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Trimming Sweetcorn Shanks Better Maintains Total Sugars and Water Content of Kernels During Storage

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Shrunken-2 (*sh*2) type sweetcorn is known for its slow sugar-to-starch conversion and long shelf life. It became the industry standard for fresh market sweetcorn in the mid-1990s. The industry currently ships sweetcorn with the shank attached, which complicates packing due to non-uniform ear length. In this study, sweetcorn (*sh2* type) with either untrimmed shanks or trimmed shanks (2-cm in length) were immersion hydrocooled immediately or following three hours at 30 °C (86 °F), then stored at 5 °C (41 °F) and 95% relative humidity for 0, 5, or 10 days. Husk drying, silk appearance, and kernel appearance declined in overall quality uniformly, irrespective of treatment. Due to trimming, after 10 days of storage husk color was slightly dull, and light to medium green while untrimmed ears were a slightly brighter green. Sweetcorn kernels developed splitting, denting, and microbial growth, but these were unrelated to trimming or cooling treatment. Denting incidence was highest (14-15 kernels per ear) after 10 days. After 5 and 10 days, kernels from trimmed ears had slightly higher moisture content than untrimmed ears, with no variation between immediate and delayed cooling. As the storage period increased, total alcohol soluble carbohydrates [total soluble sugars (TSS)] increased; TSS in kernels from untrimmed ears rose from 5 to 17.5% (% sucrose) and those from trimmed ears from 3.5 to 12.75%. Microbial growth and denting were the limiting factors with regard to marketability, appearing in low incidence throughout kernels in all treatments after 10 days of storage. Overall ear and kernel quality was not compromised by trimming the shanks, or with delayed cooling for three hours. Trimming shanks shows promise to make sweetcorn packing more efficient.

Florida is the largest producer of fresh market sweetcorn in the U.S. with a production value of $717 million in 2017 (USDA, NASS, 2018). Compared to other commodities in Florida, sweetcorn ranks fifth in production value, behind oranges, strawberries, tomatoes, and peppers. The prominent mutant type grown for fresh market is shrunken-2 (*sh2*) (Hallauer, 2000). The *sh2* mutation inhibits sugar conversion into starch as kernels remain attached on the ear (Tsai and Nelson, 1966; Dickinson and Preiss, 1969). The enzyme ADP-glucose pyrophosphorylase is partially encoded by *sh2* and is involved in sugar-to-starch conversion. The mutated kernels contain 10% of the activity as non-mutated kernels (Dickinson and Preiss 1969; Hannah and Nelson 1976; Hannah et al. 1980; Tsai and Nelson 1966; Weaver et al. 1972). According to consumer preference tests, sweetness is ranked as the highest quality factor for sweetcorn (Culpepper and Magoon, 1927; Evensen and Boyer, 1986; Showalter and Miller, 1962; Wann et al. 1971). The result of *sh2* is higher sucrose content of 5- to 6-fold and lower starch content by two-thirds in comparison with normal (*su*) sweetcorn kernels (Creech, 1968; Laughnan, 1953). The University of Florida released two commercial *sh2* sweetcorn cultivars in the 1970s: 'Florida-Sweet' and 'Florida Staysweet'. 'Florida-Sweet', released in 1974, had poor germination emergence and, in collaboration with breeders from Crookham Seed Company in Idaho, 'Florida Staysweet', the first commercially successful *sh2* cultivar, was released in 1978 (Tracy, 1997).

Trimming shanks and flag leaves has been an area of interest for reducing moisture loss in sweetcorn throughout shipping and handling (Showalter, 1967). Currently, sweetcorn ears with husks are packed in reusable plastic containers (RPCs) or tightly in wooden wirebound crates either in the field or immediately after cooling (Sargent and Brecht, 2010). The respiration rate of sweetcorn is very high (43–83 mg CO_2/kg-h) at 5 °C (41 °F) (Brecht, 2016); thus the rapid breakdown of sugars, starches, and other complex molecules continues until cooled sufficiently (Kader and Saltveit, 2003; Mohammed and Brecht, 2003). Rapid removal of field heat is necessary to reduce the high respiration rate that leads to rapid senescence. Mature sweetcorn with the *sh2* mutant maintains sucrose levels after 48 h at 27 °C (80.6 °F) (Garwood et al., 1976), although the effect of extended time in warm temperatures on shelf-life expectancy is not well documented. Brecht (2016) and Mohammed and Brecht (2003) suggested cooling to 0 °C (32 °F) immediately following harvest and storing ears at 0 °C (32 °F).

Two common methods of cooling sweetcorn are hydrocooling and vacuum cooling. Hydrocooling by overhead shower or by immersion using 0 to 3 °C (32 to 38 °F) water, effectively cools bulk sweetcorn in less than 60 min if water temperature is maintained. However, packing ears tightly in crates restricts water flow during hydrocooling and air flow during cold storage. Talbot et al. (1990; 1991) reported that crated sweetcorn required 80 min for adequate cooling; however, many operations cool for only 60 min, stressing the importance of allowing effective water and air

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flow. In addition, efficacy of rapid cooling may be diminished by extended delays in field heat, long transport times, or inefficient packinghouse handling. Vacuum cooling is much faster than hydrocooling, cooling sweetcorn from approximately 30 °C to 5 °C (86 °F to 41 °F) in about 30 min. Vacuum cooling, however, is not widely used due to high installation and operation costs.

The shank of corn is the stalk-like structure at the base of the ear by which the ear is attached to the plant. The shank is snapped to remove the ear from the plant at harvest. Shank length varies from ear-to-ear (6–17 cm or 2.3–6.7 in), making it difficult to pack ears uniformly in wooden, wirebound crates or RPCs (Showalter, 1967). Trimming the shanks could facilitate uniform packing, and potentially increase cooling efficiency. Lower respiration rates by ears with trimmed shanks have been found in previous studies [Brecht et al. (unpublished data); Creech, 1965] and trimming is thus a potential method for extending the shelf-life of sweetcorn. Trimming could be accomplished during field packing or at the packinghouse for machine-harvested sweetcorn.

The objective of this study was to investigate the effects of trimming sweetcorn shanks and delay to hydrocooling on overall appearance and quality of sweetcorn during simulated commercial storage.

Materials and Methods

Commercially grown sweetcorn (shrunken-2 (*sh2*) type; 'BSS 1075', Syngenta Intl., Switzerland) was mechanically harvested on July 26, 2017 and transported 45 min to the Postharvest Horticulture Laboratory (Gainesville, FL). Upon arrival, sweetcorn ears were either immediately immersion hydrocooled or following a 3-h delay at 30 °C (86 °F). Pulp temp was verified by inserting a temperature probe in the cob center and 7/8 Cooling was calculated as follows. For ears immediately cooled (IC), the initial pulp temperature was 25 °C (77 °F) with a final temperature of 3 °C (38 °F). For the 3-h delayed cool (DC), the pulp temperature rose to 32 °C (90 °F) with a final temperature of 4 °C (39 °F). Water was held at 0.2 °C (32 °F) with ice and sanitized with 100 ppm chlorine (Fig. 1). For the DC treatment, samples were left in shaded, ambient conditions to maintain initial field heat. For each cooling treatment, half of the samples had the shanks trimmed to 2-cm length and the other half was left untrimmed. Ears were stored on trays in single layers at 4 °C (± 0.5 °C) / 40 °F (± 0.5 °F) and 95% relative humidity (RH) and evaluated after 0, 5, and 10 d.

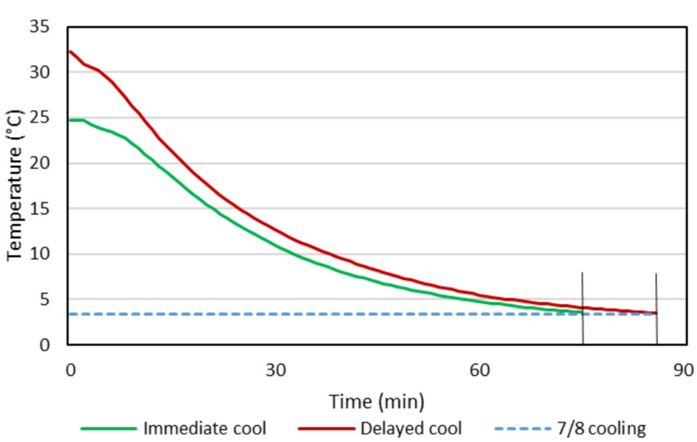

Fig. 1. Cob pulp temperatures during immediate and delayed cooling. Mean 7/8 Cooling temperature for immediate cool (IC) and delayed cool (DC) was 3.4 °C (38 °F). Vertical lines indicate 7/8 Cooling times for both treatments. (n = 2 ears).

At the initial evaluation, samples were measured for diameter at midpoint of ear, ear length, and shank length, and rated for husk color and husk dryness (Table 1). During storage, additional ratings were made for silk appearance and kernel appearance, and counts were made of kernel denting, split kernels, and kernels with microbial growth. Five-point subjective rating scales were utilized for husk color, husk dryness, silk appearance, and kernel appearance from Brecht et al. (1990). These scales ranged from 1 (poorest quality) to 5 (field-fresh quality); a rating of 3 was considered the limit of marketability.

For all evaluations, five ears from each treatment were measured for moisture content and total sugar concentration (total alcohol soluble carbohydrates), and subjective measurements were made for husk and kernel dryness and damage. Kernel samples for moisture content and total sugar concentration were taken by slicing 30 g of kernels from each ear and drying at 65 °C (149 °F) for 24 h. Immediately following removal from the drying oven, each sample was re-weighed, and moisture content (%, fresh wt. basis) was calculated:

$$[\text{fresh weight (g)} - \text{dry weight (g)}] / [\text{fresh weight (g)} \times 100]$$

Fifty g of kernels from each ear were frozen at –30 °C (–22 °F) for later analysis of total soluble sugars (TSS) content (DuBois et al., 1956). Upon thawing, 2 g of tissue were added to 50 mL centrifuge tubes with 20 mL cold 80% ethanol. Samples were homogenized (Omni International GLD-01; Kennesaw, GA) and placed at –20 °C (–4 °F) overnight for precipitation of ethanol-insoluble solids. Then, the tubes were centrifuged at 391g (radius minimum 165; max 617) for 5 min and 0.5 mL aliquots were pipetted from each tube into a glass test tube. An 18% phenol solution (0.5 mL) was then added and tubes vortexed carefully. Sulfuric acid (2.5 mL) was

Table 1. Subjective appearance rating criteria for sweet corn. (from Brecht et al. 1990).

Appearance factor	Numerical score	Description
Husk drying	1	Completely dried out
	2	Portions completely dry, objectionable
	3	Drying apparent, leaves brittle
	4	Reasonably fresh, leaves flexible
	5	Field fresh turgid appearance
Husk color	1	Yellow-tan color
	2	Pale green, brown areas apparent
	3	Dull, light to medium green
	4	Medium green, bright appearance
	5	Dark, bright green
Silk appearance	1	Limp, watery, decay
	2	Obvious discoloration, dry or limp
	3	Slight browning, some drying
	4	Not fresh, still light color and reasonable turgid
	5	Light color, fresh and turgid
Kernel appearance	1	Extensive denting, objectionable
	2	One to a few dented kernels
	3	Dull appearance, no denting
	4	Reasonably bright and turgid
	5	Fresh, bright color, very turgid

added and tubes vortexed again. After 10 min, color development was read at 490 nm on a spectrophotometer (BioTek Powerwave XS2 with Gen5.1.11 software; Winooski, VT) and expressed as TSS (% sucrose) by comparison to a standard curve made using certified ACS grade sucrose (Fisher Scientific, Fair Lawn, NJ).

Results and Discussion

Corn ear (n = 40) dimensions ranged from 5.2 to 5.9 cm maximum diameter, 15.5 to 20 cm cob length, and 6 to 17 cm shank length. For subjective ratings (Fig. 2), husk color score was lower for trimmed ears due to the base of external husk leaves being cut. Trimmed ears maintained a dull, light to medium green throughout storage, while untrimmed ears were a slightly brighter green. Husk drying and kernel appearance were only impacted by storage period, with drying in husks and denting of kernels apparent after 10 d. All husks maintained freshness and flexibility up to 5 d of storage and began to dry and become brittle after 10 d. Silk appearance maintained slight browning throughout storage; no differences were found for any treatments.

Denting increased from 5 to 10 d of storage. There were ≤ 5 dented kernels per ear after 5 d but some ears had as high as 40 dented kernels after 10 d (Fig. 3). Degree of denting did not appear to be treatment dependent as it occurred in all ears. Standard error for denting was between 0.5 and 6.7.

Split kernels, which may be associated with water uptake during hydrocooling, increased during storage; there were ≤ 6 split kernels after 5 d of storage. After 10 d, splitting ranged from 0–15 kernels per ear and appeared in 40% of ears, independent of treatment.

Microbial growth, which flourishes in split kernels, appeared in a single kernel in two of twenty ears after 5 d. After 10 d, the incidence of microbial growth ranged from 0–50 kernels with 45% of ears affected (Fig. 3). Treatment (time to hydrocooling or shank trimming) did not impact severity of growth.

Moisture content remained constant throughout storage at 4 °C (39 °F), averaging 78.2% (Table 2). Rosenbrook and Andrew (1970) reported similar values for moisture content, in which moisture content ranged from 70.5 to 79.6% for multiple varieties with *sh2* mutants.

Total soluble sugars (TSS) in kernels from untrimmed shanks ranged from 5% at initial evaluation to 17.5% after 10 d of storage, while those from trimmed shanks ranged from 3.5 to 12.8% during the same period (Fig. 4). Additionally, delay to hydrocooling did not influence TSS during storage. Previous studies report ranges in *sh2* varieties from above 5% after 9 d at 4.5 °C (Brecht et al. 1990) and an average of 10.9% after 5 d at 6 °C (Zhu et al. 1992). Bader (2003, unpublished data.) reported sweetness of *sh2*, as detected by panelists, remained constant during 2 weeks of storage. Total soluble solids are primarily sucrose, fructose, and glucose. Zhu et al. (1992) reported decreases in °Brix, fructose, glucose, and sucrose, and an increase in maltose for *sh2* cultivars over 5 d at 6 °C (43 °F).

Harvest and transport may delay cooling of sweetcorn. Results suggest that the quality of mature, freshly harvested *sh2* sweetcorn will not significantly decline within a 3-h delay at a typical ambient temperature of 30 °C (86 °F) likely to be encountered during the Florida harvest season. However, cooling is an important practice and its extended delay can lead to decreased sweetness, denting, husk drying, and tougher kernel texture (Sargent and Brecht, 2010;

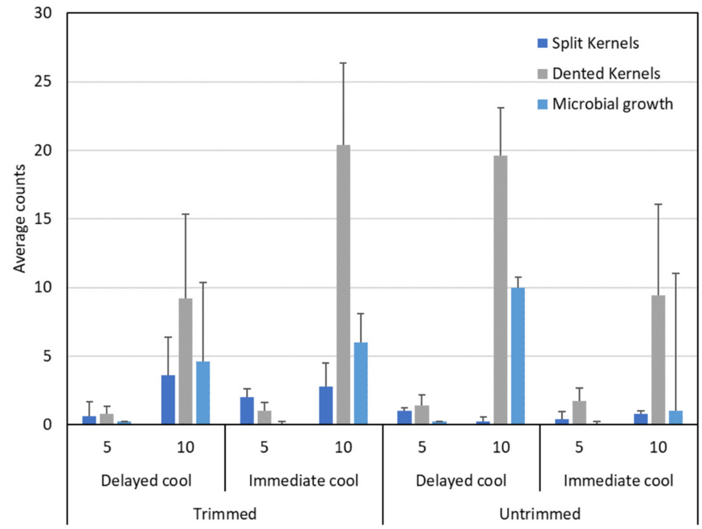

Fig. 3. Individual kernel defect counts for *shrunken-2* sweetcorn kernels from trimmed or untrimmed ears either cooled immediately or following a 3-h delay at 30 °C (86 °F), plus storage at 5 °C (41 °F) for 5 and 10 d. Standard error bars are shown. (n = 5).

Table 2. Moisture content (%) for *shrunken-2* sweetcorn kernels from trimmed or untrimmed ears hydrocooled immediately or following a 3-h delay at 30 °C (86 °F) plus storage at 5 °C (41 °F) for 5 and 10 d. (n = 5).

Treatment	Trimming	0 days	5 days	10 days
Immediate cool	Untrimmed	77.33 (0.61)[z]	77.98 (0.57)	78.57 (1.27)
	Trimmed	_	77.71 (0.82)	79.09 (0.60)
Delay to cool	Untrimmed	78.09 (0.45)	77.97 (0.25)	78.49 (0.72)
	Trimmed	_	78.67 (0.62)	78.68 (1.17)

[z]Standard error.

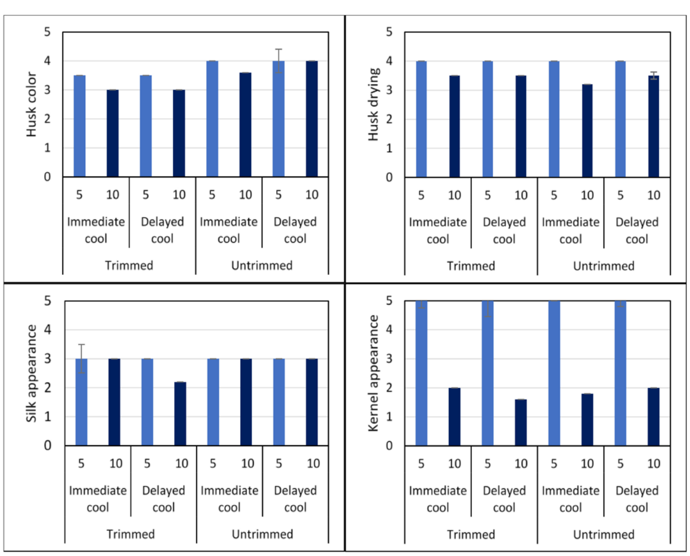

Fig. 2. Subjective ratings for husk, silk, and kernel appearance of *shrunken-2* sweetcorn from trimmed or untrimmed ears cooled immediately or following a 3-h delay at 30 °C (86 °F), plus storage at 5 °C (41 °F) for 5 and 10 d. Standard error bars are shown. (n = 5).

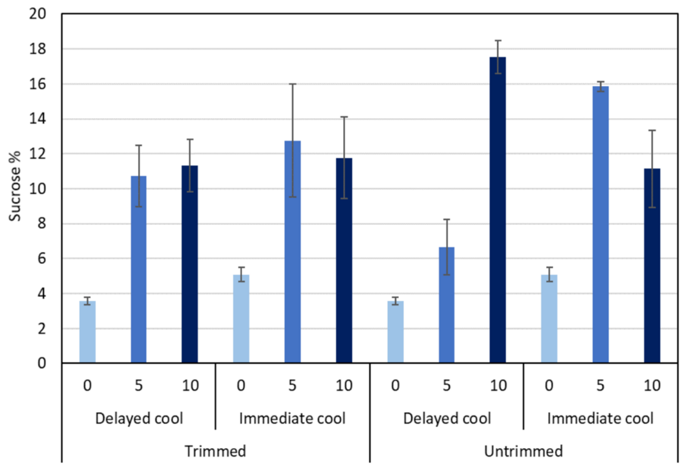

Fig. 4. Total soluble sugars (TSS, % sucrose) for *shrunken-2* sweetcorn kernels from trimmed or untrimmed ears either cooled immediately or following a 3-h delay at 30 °C (86 °F), plus storage at 5 °C (41 °F) for 5 and 10 d. Standard error bars are shown. (n = 5).

Showalter, 1967). In addition, trimmed ears maintained kernel appearance and integrity of kernel structure up to 5 d of storage.

In summary, trimming sweetcorn shanks did not negatively impact shelf-life. Trimming sweetcorn can benefit packinghouses and shippers that use RPC or wooden crates to reduce damage and loss of quality. Moisture content and husk appearance were maintained in *sh2* sweetcorn throughout 10 d of storage. Shelf-life was limited by split and dented kernels with microbial growth after 10 d of storage, which occurred in both trimmed and untrimmed shanks. This would be considered unmarketable, based on USDA quality standards, in which high quality sweetcorn is free from insect injury, mechanical damage, and decay (Brecht, 2016). A postharvest treatment or sanitizer would be useful for extending the quality of *sh2* sweetcorn for a longer time.

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