Comparing the Efficacy of Postharvest Cooling Methods to Enhance Fruit Quality and Reduce *Salmonella* in Artificially Inoculated Southern Highbush Blueberry

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Additional index words. forced-air cooling, hydrocooling, 7/8 cooling, sanitizer, shelf life, *Vaccinium corymbosum*

Summary. **Cooling procedures used by blueberry (*Vaccinium* sp.) growers often include delays up to 24 hours that can damage the fruit through rough handling and adverse temperatures, thereby potentially compromising quality and, subsequently, safety. The objectives of this experiment were to compare forced-air cooling (FAC) compared to hydrocooling without sanitizer (HW) and hydrocooling with sanitizer (HS) regarding the quality and shelf life of southern highbush blueberry [SHB (*Vaccinium corymbosum*)] and to determine the efficacy of these treatments for reducing *Salmonella* in SHB. Freshly harvested SHB that were inoculated with a five-serovar cocktail of rifampin-resistant *Salmonella* were rapidly chilled by FAC or hydrocooling (HW and HS) using a laboratory model system. FAC did not show any significant reduction ($P > 0.05$) in *Salmonella* or in the effects on the microbiological quality of blueberries. HW and HS reduced *Salmonella* by ≈2 and >4 log cfu/g SHB, respectively, on day 0. These postharvest treatments was also evaluated for their ability to help maintain fruit quality throughout a storage period of 21 days at 1 °C. Hydrocooling (both HS and HW) provided more rapid cooling than FAC. Hydrocooled blueberries showed significant weight gain ($P < 0.05$), whereas FAC resulted in a slight, but insignificant ($P > 0.05$), reduction in final weight. The results of hydrocooling, both HS and HW, shown in this study could help to extend the shelf life while maintaining or increasing the microbiological quality of fresh market blueberries. Information obtained by this study can be used for developing the best temperature management practices to maintain the postharvest safety and quality of blueberries.**

In a recently released report (U.S. Department of Agriculture, 2018), the United States was ranked the largest producer of blueberries in the world in 2016, with cultivated and wild blueberry total market values of $720.2 million and $27.7 million, respectively. The short postharvest shelf life of fresh fruit like blueberries requires efficient technologies for postharvest cooling, handling, and storage to keep losses to a minimum. Blueberries, like many other small fruits that are consumed raw, have the potential for foodborne illness due to microbiological contamination (Macori et al., 2018). Outbreaks associated with blueberries have involved organisms such as *Salmonella* (Miller et al., 2013) and hepatitis A (Calder et al., 2003). Intervention strategies such as hydrocooling (Sargent et al., 2017) can be used to reduce the microbial load on the surface of fruit that presents an increased risk of cross-contamination and reduction in quality (Sreedharan et al., 2015; Tokarskyy et al., 2015).

Fruit quality depends on many variables such as cultivar, preharvest practices, climacteric conditions, maturity at harvest, harvesting methodology, and postharvest conditions (Sousa-Gallagher et al., 2016). These make predicting the shelf life a difficult task compared with predicting that of other food products. Postharvest temperature management in the blueberry industry is a key factor that contributes to fruit quality and shelf life (Sargent et al., 2017). Postharvest abiotic and biotic deterioration can be controlled by reducing the storage temperature and respiration rate, and by modifying the atmosphere surrounding the product (Van Hoorn, 2004).

Blueberries are climacteric fruit (Ban et al., 2007; El-Agamy et al., 1982; Ismail and Kender, 1969; Lipe, 1978; Windus et al., 1976). To obtain the best flavor and appearance, they should be harvested during the fully ripe stage (Sargent et al., 2009). Ripe blueberries are easily damaged by rough handling (Demir et al., 2011; Xu et al., 2015; Yu et al., 2012) and adverse temperatures (Sousa-Gallagher et al., 2016). Blueberry softening is known to be influenced by cell wall modifications during ripening of the fruit, although these changes are largely complete by the time of harvest (Paniagua et al., 2013). Freshly harvested blueberries constantly lose water to the surrounding environment by transpiration (Wills et al., 1998); therefore, rapid

Received for publication 25 Jan. 2019. Accepted for publication 26 Feb. 2019.

Published online 7 May 2019.

The authors express their appreciation to Mark Mattson, Straughn Farms, Archer, FL, for providing samples for this study, and to Rachael Silverberg, laboratory technician, for helping with sample collection and processing. This project was funded by the U.S. Department of Agriculture Specialty Crop Block Grant Program administered by the Florida Department of Agriculture & Consumer Services (Project #00120621).

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https://doi.org/10.21273/HORTTECH04238-19

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
29,574	fl oz	µL	3.3814×10^{-5}
29.5735	fl oz	mL	0.0338
3.7854	gal	L	0.2642
1	micron(s)	µm	1
1.6093	mile(s)	km	0.6214
28.3495	oz	g	0.0353
1	ppm	$mg \cdot L^{-1}$	1
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

cooling and good temperature management are vital if ripening and deterioration processes are delayed (Sousa-Gallagher et al., 2016; Van Hoorn, 2004).

Temperature management, including keeping the harvested fruit under shade and/or transferring them in a precooled vehicle for transportation, starts in the field, and deterioration is a function of time and temperature; however, faster cooling retains fruit quality and can significantly extend the shelf life (Jackson et al., 1999). Brecht et al. (2003) associated forced-air precooling to 1 to 2 °C immediately after harvest with improved preservation of natural blueberry quality during storage, distribution, and export. Florida blueberries are typically subjected to forced-air cooling (FAC) to an intermediate temperature of ≈16 °C in field lugs soon after harvest. Then, they are kept overnight at that temperature before being sorted and packed in clamshell containers the following day and undergoing FAC for ≈1 h to a final storage temperature of 1 to 2 °C. Less typically, the fruit are packed and cooled on the day of harvest.

As previously mentioned, blueberries have been associated with *Salmonella*-related outbreaks (Miller et al., 2013; Wu et al., 2017); therefore, further research considering the likelihood of the persistence and survival of bacterium is warranted. Moreover, during postharvest processing, including hydrocooling, blueberries may be bruised or damaged such that the survival of bacterium on fruit is affected. Intervention strategies such as hydrocooling can be used to reduce the microbial load on the surface of fruit. However, the increased risk of cross-contamination and reduced fruit quality must be considered before application of these strategies (Sreedharan et al., 2015; Tokarskyy et al., 2015). *Salmonella* has been reported to survive but not proliferate in low pH environments, including damaged fruit such as blueberries (Bassett and McClure, 2008; Nguyen et al., 2014).

Because the consumption of *Salmonella*-contaminated blueberries can cause foodborne disease outbreaks, it is necessary to evaluate the effects of hydrocooling on the quality of blueberries, the potential damage it could cause to the fruit, and its ability to facilitate *Salmonella* proliferation. The objectives of this study were to compare the efficacy of FAC to that of hydrocooling with sanitizer and of hydrocooling without sanitizer to reduce *Salmonella* on inoculated blueberries and to assess the effects of these treatments on the shelf life and quality of fruit.

Materials and methods

Fruit and storage conditions. Freshly harvested (within 4 h of harvest) southern highbush blueberries (mixture of 'Farthing', 'Sweetcrisp', and 'Emerald') were collected at a local farm in Archer, FL (lat. 29.5300°N, long. 82.5190°W), and transported on ice in insulated coolers to the laboratory at the University of Florida in Gainesville (≈15 km) for three separate cooling trials. Blueberries were placed in 6-oz plastic clamshell containers (Highland Corp, Mulberry, FL). Four sets, each with three replicates (n = three clamshells), were used for each of the three trials (N = 3). Each clamshell was weighed at room temperature (22 °C, 50% relative humidity) and then re-weighed following the cooling treatment for comparisons with the initial weight. Visual inspection of the blueberries was performed before and after cooling, and rating scores were assigned to the blueberries based on a subjective appearance scale (Table 1) that accounted for bruising, shrivel, and decay conditions (n = 10 fruit), whole fruit firmness, and presence or absence of bruising. On each respective sampling day, 10 blueberries were randomly selected from each clamshell and inspected for evidence of bruising.

Bacterial cultures and inoculum preparation. Five rifampin (RIF)-resistant (RIF$^+$) serovars of *Salmonella enterica*, which are deposited with the American Type Culture Collection (ATCC), were used. These were *S. enterica* ser. Newport (ATCC 6962), Javiana (ATCC BAA-1593), Enteritidis (ATCC 4931), Typhimurium (ATCC 13311), and Braenderup (ATCC BAA-664). A RIF stock (Fisher Scientific, Fair Lawn, NJ) of 10,000 ppm was made by dissolving 1.5 g RIF in 150 mL methanol. The solution was then filtered (pore size, 0.20 μm; Fisher Scientific) and stored in an opaque bottle at 2 °C until further use. Then, 80 ppm RIF was added to tryptic soy agar [TSA (Difco; BD, Sparks, MD)] and tryptic soy broth [TSB (Difco; BD)] and designated as TSA-RIF80 and TSB-RIF80, respectively. The use of RIF$^+$ *Salmonella* was adopted to differentiate between the inoculum and the natural flora. All cultures were streaked on TSA-RIF$^+$ with increasing levels of RIF until a resistance to 200 ppm was achieved. When this level was achieved, final cultures were grown at 37 °C for 24 h, and a single colony from each plate was transferred to TSB supplemented with 200 ppm RIF to make TSB-RIF200 and incubated overnight at 37 °C. All 200 ppm RIF$^+$ strains were stored as 70% glycerol stocks at –80 °C.

Before the cooling experiments, each strain was individually streaked on TSA-RIF200 (37 °C, 24 h), followed by two subsequent transfers to 10 mL TSB-RIF200 (12 and 24 h at 37 °C, respectively). Cultures were centrifuged (Eppendorf microfuge; Eppendorf, Hamburg, Germany) for 1 min at 14,000 g_n at 20 °C and washed twice in 0.1% buffered peptone water (BPW; BD Difco), followed by final resuspension in 10 mL BPW. The five serovars of *Salmonella* were combined (5 × 10 mL = 50 mL), resulting in a cocktail ≈9 log cfu/mL

Table 1. Change in clamshell weight (clamshell + southern highbush blueberry fruit) before and after cooling treatments: forced-air cooling (FAC), hydrocooling with no sanitizer (HW), and hydrocooling with sanitizer (HS). Values are from three trials (N = 3).

	Treatment[z]			
	Control	FAC	HW	HS
Condition	Clamshell wt [mean ± SD (g)]			
Before treatment	170.4 ± 0.4	170.6 ± 2.1 a[y]	170.4 ± 0.9 b	170.5 ± 0.3 b
After treatment	ND	170.3 ± 2.6 a	177.7 ± 1.5 a	179.9 ± 4.0 a

[z]ND = not done. FAC treatment was 60–90 min. HW and HS treatments were 6 min. 1 g = 0.0353 oz.
[y]Values with the same letters within a column for the same treatment are not significantly different according to the *t* test at $P > 0.05$.

HortTechnology · https://doi.org/10.21273/HORTTECH04238-19

that was serially diluted in BPW to determine the final cell concentration of *Salmonella* in the cocktail. The bacterial concentration was confirmed by pour-plating of serial dilutions (BPW) on TSA-RIF80 and incubation of the plates at 37 °C for 48 h.

Fruit inoculation and treatment. The five-serovar *Salmonella* cocktail was spot-inoculated on the blueberries (blossom scar side) with 9 log cfu/mL inoculum (10 µL), which resulted in an SHB inoculum level of ≈7 log cfu/g. Blueberries were dried for 1 h in a biosafety hood. One set of clamshells (three clamshells/set) was placed on a modified FAC unit for 60–90 min in a walk-in cooler until the desired pulp temperature was reached. For hydrocooling, clamshells with inoculated blueberries were placed in a wire basket and hydrocooled by complete immersion in chilled water (≈2 °C) and kept in a cooler (25 gal). One set of fruit was hydrocooled for 6 min (with agitation) in deionized water containing no sanitizer. The other set was hydrocooled for 6 min (with agitation) with 150 ppm free chlorine (Cl) sanitizer solution (pH 6–6.5). Free chlorine levels were adjusted using a 5.7% to 6% sodium hypochlorite (NaOCl) solution (Fisher Scientific), and the pH was adjusted using 50% citric acid (Alcide Corp., Redmond, WA). The FAC and hydrocooling times were selected to achieve 7/8 cooling, which is a decrease in fruit temperature equal to 7/8 of the difference between the initial fruit temperature and the cooling medium temperature (Sargent et al., 2017). Water temperature, pH, and free Cl concentration were measured before and after immersion of the clamshells with blueberries. A combination pH and ORP meter (Hanna Instruments USA, Smithfield, RI) was used for measuring temperature and pH. Free chlorine levels were verified with a colorimeter (DR/890; Hach Co., Loveland, CO) using the Hach method 8091, which uses an N, N-diethyl-p-phenylenediamine (DPD) sulfate indicator. The water in the hydrocooler was maintained at <5 °C with ice during hydrocooling. After hydrocooling, drained clamshells were placed on paper towels and weighed. Pulp temperatures of the SHB were measured before and after each cooling treatment. The fourth set of clamshells with *Salmonella*-inoculated blueberries was allowed to reach room temperature (≈20 °C) and served as a positive control. All four sets of clamshells were wrapped in clingwrap film to prevent moisture loss and stored at ≈1 °C for 21 d. Recovery and enumeration of *Salmonella* from the blueberries were performed on days 0, 1, 3, 5, 7, 14, and 21 after inoculation.

***Salmonella* recovery and enumeration from blueberries.** For enumeration, five intact blueberries (≈10 g) were aseptically transferred to a sterile bag with a filter (Stomacher; Seward, Bohemia, NY) prefilled with 90 mL of sterile BPW and supplemented with 0.1% sodium thiosulfate ($Na_2S_2O_3$; Fisher Scientific) to quench excess free Cl. The bags were placed in a laboratory paddle blender (Smasher; Microbiology International, Fredrick, MD) and smashed at a slow rate (500 strokes/min) for 1 min. The sample was serially diluted, and 1.0 mL from each dilution was pour-plated using TSA-RIF$^+$. Plates were dried and incubated in inverted conditions at 37 °C for 24 h. Colonies were counted at the end of the incubation period, recorded, and expressed as cfu/gram of SHB.

Statistical analysis. Three independent trials were performed for all treatments. The average colony counts for *Salmonella* were calculated for each treatment (FAC, HW, and HS) and day (days 0, 1, 3, 5, 7, 14, and 21) and compared with the control (no treatment). The limit of detection for colony counts was set to 1.0 log cfu/g SHB. Bacterial counts were log-transformed before the analysis. Means were calculated and comparisons of all pairs were performed using the Tukey-Kramer HSD analysis. The significance level (α) for all analyses was set at 0.05. Data were analyzed by JMP pro (version 13; SAS Institute, Cary, NC) and Microsoft Excel (version 1808, Microsoft Office 365 ProPlus; Microsoft, Redmond, WA).

Results

The blueberries had an initial pulp temperature of 23.0 ± 1.4 °C at the time of inoculation; following FAC, the pulp temperature decreased to 7.1 ± 2.1 °C. After hydrocooling, the pulp temperatures decreased to 6.3 ± 0.8 and 6.3 ± 1.4 °C without and with sanitizer, respectively. Sanitary conditions were maintained in the hydrocooling water throughout cooling. The average free Cl amounts in the hydrocooling water (HS treatment) were 147 ± 3.5 and 138 ± 7.9 ppm at the start and at the end of the experiments, respectively. The pH of this water changed from an average of 7.0 ± 0.1 at the beginning to 7.1 ± 0.2 at the end of the experiment. The water temperature during the HS treatment increased from an average of 3.0 ± 0.3 to 3.8 ± 0.1 °C at the end of the experiment. For HW treatment, the initial water temperature increased from 3.4 ± 1.0 °C at the beginning to 4.1 ± 0.9 °C at the end of the experiment.

Each clamshell weighed ≈170 g before the cooling treatments. FAC resulted in slight, but insignificant ($P > 0.05$), weight loss (0.2%) after the treatment. Hydrocooling resulted in significant ($P < 0.05$) weight gain, with the highest noted (5.5%) in blueberries after hydrocooling with sanitizer (Table 1). This weight gain probably occurred due to the adherence of water to the clamshell and SHB, and, to a lesser extent, the absorption of water by the fruit. Appearance scores (Table 2) of blueberries (1–5 scale) showed no significant difference between treatments. Most blueberries had very low scores (3–4) on days 14 and 21, irrespective of the type of cooling treatment or whether they were part of the untreated control set (data not shown). On day 14, HW blueberries displayed a bruising incidence of 22.2%, which was significantly higher ($P < 0.05$) than in the HS blueberries (12.2%). The bruising incidence rates for the untreated control and the FAC blueberries were 33.2% and 23.3%, respectively. On day 21, hydrocooled blueberries displayed bruising incidence rates of 17.8% and 15.6% for HW and HS, respectively ($P > 0.05$), whereas control and FAC blueberries had the same bruising incidence (33.3%).

Salmonella on the inoculated SHB decreased >1 log cfu/g on the untreated controls (5.7 log cfu/g) after 2 h of drying. This reduced *Salmonella* on the control blueberries was possibly due to desiccation stress during the 2-h drying process. FAC had no significant effect ($P > 0.05$)

on the reduction in *Salmonella* compared with the control (Table 3). The HW and HS both showed a significant ($P < 0.05$) reduction in *Salmonella* compared with controls. The HW treatment significantly ($P < 0.05$) reduced *Salmonella* to 3.66 ± 0.39 log cfu/g of blueberries on day 0. This decrease was most likely due to the mechanical action of the hydrocooling water washing the inoculum off the surface of the blueberries. The HS significantly ($P < 0.05$) reduced the number of inoculated *Salmonella* by >4 log cfu/g of blueberries on day 0. Over time, the levels of *Salmonella* from the inoculated blueberries steadily decreased, even on the untreated inoculated controls (Fig. 1). On days 0, 3, 5, 7, and 14, the HS treatment significantly ($P < 0.05$) reduced *Salmonella* more than the HW treatment group. On day 21, there was no significant difference ($P > 0.05$) between HW and HS treatments. In comparison, at no point during the 21-d incubation period was there a significant difference in *Salmonella* recovered from the control and FAC. These results indicated that HS was the most effective cooling treatment, resulting in the maximum reduction of inoculated *Salmonella*; however, FAC had no significant effect.

Discussion

The use of water, especially with sanitizer, has been reported to be effective for the reduction of microbial loads from minimally processed fruit like blueberry (Li and Wu, 2013; Tadepalli et al., 2018) and table grapes (*Vitis vinifera*) (Ergun and Doğan, 2018). Previous studies also reported that the utilization of hydrocooling with sanitized water did not affect the postharvest quality of strawberries (*Fragaria ×ananassa*) (Ferreira et al., 2006) or blueberries (Sargent et al., 2017). Several other technologies, including the use of water-assisted pulsed-light (PL) processing (Cao et al., 2017; Huang and Chen, 2014; Huang et al., 2015), ultraviolet light radiation treatments (Kim and Hung, 2012), gamma irradiation (Wang et al., 2017), and chlorine dioxide (ClO_2) gas treatments (Sun et al., 2014), have been developed and tested for efficacy to improve the postharvest shelf life of blueberries during cold storage. One study compared the efficacy of water-assisted (wet) and dry PL processing for maintaining the postharvest quality of blueberries inoculated with *Escherichia coli* O157:H7 or *Salmonella* (Huang and Chen, 2014). Although both *E. coli* O157:H7 and *Salmonella* were effectively inactivated by the dry PL treatments, sample heating during treatment caused degradation in the appearance of the blueberries. However, the appearance of the blueberries remained unchanged after wet PL treatments, most likely due to the significant reduction in sample heating. Technology involving the controlled release of ClO_2 gas fumigation removed ≈1 log cfu/g of *E. coli* and *Colletotrichum acutatum* from inoculated blueberries (Sun et al., 2014). This fumigation treatment also removed ≈1.5 log cfu/g of aerobic bacteria and yeast and molds from uninoculated blueberries. In study by Kim and Hung (2012), the use of an electrostatic spray of electrolyzed oxidizing water was shown to be effective for the inactivation of *E. coli* O157:H7 by ≈1 log cfu/g on blueberries.

Sargent et al. (2017) hydrocooled four SHB cultivars (Windsor, Emerald, Jewel, and Farthing) and found that none exhibited splits following hydrocooling with 100 ppm chlorinated water or during subsequent 14-d storage at 1 °C. Greater weight loss by the Windsor cultivar, because of its tendency to lose more

Table 2. Rating scale for southern highbush blueberry fruit appearance quality based on freshness, sheen, shrivel, and skin damage.

Index	Grade	Description
1	Excellent	Fresh appearance, high sheen, turgid, bright color, no damage
2	Fair	Still looks fresh, still shiny, slight dullness and/or shriveling
3	Good	Not fresh appearance, low sheen, limit of marketability
4	Poor	Dull, extreme shriveling and/or decay, limit of usability
5	Extremely poor	Shriveled appearance, not edible

Table 3. Effect of different postharvest cooling treatments: forced-air cooling (FAC), hydrocooling with no sanitizer (HW), and hydrocooling with sanitizer (HS) on survival of *Salmonella* on southern highbush blueberry fruit during 21 d of storage at 1 °C (33.8 °C). Values are from three trials (N = 3).

	Treatment[z]			
	Control	FAC	HW	HS
Incubation (d)	*Salmonella* count [mean ± SE (log cfu/g)]			
0[y]	5.66 ± 0.11 a A	5.61 ± 0.12 a A	3.66 ± 0.39 a B	1.32 ± 0.38 a C
1	5.20 ± 0.11 ab A	5.31 ± 0.12 ab A	3.31 ± 0.39 a B	0.77 ± 0.38 a C
3	5.15 ± 0.11 b A	5.22 ± 0.12 ab A	3.11 ± 0.39 ab B	0.57 ± 0.38 a C
5	4.74 ± 0.11 bc AB	5.04 ± 0.12 bc A	2.76 ± 0.39 a B	0.11 ± 0.38 a C
7	4.50 ± 0.11 cd A	4.51 ± 0.12 c A	3.32 ± 0.39 a B	1.15 ± 0.38 a C
14	3.56 ± 0.11 d AB	3.93 ± 0.12 d A	1.23 ± 0.39 bc B	0.52 ± 0.38 a C
21	3.43 ± 0.11 d A	3.57 ± 0.12 d A	0.40 ± 0.39 c B	0.11 ± 0.38 a B

[z]FAC treatment was 60–90 min. HW and HS treatments were 6 min. 1 g = 0.0353 oz.
[y]Day 0 values were obtained immediately after the cooling treatment.
[x]Values with the same lowercase letters (a, b, c) within columns for the same treatment or the same uppercase letters (A, B, C) within rows for the same day are not significantly different according to one-way analysis of variance at $P > 0.05$.

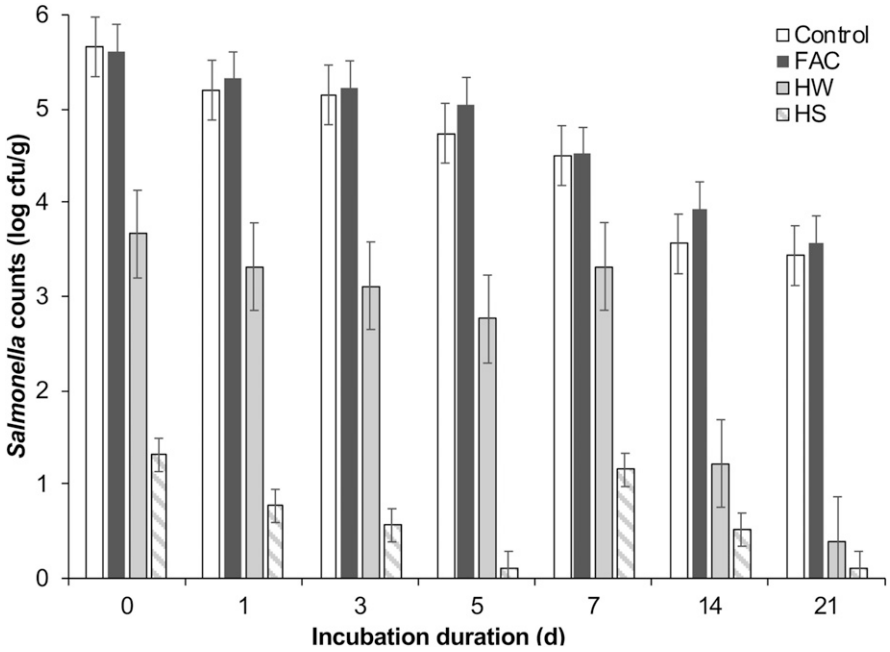

Fig. 1. *Salmonella* counts on inoculated southern highbush blueberry for control, cooled by forced-air cooling (FAC), hydrocooling with water only (HW), or hydrocooling with water and sanitizer (HS) groups during 21 d of storage at 1 °C (33.8 °C).

water during the study, resulted in a higher shriveling incidence. Shrivel symptoms for 'Windsor' increased from 66% to 100% after storage for 7 and 14 d, respectively, whereas these symptoms for the three other cultivars increased from 24% to 43% during the same respective storage times. Hydrocooling helped the fruit look fresh for a longer time, which was evident from the lack of splits and delayed shriveling. Moreover, only 'Windsor' had visible decay (5%) after 14 d of storage (Sargent et al., 2017). In a study by Ergun and Doğan (2018), washing table grapes with water containing sodium hypochlorite (50 ppm) for 1 min significantly reduced aerobic microbial and fungal counts on the fruit.

The hydrocooling treatments (HS and HW) in this experiment resulted in rapid cooling of the fruit and significantly higher reductions of *Salmonella* from the inoculated blueberries. The FAC treatment took 10- to 15-times longer to achieve ≈7/8 cooling (Teruel et al., 2004), and the pulp temperature was >0.5 °C higher than that of the hydrocooled blueberries. The appearance ratings of the hydrocooled blueberries were better than those for the control or FAC on days 14 and 21 (data not shown) in the first two trials. In the third trial, 100% of the blueberries from all three treated and the untreated control sets showed poor quality (4 on the quality scale) on days 14 and 21. These results for the changing appearance of the fruit after storage for 14 d corroborated the findings of Sargent et al. (2017), which indicated that HW 'Windsor' blueberries showed 100% shrivel and almost 5% decay after 14 d of storage. The hydrocooled blueberries were less susceptible to bruising, whereas FAC fruit showed no treatment effect on day 21. This difference in susceptibility to bruising could potentially be attributed to the moisture gain by blueberries through water absorption during hydrocooling, which may have caused the hydrocooled fruit to be firmer, thus making them less susceptible to bruising.

Although both HS and HW of blueberries in the present study showed significantly higher ($P < 0.05$) efficacy for controlling the postharvest microbial load and appearance of the fruit compared with FAC and control treatments, HS was most effective. The recirculating water in the hydrocooler was not tested for the presence of viable bacterial cells, which would have confirmed whether the HS treatment could reduce the risk of cross-contamination, as shown by several other studies (Goodburn and Wallace, 2013; Huang et al., 2018) during the cooling process. Future work regarding cross-contamination is crucial to fully evaluate the applicability of hydrocooling for blueberries. The information from this study can be used to develop the best handling techniques and temperature management recommendations, including rapid and thorough cooling, for maintaining the postharvest microbial quality and appearance of fresh blueberries and possibly aid in reducing costs.

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