Research Article

Received: 21 October 2008 Revised: 4 January 2009 Accepted: 14 January 2009 Published online in Wiley Interscience: 9 March 2009

(www.interscience.wiley.com) DOI 10.1002/jsfa.3544

Mechanical behaviour and quality traits of highbush blueberry during postharvest storage

Valentina Chiabrando,[a*] Giovanna Giacalone[a] and Luca Rolle[b]

Abstract

BACKGROUND: Berry firmness is one of the most important characteristics for fresh market consumption. Blueberry firmness is also an important attribute because it is considered to be a measure of its freshness. Berries lose their firmness by loss of water and by changes in their structure.

RESULTS: The postharvest life of two highbush blueberry cultivars (Bluecrop and Coville) was investigated. Several parameters related to blueberry quality were evaluated during the postharvest storage period. To assess berry texture characteristics (firmness, hardness, cohesiveness, gumminess, chewiness, springiness, resilience), a rapid non-destructive penetrometer test by Durofel® and texture profile analysis (TPA) using a texture analyser were carried out. Low temperature inhibited the decrease of total soluble solids, total titratable acidity and increase of flesh pH value, thereby maintaining good taste quality. There was an increase in fruit firmness (Durofel index) and hardness and a decrease in chewiness and springiness during storage.

CONCLUSION: There was a significant correlation among the TPA parameters and Durofel index. The Durofel index could therefore be used as a suitable indicator of fruit quality and storability, and low-temperature storage is beneficial to maintain the taste quality of blueberry fruit after harvest.

Keywords: Bluecrop; Coville; texture profile analysis; Durofel index; shelf-life

INTRODUCTION

Blueberries have become increasingly popular because of their health-promoting (nutraceutical) properties. Consumers demand high-quality fruit, which depends on harvest method, cultivar characteristics, postharvest handling and storage temperature.

Minimal mechanical damage and storage at low temperature help in maintaining berry quality.[1,2] As has been suggested by Ceponis and Cappellini,[3] decay development during postharvest storage of blueberry fruit is mainly inhibited by low storage temperature. Conversely, increasing storage and handling temperature can increase loss of fruit quality through fruit deterioration and flesh softening.[4,5]

The postharvest life of fruit and vegetables has been traditionally defined in terms of flavour and texture. Flavour plays an important role in consumer satisfaction and influences further consumption of fruits and foods in general.[6] Firmness is dependent on the microstructure of the fruit, and during storage berry firmness may decrease, increase or remain unchanged. This variation may be attributed to cultivar differences and/or their interaction with postharvest storage conditions.[7]

Changes in flavour and texture during blueberry storage can have a profound effect on consumer acceptability.

Texture of fruits is affected by traits such as cellular organelles and biochemical constituents, water content or turgor, and cell wall composition,[8] and changes in texture occur due to changes in the chemistry of the primary cell wall components cellulose, pectins and hemicelluloses that occur during growth and development.

Firmness testing of fruits is mostly used for scientific purposes and provides information on the storability and resistance to injury of the product during storage and marketing.

Instrumental measurements of texture are preferred rather than sensory evaluation since instruments may reduce variation among measurements due to human factors and are in general more precise.[9] However, texture is not easy to define, in particular in small fruit like blueberry, because there is no common standardized method. For this reason many instruments and techniques have been studied extensively.[10–18] Most of these methods measure the force needed to puncture, penetrate or deform the fruit.

In this work two different equipments and techniques for blueberry fruit firmness testing are discussed. In this research it was also monitored how the textural and qualitative properties of blueberries change during the storage period. Physical

* Correspondence to: Valentina Chiabrando, Department of Arboriculture, Turin University, Via L da Vinci 44, 10095 Grugliasco (TO), Italy. E-mail: valentina.chiabrando@unito.it

a Department of Arboriculture, Turin University, 10095 Grugliasco, Italy

b Department of Exploitation and Protection of the Agricultural and Forestry Resources (DiVaPRA) – Food Technology Sector, Turin University, 10095 Grugliasco, Italy

characteristics and chemical composition measured before and after cool storage were used to evaluate blueberry storage life.

MATERIALS AND METHODS

Sampling

The trial was carried out during the summer of 2006 using the highbush blueberry cultivars Bluecrop (medium-maturing cultivar with medium-large blue fruit, firm, crack resistant, with good sub-acid flavour) and Coville (late-maturing cultivar with large fruit size and average storage life).

Berries were hand-picked at full maturity from commercial plantations situated in Cuneo Province (Piedmont region, north-west Italy). Only fully coloured fruits were used. Samples were harvested at three different picking dates at regular 4-day intervals, starting in the first week of July. Twelve samples of 250 g of blueberries were harvested at each picking date and placed directly into transparent plastic clamshell containers.

Storage conditions

After collection, samples were cold stored under regular storage conditions: normal atmosphere (0 °C, in a temperature-controlled cold room, with an average relative humidity of 3.5 g H_2O kg^{-1} air). The temperature of 0 °C has been recommended for maintaining postharvest storage quality of blueberry fruit.[1] A long cold storage period was investigated (5 weeks).

Texture analysis methods

Textural measurements were carried out at harvest and after 3, 4 and 5 weeks during postharvest storage. Berry samples for analysis were randomly selected and sample size was of 15 berries each testing, according with Doving *et al*.[19] Before the analysis, samples were cooled to room temperature (20 °C) for 3 h, because most fruits and vegetables showed decreasing firmness with increasing temperature.[11]

The textural measurements were carried out with: (a) a rapid non-destructive instrument – a penetrometer test using a Durofel® (CTIFL Copa Technologie, Saint Etienne du Grès, France) dynamometer with a bolt of 3 mm diameter (0.10 cm^2), on a scale of 1 (soft) to 60 (firm); (b) a laboratory instrument – texture profile analysis (TPA) using a Universal Testing Machines (UTM) TA-XT2i texture analyser (Stable Micro Systems, Godalming, UK) equipped with a 5 kg load cell and HDP/90 platform. The samples were deformed to 30% of the original height using a crosshead speed of 0.8 mm s^{-1} and a 35 mm diameter cylinder stainless flat probe. Each sample was subjected to a two-cycle compression with 10 s between cycles. All measurements were made on a 30-berry sample for each treatment. Data were collected using Texture Expert Version 1.17 software. From the resulting force–time curve, the following parameters were calculated:[20,21]

- Hardness (N): the peak force of the first compression cycle. Maximum force required to compress the sample.
- Cohesiveness (-): how well the product withstands a second deformation relative to how it behaved under the first deformation. It is measured as the area of work during the second compression divided by the area of work during the first compression.
- Gumminess (N): calculated as hardness × cohesiveness.
- Chewiness (mJ): calculated as gumminess × springiness.
- Springiness (mm): how well a product physically springs back after it has been deformed during the first compression. The spring-back is measured at the downstroke of the second compression. Springiness is measured by the distance of the detected height of the product on the second compression.
- Resilience (-): how well a product 'fights to regain its original position'. Resilience is measured on the withdrawal of the first penetration, before the waiting period is started. The calculation is the area during the withdrawal of the first compression, divided by the area of the first compression.

Physicochemical determinations

To evaluate the quality of the blueberry, the following quality parameters were measured: weight loss (% of initial weight), total soluble solids content (°Brix) (TSS), titratable acidity (meq L^{-1}) (TA) and pH. For chemical measurements of soluble solid content, TA and pH, 100 g samples were weighed and centrifuged (Rotofix 32, Hettich Zentrifugen, Tuttlingen, Germany) at 3000 × *g* for 10 min at 20 °C. TSS was measured by placing a few drops of the filtered juice on a digital refractometer (PR-32 α, Atago, Bellevue, WA, USA). TA and pH were measured by titrating 1 : 10 diluted juice with 0.1 mol L^{-1} NaOH using an automatic titrator (Compact 44-00, Crison, Barcelona, Spain). All measurements were made three times.

Statistical analysis

The textural and chemical data were subjected to one-way analysis of variance (ANOVA), the sources of variance being storage time and cultivar influence. The textural parameters were also subjected to the Pearson correlation coefficient procedure. Tukey's HSD (honestly significant difference) test was used to determine significant differences among treatment means. Mean values were considered significantly different at $P \leq 0.05$. Data were analysed using the program package STATISTICA version 7.1 (Statsoft Inc., Tulsa, OK, USA).

RESULTS AND DISCUSSION

Durofel test

The firmness of fresh berry fruit changed during 5 weeks of storage. The values of Durofel index (DI) by Durofel test are presented in Table 1. At harvest, the average fruit firmness for Bluecrop and Coville was 19.8 and 23.9 DI, respectively. This difference is due to the berry size: smaller blueberries tended to be slightly firmer than larger ones.[22,23] Coville firmness was significantly higher during postharvest storage period (Table 1). Berry firmness increased initially with the advancement of storage period and declined thereafter, in agreement with results reported by Allan-Wojtas *et al*.[24]

At the end of the storage period (5 weeks), the increase in firmness was 40.3% in Bluecrop and 36.1% Coville, compared to firmness values at harvest. This increase in firmness may be attributed to moisture loss during storage, which corresponds to fruit drying and hardening characteristics.[25] Similar results were reported by Pelayo *et al*.[6] for strawberries and Basiouny and Chen[26] for rabbiteye fruits. Firming of Bluecrop blueberries during storage could also be related to the presence of stone cells in the fruit.[24] Moreover, a significant amount of fruit-to-fruit variability in firmness values was observed, according with Doving and Mage.[18]

Texture profile analysis

In Bluecrop, only the berries' hardness (the peak force of the first compression cycle, maximum force required to compress the

Table 1. Durofel index, hardness, cohesiviness, gumminess, springiness, chewiness and resilience of blueberry fruit stored in air (0 °C and 90–95% RH)

Texture parameters	Cultivar	Storage times (days at 0 °C) 0	21	28	35
Durofel index (DI)	Bluecrop	19.86b,β	28.24a,β	28.33a,β	27.79a,β
	Coville	23.86b,α	33.27a,α	32.44a,α	32.49a,α
Hardness (N)	Bluecrop	5.70a,α	6.38a,β	6.56a,β	6.82a,β
	Coville	5.67b,α	8.90a,α	8.98a,α	8.74a,α
Cohesiviness (-)	Bluecrop	0.41a,α	0.36b,α	0.38ab,α	0.39a,α
	Coville	0.41a,α	0.36b,α	0.36b,β	0.37b,α
Gumminess (N)	Bluecrop	2.33ab,α	2.31b,β	2.49ab,β	2.62a,β
	Coville	2.30b,α	3.21a,α	3.16a,α	3.16a,α
Springiness (mm)	Bluecrop	2.32a,α	1.71b,α	1.77b,α	1.76b,α
	Coville	1.96a,β	1.72b,α	1.68bc,α	1.59c,β
Chewiness (mJ)	Bluecrop	5.43a,α	4.08b,β	4.45b,β	4.68ab,α
	Coville	4.53b,β	5.47a,α	5.33ab,α	5.06ab,α
Resilience (-)	Bluecrop	0.16a,α	0.13b,α	0.14ab,α	0.15a,α
	Coville	0.17a,α	0.14b,α	0.14b,α	0.14b,α

Means values followed by the same letter are not significantly different at $P \leq 0.05$ level. Latin letters (a, b, c) in the same row are used to compare the storage time influence. Greek letters (α, β) in the same column are used to compare the cultivar influence.

Table 2. Total soluble solid, titratable acidity and pH of blueberry fruit stored in air (0 °C and 90–95% RH)

Quality parameters	Cultivar	Storage times (days at 0 °C) 0	21	28	35
Weight loss (%)	Bluecrop		4.05c,α	5.44b,α	6.68a,α
	Coville		3.97c,α	5.15b,α	6.20a,α
Total soluble solid (°Brix)	Bluecrop	10.49a,β	10.76a,α	10.68a,β	10.87a,α
	Coville	11.42ab,α	10.87b,α	11.50a,α	11.17ab,α
Titratable acidity (meq L^{-1})	Bluecrop	128.93a,α	104.76a,β	110.49a,β	112.03a,β
	Coville	156.82a,α	137.99a,α	143.38a,α	152.57a,α
pH	Bluecrop	2.82b,α	3.27a,α	3.37a,α	3.36a,α
	Coville	2.75b,α	3.08b,β	3.16b,β	3.22b,α

Mean values followed by the same letter are not significantly different at $P \leq 0.05$ level. Latin letters (a, b, c) in the same row are used to compare the storage time influence. Greek letters (α, β) in the same column are used to compare the cultivar influence.

berry) was not influenced significantly ($P \leq 0.05$) by postharvest storage. The tendency in fruit hardness was similar in both cultivars, reaching, at the end of the storage period, 6.82 N for Bluecrop and 8.74 N for Coville – significantly higher values. In this cultivar, the level of hardness showed a significant ($P \leq 0.05$) increase with the advancement of storage period (Table 1). Under high humidity, degradation of the middle lamella and disintegration of the primary cell wall were the main factors determining fruit softening.[27] These results indicated that low-temperature conditions may delay berry softening by inhibiting enzymatic activities and ethylene production.

Gumminess followed the same trend of hardness. These results could be explained in terms of a soft and more deformable (elastic) berry structure, probably due to water leak as reported for other products.[28] The changes in gumminess during storage were also dependent upon the shrivelling of berries. As suggested by Nunes *et al*.,[29] shrivelling of the berries increased during storage regardless of the storage temperature.

In Bluecrop samples the data indicate that the intensity of initial chewiness (how well a product physically springs back after it has been deformed during the first compression) and values decrease during the storage period, indicating a less elastic berry structure.[30] Overall mean values were significantly higher for Bluecrop, ranging from 2.32 mm at harvest to 1.76 mm at the end of the storage period, but Coville showed a higher statistical decrease during storage: springiness values ranged from 1.96 mm at harvest to 1.59 mm at the end of the storage period.

In order to determine whether DI values correlated with TPA parameters, we conducted a Pierson correlation analysis. Correlation values showed a high correlation with the overall TPA and Durofel values. Only springiness was not correlated with Durofel values. Hardness and gumminess were found to be positively correlated with DI.

Quality parameters

Values for average quality parameters of berries are presented in Table 2. In general, there were few differences ($P \geq 0.05$) during the storage period in the physicochemical parameters evaluated.

In Bluecrop, TSS content was quite stable during storage and ranged from 10.49 to 10.76° Brix. This observation is not surprising in view of the fact that blueberry fruit does not have starch to support soluble sugar synthesis after harvest, and little increase may be a consequence of cell wall degradation.[31] However, changes in soluble solid content were recorded in Coville, with significantly higher values in the last weeks of storage, in particular after 28 days of storage. Postharvest TA values varied among cultivars, while within each cultivar there were no significant ($P \geq 0.05$) changes during the postharvest storage period, according with Smittle and Miller.[32] TA ranged from 104.7 to 128.9 meq L^{-1} in Bluecrop and from 137.9 to 156.8 meq L^{-1} in Coville. In this cultivar all values were significantly higher, which is recommended for the longest storage life.[33]

Significant changes in pH were observed during storage. Changes in pH were similar in both cultivars. Initial pH values were significantly lower (less than 3.0) and then increased with the advancement of storage period, as presented in Table 3. Postharvest pH values were all less than the 3.5, usually related to good storage quality.[1]

CONCLUSIONS

DI and TPA could be used as suitable indicators of berry quality and storability, but the choice of method will depend on the objectives of the measurement. In many cases, two methods should be combined to obtain reliable results, which several authors have done with strawberries.[34,35] According with Khanizadeh *et al*.,[17] the Durofel method appears to show considerable

J Sci Food Agric 2009; **89**: 989–992

Table 3. Correlation matrix beetween texture parameters derived from Texture Profile Analysis (TPA) and Durofel Index of blueberry fruits stored in air (0 °C and 90-95%R.H.). The correlation coefficients were calculated using Pearson's regression model

	Hardness	Cohesiviness	Gumminess	Chewiness	Springiness	Resilience
Durofel Index	0.34	−0.26	0.29	−0.35	0.08	−0.30
significance	*	*	*	*	n.s.	*

* indicate significant correlation at P ≤ 0.05 level.
n.s. indicate no significant correlation at P ≤ 0.05 level.

promise for the non-destructive evaluation of blueberry firmness. The Durofel technique does not require a large investment in money and it is certainly easy to use. A universal testing machine is needed, however, when accurate and detailed measurements are required.[18] Moreover, Doving *et al*.[19] suggested that the texture analyser had greater operator independence compared to other methods.

During storage, firmness for both cultivars was not considered a critical quality factor since it remained quite constant during storage and did not fall during the postharvest storage period. This trend, which may occur during cold storage, is advantageous to producers who may wish to delay or extend marketing.[3] Also, the quality parameters evaluated were quite stable during storage.

REFERENCES

1 Mitcham EJ, Crisosto CH and Kader AA, Bushberries: blackberry, blueberry, cranberry, raspberry, in *Fresh Produce Facts* (1999) [Online]. Available: http://postharvest.ucdavis.edu/produce/producefacts/fruit/berry.shtml.
2 Sanford K, Lidster PD, McRae KB, Jackson ED, Lawrence RA, Stark R, *et al*, Lowbush blueberry quality changes in response to mechanical damage and storage temperature. *J Am Soc Hortic Sci* **116**:47–51 (1991).
3 Ceponis MJ and Cappellini RA, Reducing decay in fresh blueberries with controlled atmospheres. *HortScience* **20**:228–229 (1985).
4 Miller WR, McDonald RE, Melvin CF and Munroe KA, Effect of package type and storage time–temperature on weight loss, firmness, and spoilage of rabbiteye blueberries. *HortSci* **19**:638–640 (1984).
5 NeSmith DS, Prussia S and Tetteh M, Firmness losses of rabbiteye blueberries (*Vaccinium ashei* Reade) during harvesting and handling. *Acta Hortic* **574**:287–293 (2002).
6 Pelayo C, Ebeler SE and Kader AA, Postharvest life and flavour quality of three strawberry cultivars kept at 5 °C in air+kPa CO_2. *Postharvest Biol Technol* **27**:171–183 (2003).
7 Forney CF, Kumudini UKGN and Jordan MA, Effect of postharvest storage conditions on firmness of 'Burlington' blueberry fruit, in *Proceedings of the 8th North American Blueberry Research and Extension Workers Conference*, pp. 227–232 (1998).
8 Jackman RL and Stanley DW, Perspectives in the textural evaluation on plant foods. *Food Sci Technol* **6**:187–194 (1995).
9 Abbot JA, Lu R, Upchurch BL and Stroshine RL, Technologies for non-destructive quality evaluation of fruits and vegetables. *Hortic Rev* **20**:1–120 (1997).
10 Barrit BH and Torre LC, Fruit firmness measurements in red raspberry. *HortScience* **15**:38–39 (1980).
11 Bourne MC, Textural evaluation of horticultural crops. *HortScience* **15**:51–56 (1980).
12 Bernstein Z and Lustig I, A new method of firmness measurement of grape berries and other juicy fruits. *Vitis* **20**:15–21 (1981).
13 Mencarelli F, Massantini R, Lanzarotta L and Rotondi R, Accurate detection of firmness and color changes in the packing of table grapes with paper dividers. *J Hortic Sci* **69**:299–304 (1994).
14 Mouquet C, Intérêt de la mesure de la texture des fruits dans l'évaluation de leur qualité. *Fruits* **51**:307–315 (1996).
15 Duprat F, Grotte MG, Pietri E and Loonis D, The acoustic impulse response method for measuring the overall firmness of fruit. *J Agric Eng Res* **66**:251–259 (1997).
16 Barreiro P and Ruiz-Altisent M, Instrumentación de la calidad en frutas y hortalizas frescas. *Horticultura* **8**:14–20 (2000).
17 Khanizadeh S, DeEll J and Cousineau J, Comparison of three methods to evaluate fruit firmness in advanced strawberry selections. *Acta Hortic* **517**:463–465 (2000).
18 Doving A and Mage F, Methods of testing strawberry fruit firmness. *Acta Agric Scand B: Soil Plant Sci* **52**:43–51 (2002).
19 Doving A, Mage F and Vestrheim S, Methods for testing strawberry fruit firmness: a review. *Small Fruit Rev* **4**:11–34 (2005).
20 Letaief H, Rolle L and Gerbi V, Mechanical behavior of winegrapes under compression tests. *Am J Enol Vitic* **59**:323–329 (2008).
21 Bourne MC, Texture profile of ripening pears. *J Food Sci* **33**:223–226 (1968).
22 Smagula JM, Litten W, Chen Y and Dunham S, Variation of fruit set and fruit characteristics of wild lowbush blueberries (*Vaccinium angustifolium* Ait.) in a managed field. *Acta Hortic* **446**:109–115 (1996).
23 Khazaei J and Mann DD, Effects of temperature and loading characteristics on mechanical and stress–relaxation properties of sea buckthorn berries. Part 1. Compression tests. *Agricultural Engineering International: CIGR Journal of Scientific Research and Development* Manuscript FP 03 011 (2004).
24 Allan-Wojtas PM, Forney CF, Carbyn SE and Nicholas KUKG, Microstructural indicators of quality-related characteristics of blueberries: an integrated approach. *Lebensm Wiss Technol* **20**:23–32 (2001).
25 Mahajan PB and Goswami TK, Extended storage life of litchi fruit using controlled atmosphere and low temperature. *J Food Process Preserv* **28**:388–403 (2004).
26 Basiouny FM and Chen Y, Effects of harvest date, maturity and storage interval on postharvest quality of rabbiteye blueberry (*Vaccinium ashei* Reade). *Proc Fla State Hortic Soc* **101**:281–284 (1988).
27 Deng Y, Wu Y and Li Y, Effect of high O_2 levels on postharvest quality and shelf life of table grapes during long-term storage. *Eur Food Res Technol* **221**:392–397 (2005).
28 Kader AA, Postharvest handling, in *The Biology of Horticulture: An Introductory Textbook*, ed. by Preece JE and Read PE. Wiley, New York, pp. 353–377 (1993).
29 Nunes MC, Emond J and Brecht J, Quality curve for highbush blueberry as a function of the storage temperature. *Small Fruits Rev* **3**:423–438 (2004).
30 Walter WM, Truong VD and Espinel KR, Textural measurements and product quality of restructured sweet potato french fries. *Lebensm Wiss Technol* **35**:209–215 (2002).
31 Cordenunsi BR, Nascimento JRO and Lajolo FM, Physico-chemical changes related to quality of five strawberry fruit cultivars during cool-storage. *Food Chem* **83**:167–173 (2003).
32 Smittle DA and Miller WR, Rabbiteye blueberry storage life and fruit quality in controlled atmospheres and air storage. *J Am Soc Hortic Sci* **113**:723–728 (1988).
33 Galletta GJ, Ballinger WE, Monroe RJ and Kushman LJ, Relationships between fruit acidity and soluble solids level of highbush blueberry clones and fruit keeping quality. *J Am Soc Hortic Sci* **6**:758–762 (1971).
34 Testoni A, Lovatti L and Faedi W, Shelf life and fruit quality of strawberry varieties and selections after storage. *Acta Hortic* **265**:435–442 (1989).
35 Yu L, Reitmeier CA, Gleason ML, Olson DG and Gladon RJ, Quality of electronic beam irradiated strawberries. *J Food Sci* **60**:1084–1087 (1995).

