A Comparison of Two Firmness-testing Machines for Measuring Blueberry Firmness and Size

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Keywords. force deformation, fruit firmness, postharvest, *Vaccinium corymbosum*

Abstract. **Firmness is an important fruit quality trait in northern highbush blueberry (*Vaccinium corymbosum*). Many researchers, growers, and packers rely on machines for measuring firmness right after harvest and during postharvest cold storage of fresh fruit. In this study, we compared two machines that use compression firmness measurements to determine a force-deformation value. The first firmness-testing machine has been in use for the past 30 years by blueberry (*Vaccinium*) researchers and packers worldwide. The second has been on the market for the past 5 years. We compared fruit firmness and size measurements for several commercial cultivars and breeding accessions of northern highbush blueberry by both machines at harvest and 2 weeks postharvest. In general, we found there were slight differences in fruit firmness and size measurements between the two machines, but these measurements were generally consistent across the machines. Our study suggests that, in general, one machine can predict the measurements taken on the other machine.**

Firmness is an important fruit quality trait in northern highbush blueberry (*Vaccinium corymbosum*) and contributes to machine harvestability, postharvest quality, shelf life, and the consumer eating experience. Fruit firmness, particularly resistance to bruising, is important for machine harvesting in both processing and fresh blueberry (*Vaccinium*) markets. The suitability of a particular cultivar harvested for fresh market by machine relies on its firmness and resistance to bruising during harvest (Moggia et al. 2017). Postharvest storage and shelf life are improved in firmer berries, especially for those harvested mechanically (DeVetter et al. 2019; Sargent et al. 2021; Takeda et al. 2017). Fruit often loses its firmness during storage, although in some cultivars, fruit without damage at harvest can increase in firmness during storage (Yang et al. 2008). Because fruit firmness contributes to fruit texture, which influences consumer acceptance and eating experience (Blaker et al. 2014; Giongo et al. 2022), a goal of the blueberry industry is to deliver consistently firmer berries to grocery store shelves. Fruit firmness can be affected by several factors including genetics, harvesting method, fruit temperature at harvest, sorting and packing, and postharvest treatment of fruit, including field heat removal, storage duration, and temperature (Cappai et al. 2018; DeVetter et al. 2022; Ehlenfeldt 2005; NeSmith et al. 2000; Prussia et al. 2006; Sater et al. 2021).

There are different ways of measuring blueberry firmness, and many of those techniques do not necessarily measure the same aspects of the fruit. Some measure skin toughness, others internal texture, and others are a measure of compression. These measurements can be taken by various instruments or by human sensory perception. Although subjective human measurements, such as squeezing berries between the fingers, or eating fruit, can give a cursory measurement of firmness, accuracy is improved through objective mechanical testing. Most firmness tests are destructive and involve either compression or penetration of fruit. Studies have compared devices for measuring blueberry firmness (Moggia et al. 2022), concluding that hand-held devices produce the most variable firmness results.

In this study, we compared two machines that use compression to obtain a measure of firmness. The FirmTech II (Bioworks Inc., Wamego, KS, USA) has been used as a standard instrument for measuring firmness of blueberry through compression for ~ 30 years (Timm et al. 1996). This machine uses a load cell to compress berries and determines a force-deformation value as a measure of firmness. Fruit size is obtained simultaneously with the fruit firmness measurements for each fruit by using a standardized size reference. The FruitFirm 1000 (CVM Inc., Pleasanton, CA, USA) is a newer machine from 2017. It is quite similar in that it also uses a load cell to determine a force-deformation value as a measure of firmness, and measures fruit size at the same time. The FruitFirm 1000 has different software and electronics and can connect directly to Wi-Fi or ethernet or a USB thumb drive to report and save data. The FirmTech II unit is connected to a computer via a data cable that connects to an internal FirmTech data card. The software of FirmTech II includes a configuration file for users to set compression force for blueberry. The file management system allows firmness measurements to be saved in predetermined folders. The firmness data files generated from both the FruitFirm 1000 and FirmTech II are text files that need to be manually manipulated in a data processing software for statistical analysis. We have automated the text file ma-

Received for publication 18 Apr 2022. Accepted for publication 15 Nov 2022.

Published online 28 Dec 2022.

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https://doi.org/10.21273/HORTTECH05060-22

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
25.4	inch(es)	mm	0.0394
1.1161	oz/inch	$g \cdot mm^{-1}$	0.8960
(°F − 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32
(°F ÷ 1.8) + 255.37	°F	K	(K − 255.37) × 1.8

nipulation process by developing a macro program. The FirmTech II has provided researchers and the blueberry and sweet cherry (*Prunus avium*) industries with repeatable fruit firmness measurements since its development in the early 1990s. With this study, we wanted to examine whether the newer FruitFirm 1000 produced repeatable and comparable results to the FirmTech II, as researchers and packers are beginning to use this machine.

Methods

Fruit of two standard cultivars of northern highbush blueberry, Liberty and Legacy, as well as four advanced selections of northern highbush blueberry from the US Department of Agriculture (USDA), Agricultural Research Service and Oregon State University cooperative breeding program were collected during the peak ripeness harvest window for each accession at the North Willamette Research and Extension Center in Aurora, OR, USA (lat. 45°19′51.27″N, long. 122°44′55.89″W) in Jul 2021. For the purposes of this report, we use the names USDA 1, USDA 2, USDA 3, and USDA 4. At least 800 fruit of each accession were collected by hand picking into clamshells (≥ 50 fruit per clamshell). A total of 200 fruit (four clamshell replications of 50 fruit) were tested on each of the two machines, FirmTech II and the FruitFirm 1000, for size and firmness measurements within 48 h of harvest. The remaining fruit was stored in clamshells placed in cardboard boxes, the industry standard, at 1 °C for 2 weeks. After 2 weeks in storage, 200 fruit (four clamshell replications of 50 fruit each) were again tested for size and firmness on each of the two machines. To verify the accuracy of fruit size determined by both firmness machines, 'Legacy' fruit were purchased in local supermarkets in Feb 2021, and more than 200 berries were run with each machine for firmness and size measurements. The diameter of each berry was hand measured by using a digital caliper before running machine fruit firmness and size measurements. The same person was responsible for measuring fruit on each machine.

Statistical analysis. Data were analyzed using statistical software (SAS version 9.4; SAS Institute Inc., Cary, NC, USA). Fruit firmness and size were tested for normality using the PROC UNIVARIATE before carrying out an analysis of variance (ANOVA). PROC GLM was used to perform multivariate ANOVA for fruit firmness and size, and PROC REG was used for regression

Table 1. Effect of cold storage on fruit diameter of six different northern highbush blueberry (*Vaccinium corymbosum*) accessions measured by the FruitFirm 1000 (CVM Inc., Pleasanton, CA, USA) and FirmTech II (Bioworks Inc., Wamego, KS, USA) firmness-testing machines at harvest (week 0) and 2 weeks postharvest.

	Fruit diam (mm)[i]					
	USDA 2	USDA 3	USDA 4	USDA 1	'Legacy'	'Liberty'
FirmTech II	17.5 a[ii]	17.8 a	18.4 a	16.1 a	14.5 a	17.0 a
FruitFirm 1000	15.9 b	16.9 b	17.6 b	14.4 b	14.2 b	15.1 b
Week 0	16.6 a	17.3 a	17.9 a	15.4 a	14.3 a	16.3 a
Week 2	16.8 a	17.4 a	17.7 a	14.2 b	14.5 a	15.9 b

[i] 1 mm = 0.0394 inch.
[ii] Mean followed with the same lower-case letters within each column for the main effect are not statistically different at alpha < 0.05.

Table 2. Fruit diameter ranking of six northern highbush blueberry (*Vaccinium corymbosum*) accessions measured by the FirmTech II (Bioworks Inc., Wamego, KS, USA) and FruitFirm 1000 (CVM Inc., Pleasanton, CA, USA) firmness-testing machines before and after 2 weeks in cold storage.

Fruit diam at week 0 (mm)[i]		Fruit diam at week 2 (mm)	
FruitFirm 1000	FirmTech II	FruitFirm 1000	FirmTech II
USDA 4 (17.7) a[ii]	USDA 4 (18.5) a	USDA 4 (17.5) a	USDA 4 (19.2) a
USDA 3 (16.9) b	USDA 3 (17.8) b	USDA 3 (16.9) b	USDA 3 (17.8) b
USDA 2 (15.9) c	USDA 2 (17.3) c	USDA 2 (16.0) c	USDA 2 (17.6) b
'Liberty' (15.3) d	'Liberty' (17.2) c	'Liberty' (14.9) d	'Liberty' (16.8) c
USDA 1 (14.4) e	USDA 1 (16.3) d	USDA 1 (14.4) e	USDA 1 (15.9) d
'Legacy' (14.1) f	'Legacy' (14.5) e	'Legacy' (14.4) e	'Legacy' (14.5) e

[i] 1 mm = 0.0394 inch.
[ii] Mean ranking determined by Duncan's multiple range test. Same lower-case letters within each column are not statistically different at alpha < 0.05.

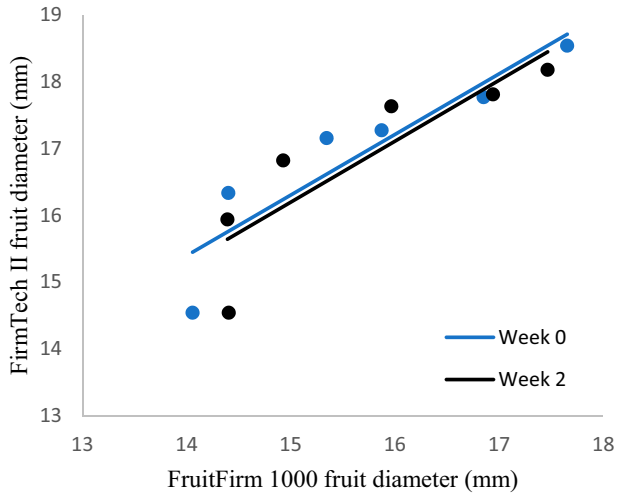

Fig. 1. Fruit diameter relationships between FirmTech II (Bioworks Inc., Wamego, KS, USA) and FruitFirm 1000 (CVM Inc., Pleasanton, CA, USA) firmness-testing machines for six northern highbush blueberry (*Vaccinium corymbosum*) accessions after 2 weeks of cold storage. The linear equations for harvest (week 0) and week 2 are y = 2.7 + 0.908x (R^2 = 0.837) and y = 2.5 + 0.913x (R^2 = 0.767), respectively. Combined weeks 0 and 2 data with small fruit (<12.7 mm diameter) removed; 1 mm = 0.0394 inch.

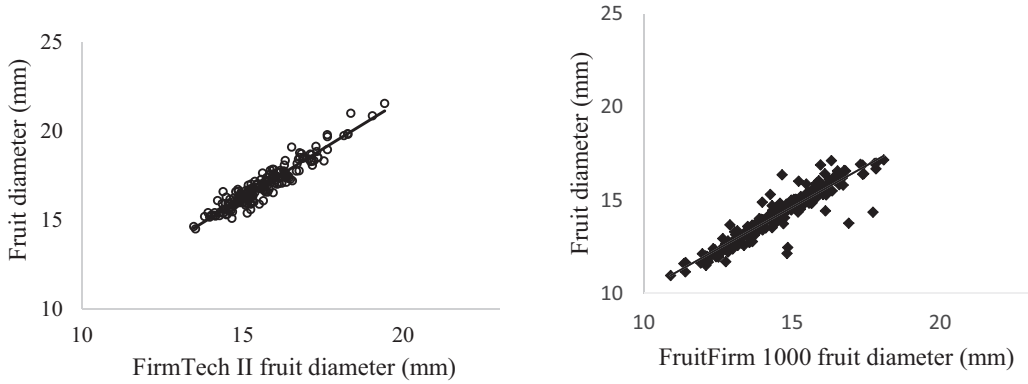

Fig. 2. Linear relationship of 'Legacy' northern highbush blueberry (*Vaccinium corymbosum*) fruit diameter measured by hand and by two firmness-testing machines: FirmTech II (Bioworks Inc., Wamego, KS, USA) and FruitFirm 1000 (CVM Inc., Pleasanton, CA, USA). For FirmTech II, the linear equation is y = 1.9 + 0.811x (R^2 = 0.903); for FruitFirm 1000, the linear equation is y = 1.2 + 0.893x (R^2 = 0.850); 1 mm = 0.0394 inch.

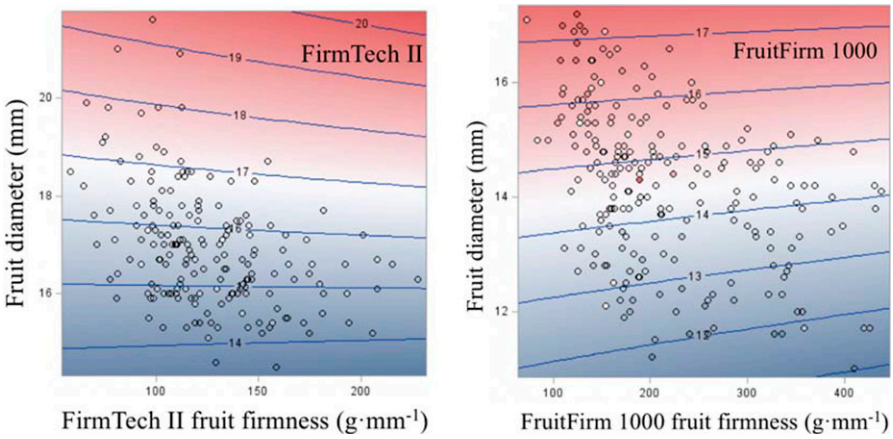

Fig. 3. Contour fit plot for 'Legacy' northern highbush blueberry (*Vaccinium corymbosum*) fruit diameter measured by hand and by FirmTech II (Bioworks Inc., Wamego, KS, USA) and FruitFirm 1000 (CVM Inc., Pleasanton, CA, USA) firmness-testing machines. Fruit firmness as a covariate for fruit diameter was not statistically significant for FirmTech II (P > 0.107) and FruitFirm 1000 (P > 0.153); 1 g·mm^{-1} = 0.8960 oz/inch, 1 mm = 0.0394 inch.

analysis between the two firmness machines. Analysis of covariance for fruit firmness and size was used to compare the slope of regression lines between storage weeks for two machines. Treatment means of fruit firmness and size were compared by Tukey's Studentized range test. In case of treatment interactions, LSMEANS were presented with Bonferroni adjustments. Because the FirmTech II automatically discards fruit smaller than 12.7 mm (0.5 inch) diameter, but the FruitFirm 1000 does not, we removed fruit smaller than 12.7 mm diameter that were measured on the FruitFirm 1000. This resulted in 4% of data being removed from the FruitFirm 1000 data sets. Removing fruit with less than 12.7 mm diameter in Fruitfirm 1000 data sets did not change the treatment main effects and interactions in ANOVA. Fruit diameter measured by hand was used for regression analysis against the fruit size determined by both firmness machines. Contour graph was used to depict the relationships among hand-measured fruit diameter, fruit size, and firmness determined by the two firmness machines.

Table 3. Effect of cold storage on fruit firmness of six northern highbush blueberry (*Vaccinium corymbosum*) accessions measured by the FruitFirm 1000 (CVM Inc., Pleasanton, CA, USA) and FirmTech II (Bioworks Inc., Wamego, KS, USA) firmness-testing machines at harvest (week 0) and 2 weeks postharvest [berries < 12.7-mm (0.5-inch) diameter removed from FruitFirm 1000 data set].

	Fruit firmness (g·mm^{-1})[i]	
	USDA 2	'Legacy'
FirmTech II	203.4 b[ii]	276.6 a
FruitFirm 1000	248.4 a	280.3 a
Week 0	228.7 a	255.7 b
Week 2	223.2 a	289.0 a

[i] 1 g·mm^{-1} = 0.8960 oz/inch.
[ii] Mean followed with the same lower-case letters within each column for the main effect are not statistically different at alpha < 0.05.

Results and discussion

Fruit size. We compared fruit size measurements between the two machines across weeks 0 and 2. The average fruit size measurement of weeks 0 and 2 for each accession on the FruitFirm 1000 machine was consistently smaller than the measurements on the FirmTech II [P < 0.05 (Table 1)]. Measurements were consistent for both machines, suggesting that both are reliable for consistently measuring fruit size. Only the accessions of USDA 1 and 'Liberty' had smaller size measurements at 2 weeks postharvest on both machines. This may be because for these accessions, many berries squished and split under the compression during the week 2 measurement and may have resulted in a slightly smaller size measurement (Table 1). When we compared the rankings of accessions for fruit size measured at week 0 and week 2, we did not see change in rankings

among USDA accessions across the two machines (Table 2). This suggests that the machines measured fruit size consistently, even though the size measurements by the FruitFirm 1000 were consistently smaller than the FirmTech II.

This consistency across machines is also confirmed through the regression analysis. When fruit size relationships were compared for the two machines in week 0 and week 2, we found that the slopes of the regression lines for both weeks were not statistically different [$P > 0.935$ (Fig. 1)].

The diameter of 'Legacy' fruit determined by hand measurement was 2% larger than the fruit size determined by the FruitFirm 1000 machine ($P < 0.001$), but 9% smaller than the fruit size obtained by FirmTech II machine ($P < 0.001$). This finding indicates the FruitFirm 1000 underestimated the true fruit size and FirmTech II overestimated it, which explained the consistently larger fruit size measurement by the FirmTech II over the FruitFirm 1000 machine. The linear relationships between fruit diameter and fruit size determined by both firmness machines are strong (Fig. 2), which can be used to adjust for true fruit size measurements. The linear relationship between fruit diameter and size are further demonstrated in Fig. 3 as horizontal contour lines for both firmness machines, which was unaffected by fruit firmness (no aggregated color formation for a given firmness value). Therefore, fruit firmness was unaffected by fruit size, meaning that smaller berries are not necessarily firmer than larger berries.

Fruit firmness. Although we might expect that fruit size is consistently measured across weeks and be consistent for both machines, we were most interested in how the two machines measured firmness. For two of the accessions in Table 3, the FirmTech II–measured USDA 2 fruit was slightly softer than the FruitFirm 1000, whereas the firmness of 'Legacy' was not significantly different between the two machines. We observed no interactions across the 2 weeks of cold storage for both accessions. Both machines found no significant change in firmness between week 0 and week 2 for USDA 2. Both machines found that 'Legacy' increased significantly in firmness in week 2 compared with week 0 (Table 3).

Table 4. Interactive effects of cold storage on fruit firmness of six northern highbush blueberry (*Vaccinium corymbosum*) accessions measured by the FruitFirm 1000 (CVM Inc., Pleasanton, CA, USA) and FirmTech II (Bioworks Inc., Wamego, KS, USA) firmness-testing machines at harvest (week 0) and 2 weeks postharvest.

	Fruit firmness ($g \cdot mm^{-1}$)[i]			
	USDA 3	USDA 4	USDA 1	'Liberty'
Week 0				
FirmTech II	232.8 c[ii]	214.6 c	173.2 b	181.4 ab
FruitFirm 1000	265.2 b	251.4 b	194.4 a	186.8 a
Week 2				
FirmTech II	255.0 b	214.1 c	160.5 c	153.4 c
FruitFirm 1000	317.2 a	298.9 a	200.0 a	172.1 b

[i] 1 $g \cdot mm^{-1}$ = 0.8960 oz/inch.
[ii] Interactive means followed with the same lower-case letters within each column are not statistically different at alpha < 0.05.

Table 5. Fruit firmness ranking of six northern highbush blueberry (*Vaccinium corymbosum*) accessions measured by the FirmTech II (Bioworks Inc., Wamego, KS, USA) and FruitFirm 1000 (CVM Inc., Pleasanton, CA, USA) firmness-testing machines at harvest (week 0) and after 2 weeks cold storage.

Fruit firmness at week 0 ($g \cdot mm^{-1}$)[i]		Fruit firmness at week 2 ($g \cdot mm^{-1}$)	
FirmTech II	FruitFirm 1000	FirmTech II	FruitFirm 1000
'Legacy' (257.2) a[ii]	USDA 3 (265.2) a	'Legacy' (291.9) a	USDA 3 (317.2) a
USDA 3 (232.8) b	'Legacy' (254.4) b	USDA 3 (255.0) b	USDA 4 (298.9) b
USDA 4 (214.6) c	USDA 4 (251.4) b	USDA 4 (214.2) c	'Legacy' (285.3) c
USDA 2 (206.7) c	USDA 2 (249.5) b	USDA 2 (200.2) d	USDA 2 (245.6) d
'Liberty' (181.4) d	USDA 1 (194.4) c	USDA 1 (160.4) e	USDA 1 (199.7) e
USDA 1 (173.2) d	'Liberty' (186.8) c	'Liberty' (153.4) e	'Liberty' (172.1) f

[i] 1 $g \cdot mm^{-1}$ = 0.8960 oz/inch.
[ii] Mean ranking determined by Duncan's multiple range test. Same lower-case letters within each column are not statistically different at alpha < 0.05.

For the other accessions, USDA 3, USDA 4, USDA 1, and 'Liberty', we did see interactive effects of cold storage on fruit firmness measured by the FruitFirm 1000 and FirmTech II (Table 4). USDA 3 and USDA 4 were the firmest accessions measured for both machines. Both 'Liberty' and

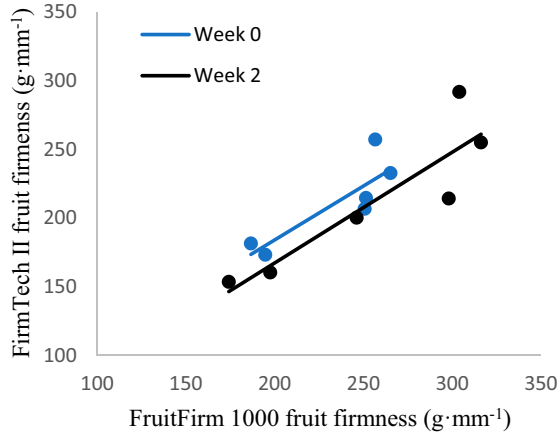

Fig. 4. Relationship of fruit firmness among six northern highbush blueberry (*Vaccinium corymbosum*) accessions measured on FirmTech II (Bioworks Inc., Wamego, KS, USA) and FruitFirm 1000 (CVM Inc., Pleasanton, CA, USA) firmness-testing machines after 2 weeks in cold storage. The slopes of two regression lines are not statistically different ($P > 0.981$). The linear equations for harvest (week 0) and week 2 are y = 27.0 + 0.787x (R^2 = 0.732) and y = 10.7 + 0.793x (R^2 = 0.752), respectively. Combined weeks 0 and 2 data with small fruit [<12.7-mm (0.5-inch) diameter] removed; 1 $g \cdot mm^{-1}$ = 0.8960 oz/inch.

USDA 1 were significantly softer after 2 weeks. USDA 3 was significantly firmer after 2 weeks on both machines and USDA 4 was significantly firmer on the FruitFirm 1000 but not on the FirmTech II.

When we compared the rankings of accessions for fruit firmness for each machine measured at week 0 and week 2, we generally saw similar trends, although we did see some changes in rankings between the two machines (Table 5). In week 0, 'Legacy' was measured as the firmest accession on the FirmTech II and was significantly firmer than USDA 3, whereas USDA 3 was the firmest accession measured on the FruitFirm 1000 and was significantly firmer than 'Legacy'. Other rankings at week 0 remained the same across the machines. At week 2, 'Legacy' was again the firmest accession measured on the FirmTech II ahead of USDA 3 and then USDA 4 but was the third firmest accession measured on the FruitFirm 1000, behind USDA 3 and USDA 4. The three least firm accessions did not change rank between the machines at week 2. Although there were some changes in rank for the firmest accessions across the two machines, in general, the same accessions were measured as firmest compared with the less firm accessions.

This consistency is also mirrored in the regression analysis. The regression analysis suggests that the two machines measured firmness similarly at both week 0 and week 2 (Fig. 4). The slopes of the two regression lines are not statistically significant ($P > 0.981$). Week 2 measurements were consistently less firm across all accessions compared with firmness measured in week 0.

Conclusions

In conclusion, this study suggests that although there might be slight differences in fruit firmness and size measurements between the two machines, measurements are generally consistent across the machines. These analyses suggest that, in general, we could use one machine to predict the measurements taken on the other machine, as they both give similar estimates of firmness. If fruit size is determined by using firmness machines, the true blueberry size will need to be adjusted slightly because the FirmTech II slightly overestimates fruit size and the FruitFirm 1000 slightly underestimates fruit size. In conclusion, one could use measurements for fruit firmness and size taken on a FruitFirm 1000 and compare them with the FirmTech II measurements. This is an important contribution, as many researchers and packers look to purchase new machines for testing firmness.

References cited

Blaker KM, Plotto A, Baldwin EA, Olmstead JW. 2014. Correlation between sensory and instrumental measurements of standard and crisp-texture southern highbush blueberries (*Vaccinium corymbosum* L. interspecific hybrids). J Sci Food Agr. 94:2785–2793. https://doi.org/10.1002/jsfa.6626.

Cappai F, Benevenuto J, Ferrão LFV, Munoz P. 2018. Molecular and genetic bases of fruit firmness variation in blueberry—A review. Agronomy (Basel). 8:174. https://doi.org/10.3390/agronomy8090174.

DeVetter L, Yang WQ, Takeda F, Chen J. 2022. Harvesting blueberries: A guide to machine picking blueberries for fresh market. Washington State Univ Ext FS368E.

DeVetter LW, Yang WQ, Takeda F, Korthuis S, Li C. 2019. Modified over-the-row machine harvesters to improve northern highbush blueberry fresh fruit quality. Agriculture. 9:13. https://doi.org/10.3390/agriculture9010013.

Ehlenfeldt MK. 2005. Fruit firmness and holding ability in highbush blueberry—Implications for mechanical harvesting. Int J Fruit Sci. 5:83–91. https://doi.org/10.1300/J492v05n0308.

Giongo L, Ajelli M, Pottorff M, Perkins-Veazie P, Iorizzo M. 2022. Comparative multi-parameters approach to dissect texture subcomponents of highbush blueberry cultivars at harvest and postharvest. Postharvest Biol Technol. 183:111696. https://doi.org/10.1016/j.postharvbio.2021.111696.

Moggia C, Valdes Y, Arancibia A, Valdes M, Radrigan C, Icaza G, Beaudry R, Lobos GA. 2022. A comparison of firmness assessment instruments for fresh blueberry fruit. HortTechnology. 32:172–181. https://doi.org/10.21273/HORTTECH04960-21.

Moggia C, Graell J, Lara I, González G, Lobos GA. 2017. Firmness at harvest impacts postharvest fruit softening and internal browning development in mechanically damaged and non-damaged highbush blueberries (*Vaccinium corymbosum* L.). Front Plant Sci. 11:535. https://doi.org/10.3389/fpls.2017.00535.

NeSmith DS, Prussia S, Tetteh M, Krewer G. 2000. Firmness losses of rabbiteye blueberries (*Vaccinium ashei* Reade) during harvesting and handling. Acta Hortic. 574:287–293. https://doi.org/10.17660/ActaHortic.2002.574.43.

Prussia SE, Tetteh MK, Verma BP, Nesmith DS. 2006. Apparent modulus of elasticity from FirmTech 2 firmness measurements of blueberries. Trans ASABE. 49:113–121. https://doi.org/10.13031/2013.20219.

Sargent SA, Takeda F, Williamson JG, Berry AD. 2021. Harvest of southern highbush blueberry with a modified, over-the-row mechanical harvester: Use of soft-catch surfaces to minimize impact bruising. Agronomy (Basel). 11:1412. https://doi.org/10.3390/agronomy11071412.

Sater H, Ferrão LFV, Olmstead J, Munoz PR, Bai J, Hopf A, Plotto A. 2021. Exploring environmental and storage factors affecting sensory, physical, and chemical attributes of six southern highbush blueberry cultivars. Scientia Hort. 289:110468. https://doi.org/10.1016/j.scienta.2021.110468.

Takeda F, Yang WQ, Li C, Freivalds A, Sung K, Xu R, Sargent S. 2017. Applying new technologies to transform blueberry harvesting. Agronomy (Basel). 7:33. https://doi.org/10.3390/agronomy7020033.

Timm EJ, Brown GK, Armstrong PR, Beaudry RM, Shirazi A. 1996. Portable instrument for measuring firmness of cherries and berries. Appl Eng Agric. 12:71–77. https://doi.org/10.13031/2013.25441.

Yang WQ, Harpole J, Finn CE, Strik BC. 2008. Evaluating berry firmness and total soluble solids of newly released highbush blueberry cultivars. Acta Hortic. 810:863–868. https://doi.org/10.17660/ActaHortic.2009.810.115.