	NS
Storage time (days)						
7	1.4	91.3	8.6	4.98	33.9	2.7
14	2.32	89.4	10.5	5.4	28.3	2.6
21	3.41	83.8	16.1	5.58	20.3	2.7
SEM ($n = 112$, df = 192)	0.033	0.5	0.5	0.024	0.31	0.03
Significant effects[c]	L***	L***	L***	L,Q***	L,Q***	NS

[a] Bloom rating scale 0–5, where 0 = no bloom, 5 = intact bloom.
[b] Prepacking temperature × Delay time interaction for marketable berries (column 3), split berries (column 4) and firmness (column 6).
[c] NS, not significant ($P > 0.05$); L, linear component; Q, quadratic component.

Table 2
Means of prepacking temperature, delay time, and storage duration at 0°C on the soluble solids, titratable acids, pH, and moisture of lowbush blueberries

Experimental factor	Soluble solids (%)	Titratable acids (g l^{-1})	pH	Moisture (%)
Zero time values	13.8	4.85	3.35	82.3
Values after packing and storage				
Location				
Minimum	11.7	4.30	3.22	81.8
Maximum	15	5.08	3.35	85.1
Prepacking temperature (°C)				
5	13.8	4.58	3.32	82.6
12	13.8	4.76	3.29	82.9
19	13.8	4.60	3.27	82.8
26	13.8	4.77	3.26	82.6
SEM ($n=84$, df = 90)	0.1	0.084	0.01	0.14
Significant effects[a]	NS	NS	L***	NS
Prepacking delay time (h)				
3	13.8	4.69	3.28	82.8
9	13.8	4.69	3.29	82.5
21	13.8	4.66	3.29	82.7
45	13.8	4.66	3.29	82.8
SEM ($n=84$, df = 90)	0.1	0.084	0.01	0.14
Significant effects[a]	NS	NS	NS	NS
Storage time (days)				
7	13.8	4.55	3.29	82.5
14	13.8	4.64	3.29	82.6
21	13.8	4.84	3.28	82.9
SEM ($n=112$, df = 192)	0.03	0.014	0.009	0.11
Significant effects[a]	NS	L*,Q***	NS	L*

[a] NS, not significant ($P>0.05$); L, linear component; Q, quadratic component.

In contrast, there was a pronounced effect of prepacking temperature on microbial counts. Regardless of delays, or the subsequent storage duration of the packed product at 0°C, a reduction in the prepacking temperature from 26 to 5°C resulted in a drop of final microbial counts from $\log_{10}$ 5.40 to $\log_{10}$ 5.21 cfu g^{-1}. This represents a 35% lower population of bacteria and yeasts by the end of storage. Significant increases in microbial counts were also associated with prepacking delays; increasing delay times resulted in higher microbial counts after storage (Table 1). The mean values associated with delay times of 9, 21, and 45 h represented increases of 48, 104, and 157%, respectively, above the counts for the 3-h delay. The dominant microbial types in all cases were yeasts and gram negative bacilli sharing characteristics typical of the family Pseudomonadaceae.

Storage time affected almost all of the quality attributes tested. Weight loss after 21 days was statistically significant but minimal (Table 1), a result of the breather wrap cover on the retail packs. However, 21 days at 0°C resulted in an average loss of 7.5% in marketable berries compared to the product after storage (Table 1). This loss was caused by an increase in split berries. The 13.6-N reduction in firmness (Table 1), the 0.29-g l^{-1} increase in titratable acids (Table 2), and the almost 300% increase in microbial counts (Table 1) were also important quality changes. However, the slight increase in the moisture content of the

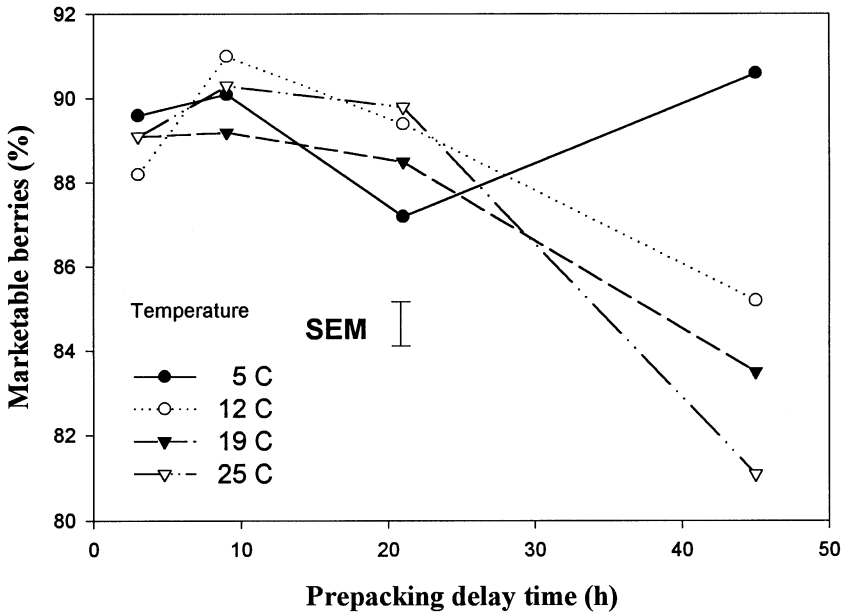

Fig. 1. Interactions between the effects of prepacking temperature and delay time on the mean percent marketable lowbush blueberries stored at 0°C ($P < 0.01$).

berries (0.44%) over the 21 days of storage (Table 2) was significant but of less importance. Storage duration did not affect bloom, soluble solids or pH.

For the quality attributes, percent marketable berries, percent split berries, and fruit firmness (Table 1), the effect of prepacking temperature changes depended on the effects of the various delay times. Prepacking temperature had no effect on marketability when delays did not exceed 21 h (Fig. 1). However, when delays reached 45 h, there was a trend toward a 9% loss of marketable product relative to storage at 5°C, mainly due to an increase in split berries as delays lengthened and holding temperatures were higher (Fig. 2). Similarly, berry firmness remained unchanged by prepacking temperatures up to a delay of 21 h. However, delays beyond 21 h resulted in a marked loss of firmness, particularly at prepacking temperatures above 5°C. In the extreme case of a 45-h delay at 26°C, the firmness loss equalled 10 N (a decrease of 30%) compared with berries subjected to lesser delays (Fig. 3).

Prepacking at 5°C to minimize the effects of long packing delays caused severe and impractical packing problems. Transfer of the cold blueberries into the ambient-temperature packing area resulted in condensation on the berries. The wet berries tended to stick to the tilt belt on the winnower and to the pick-over belt, resulting in losses estimated at 20–30%.

4. Discussion

Previous work on fresh lowbush blueberries identified impact damage and washing during primary packing as major causes of quality loss. Storage at 0°C was shown to be of great benefit in maintaining quality (Sanford et al., 1989, 1991). This was confirmed in this study. Even after 21 days at 0°C, the average visual quality of the retail packs was considered high, despite different sources and harvesting methods.

Unfortunately, there was a noticeable decline in the firmness of the berries. Average losses of firmness of 27 and 56% from that of the initial 'zero-time' berries occurred with 7 and 21 days storage, respectively. This softening, which could be important to the consumer, may have resulted

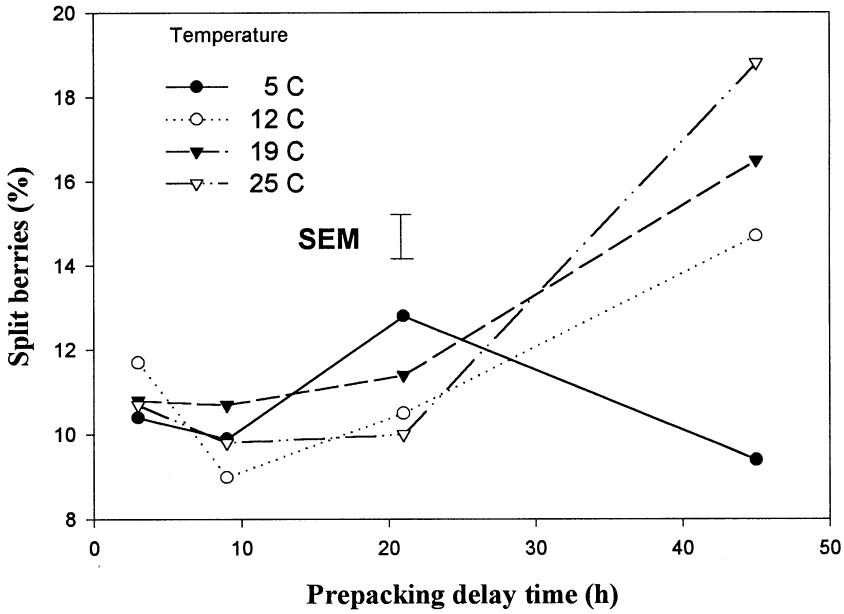

Fig. 2. Interactions between the effects of prepacking temperature and delay time on the mean percent of split lowbush blueberries stored at 0°C ($P < 0.01$)

from the unavoidable bruising during our experimental packing. Since a linear relationship exists between softening and drop height (Sanford et al., 1991), it is clear that some reduction in berry firmness was a result of our handling procedures. This problem may be compounded by subsequent compression of the berries in the box during storage. The weight of the berries in the upper layers of the package may gradually damage and soften the lower berries. Finally, normal postharvest physiological changes will continue within the blueberry tissues even at the low storage temperature. Early work by Woodruff et al. (1960) and later studies by Proctor and Peng (1989) suggest that blueberries undergo chemical and physical modifications to cell wall structure and composition during ripening and storage. While lower storage temperatures delay these changes, nonfreezing temperatures by themselves are not able to arrest cell wall breakdown and subsequent softening.

The benefits of cooling and minimizing delays before packing, when combined with the quality-retaining advantages of minimum packing damage and 0°C storage, were extremely limited. Significant changes in marketability, firmness, and splitting occurred only when prepacking delays at ambient temperatures were extreme (45 h). In these circumstances, cooling to 5°C might be considered. However, subsequent transfer of cold blueberries into a warm plant will result in condensation forming on the berries, causing severe packing problems. Although these problems could be avoided by more costly packing in a cold environment, it is perhaps far more desirable and practical to control delays to within 24 h of harvest and bypass precooling. Prepacking cooling has been shown to exaggerate the effects of impact damage, in particular, increasing the percentage of splits in the stored product (Sanford et al., 1989).

Precooling berries from ambient summer field temperatures (19–26°C) to 5°C was efficient in slowing microbial growth before packing, resulting in $\approx 35\%$ fewer microorganisms after storage at 0°C. Since microbial counts increased linearly during storage, and no opportunity for differential contamination existed during the experimental packing, the lower average counts for the 5°C berries must be related to lower average numbers

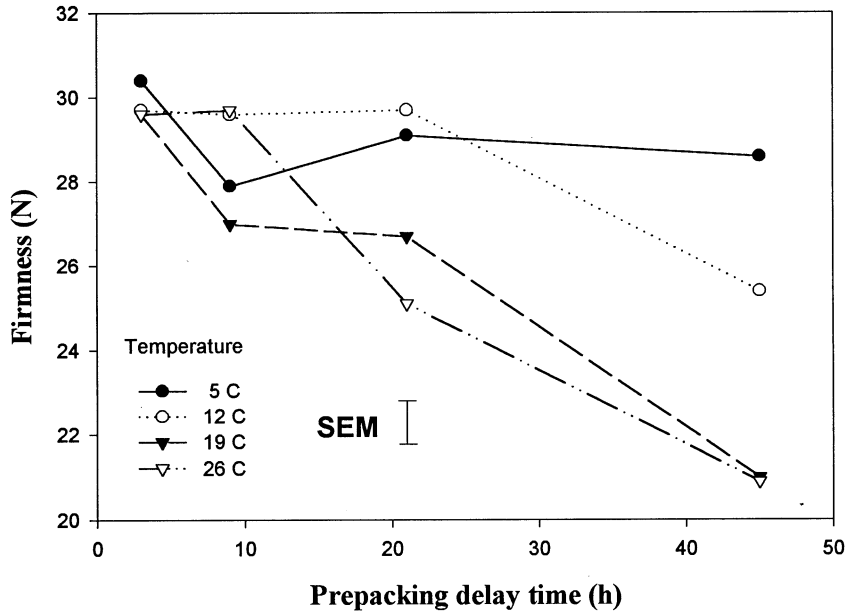

Fig. 3. Interactions between the effects of prepacking temperature and delay time on the mean firmness (N) of lowbush blueberries stored at 0°C ($P < 0.01$).

immediately before packing. However, microbial growth was not prevented. Increased prepacking delays resulted in gradually higher counts after storage at 0°C. Again, such results strongly suggest that warm temperatures and long delays should be avoided to minimize quality deterioration due to microbial activity. Since visible mould was not a factor, either in this study or in our previous work on lowbush blueberries (Sanford et al., 1991), deterioration in sensory quality is far more subtle and non-visual, resulting from yeasts and pseudomonas-type bacteria. Abnormal odours and flavours normally become apparent in foods when populations exceed $\log_{10}$ 6 cfu g^{-1} (Jay, 1986). The need to minimize prepacking delays or to implement cooling will be greatest when the average count of microorganisms on the harvested berries is high, more likely with mechanical harvesting due to increased soil and litter uptake.

We conclude that if the recognized quality retention benefits of low impact damage and 0°C storage are to be fully realized, prepacking delays at 12–26°C should not exceed 24 h. Failure to limit delays significantly increases the growth of yeasts and bacteria, increasing splitting and decreasing firmness in stored, packaged berries. When impact damage is minimized, cooling to 5°C before packing is beneficial in reducing softening and splitting mainly when delays exceed 24 h. Cooling to 5°C before packing also reduces microbial activity, particularly in dirty, abused berries. However, the benefits of precooling must be weighed against the problems of cleaning and handling, and of designing a refrigerated packing environment to avoid condensation on the berries.

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References

Ballinger, W.E., Kushman, L.J., Hamann, D.D., 1973. Factors affecting the firmness of highbush blueberries. J. Am. Soc. Hort. Sci. 98, 583–587.

Ballinger, W.E., Maness, E.P., McClure, W.F., 1978. Relationship of stage of ripeness and holding temperature to decay development of blueberries. J. Am. Soc. Hort. Sci. 103, 130–134.

Cappellini, R.A., Stretch, A.W., Maiello, J.M., 1972. Fungi associated with blueberries held at various storage times and temperatures. Phytopathology 62, 68–69.

Ceponis, M.J., Cappellini, R.A., 1979. Control of postharvest decays of blueberry fruits by precooling, fungicide, and modified atmospheres. Plant Dis. Rep. 63, 1049–1053.

Ferrell, R., 1984. Cryogenic pre-cooling for quality blueberries: feasibility and application. Proceedings of the North American Blueberry Research Workers Conference, University of Florida, Gainesville, February, 1984, pp. 246–257.

Genstat 5 Committee, 1993. Genstat 5 Release 3 Reference Manual. Oxford University Press, New York.

Hudson, D.E., Tietjen, W. H., 1981. Effects of cooling rate on shelf-life and decay of highbush blueberries. HortScience 16, 656–657.

ICMSF, 1978. Microorganisms in Foods: Their Significance and Methods of Enumeration, 2nd edn. University of Toronto Press, Toronto, Ontario, p. 139 International Commission on Microbiological Specifications for Foods.

Jackson, E.D., Sanford, K.A., 1989. Quality maintenance in fresh lowbush blueberries. I. Current knowledge and selected literature. Technical Memorandum No. 8904. Food Processing Research Section, Atlantic Food and Horticulture Research Centre, Agriculture and Agri-Food Canada, Kentville, Nova Scotia, Canada.

Jay, J.M., 1986. Microbial spoilage indicators and metabolites. In: Pierson, M.D., Stern, N.J. (Eds.), Foodborne Microorganisms and Their Toxins: Developing Methodology. IFT Basic Symposium Series. Marcel Dekker, New York, p. 220.

Kender, W.J., Abdalla, D.A., Murphy, E., True, R., Ismail, A., 1966. Storage of late season lowbush blueberries. Maine Farm Res. 13, 11–13.

Proctor, A., Peng, L.C., 1989. Pectin transitions during blueberry fruit development and ripening. J. Food Sci. 54, 385–387.

Rohrbach, R.P., Ferrell, R., Beasley, E.O., Fowler, J.R., 1984. Precooling blueberries and Muscadine grapes with liquid carbon dioxide. Trans. Am. Soc. Agric. Eng. 17, 1950–1955.

Sanford, K.A., Jackson, E.D., Lawrence, R.A., Stark, R., 1989. Quality maintenance in fresh lowbush blueberries. II. Effect of damage, storage temperature, preprocess cooling and washing. Technical Memorandum No. 8905. Food Processing Research Section, Atlantic Food and Horticulture Research Centre, Agriculture and Agri-Food Canada, Kentville, Nova Scotia, Canada.

Sanford, K.A., Lidster, P.D., McRae, K.B., Jackson, E.D., Lawrence, R.A., Stark, R., Prange, R.K., 1991. Lowbush blueberry quality changes in response to mechanical damage and storage temperature. J. Am. Soc. Hort. Sci. 116, 47–51.

Woodruff, R.E., Dewey, D.H., Sell, H.M., 1960. Chemical changes of Jersey and Rubel blueberry fruit associated with ripening and deterioration. Am. Soc. Hort. Sci. 75, 387–401.