Effect of High-tunnel Production Systems on the Preharvest Losses and Harvest Quality of 'BHN 589' and 'Cherokee Purple' Tomatoes

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SUMMARY. The objective of this study was to investigate the effect of high-tunnel production on preharvest losses and harvest quality of two tomato (*Solanum lycopersicum*) cultivars. Our results indicate that using high tunnels for tomato production can reduce the preharvest food losses for this crop compared with open-field production, as indicated by increased productivity and percent marketability during the span of three production seasons. The tomato harvest quality did not differ in terms of physical attributes. However, open-field–grown tomatoes demonstrated a significantly greater antioxidant capacity when compared with the high-tunnel–grown tomatoes.

High tunnels (HTs) are frequently used by tomato (*Solanum lycopersicum*) growers in the central United States because of their crop protection properties and their ability to increase yield and profitability (Mitchell et al. 2019). Other benefits of this production system include early warm-season crop production and season extension (Bruce et al. 2019), which is of particular interest for tomato producers. Among the most frequently cultivated tomato cultivars grown in the central United States are 'BHN 589', a hybrid determinate cultivar, and 'Cherokee Purple', an heirloom indeterminate cultivar.

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Preharvest losses occurring in the field during production contribute substantially to food losses (Food and Agriculture Organization of the United Nations 2011). Preharvest field conditions are also correlated to the harvest quality of a crop, and poor harvest quality can lead to additional losses (Kader 2000). A recent study demonstrated the ability of HTs to reduce preharvest losses and improve harvest quality of spinach [*Spinacia oleracea* (Batziakas et al. 2020)]. HTs have been reported to increase the amount of marketable tomato fruit and weight (Frey et al. 2020). The objective of this study was to determine the effect of HT production on preharvest losses and harvest quality of 'BHN 589' and 'Cherokee Purple' tomatoes.

Materials and methods

TOMATO PRODUCTION. Experimental trials were conducted from 2014 to 2016 at Kansas State University Olathe Horticulture Research and Extension Center located in Olathe, KS (lat. 38.884347°N, long. 94.993426°W). The location has Chase silt loam soil (pH = 6.3). The field experiment followed a "systems" design identical to that by Batziakas et al. (2020) for the arrangement of the main-plot factor (production system). Six 20- × 32-ft permanent Quonset-style HTs (Stuppy, North Kansas City, MO) and six adjacent 20- × 32-ft open-field (OF) plots were the six replications for each production system. The subplot treatment (cultivar) was arranged as a split-plot design. 'BHN 589' (Seedway LLC, Elizabethtown, PA) and 'Cherokee Purple' (Johnny's Selected Seeds, Winslow, ME) tomatoes were randomized within each replication. The tomatoes were transplanted in the HT on 2 Apr in 2014 and 2015, and on 19 Apr in 2016. OF tomatoes were set out exactly 3 weeks later in all 3 years. Management practices included a stake-and-weave trellis, hand-pruning, drip irrigation, and organic control of pests. The cropping history, fertilization, cultural practices, and termination date were identical for both OF and HT plots.

YIELD. Fruit was harvested weekly at the pink ripeness stage through 1 Oct. Total and marketable yields were recorded per plant, in terms of fruit weight and number, and percent marketability was calculated. Fruit marketability was assessed based on the absence of fruit diseases, blossom end rot, cracking, pest damage, and being larger than 3.8 cm in diameter.

QUALITY AT HARVEST. Skin color was measured with a chromameter (Chroma Meter CR-400; Konica-Minolta, Ramsey, NJ) and was expressed in the International Commission on Illumination (CIE) L*a*b* color space, where a* denotes the red/green value and L* indicates lightness. Respiration rate was determined according to Jacxsens et al. (1999), using a portable gas analyzer (Bridge Analyzers Inc., Bedford Heights, OH).

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.3048	ft	m	3.2808
2.54	inch(es)	cm	0.3937
0.4536	lb	kg	2.2046
28.3495	oz	g	0.0353
0.1	ppm	$mg \cdot 100\ g^{-1}$	10
1	ppm	$mg \cdot kg^{-1}$	1
1	ppm	$\mu g \cdot g^{-1}$	1

Lycopene and β-carotene content were measured spectrophotometrically (Synergy H1; BioTek Instruments, Inc., Winooski, VT) according to Nagata and Yamashita (1992). Ascorbic acid content was determined using ultraperformance liquid chromatography (Waters Corp., Milford, MA) equipped with an Acquity PDA detector and an Acquity BEH C18 column (Waters Corp.), and quantified with an external analytical ascorbic acid standard curve according to Klimczak and Gliszczynska-wiglo (2015). Oxygen radical absorbance capacity (ORAC), ferric reducing ability of plasma (FRAP), and total phenols were determined spectrophotometrically (Synergy H1) using the hydrophilic tomato juice fraction. ORAC was determined according to Prior et al. (2003); FRAP, according to Benzie and Strain (1996); and total phenols, according to Singleton and Rossi (1965).

Total soluble solids (TSS) were measured using a temperature-compensating refractometer (AR200; Reichert, Depew, NY). Titratable acidity (TA) was determined with an automated titrator (862 Compact titrosampler; Metrohm, Riverview, FL).

Statistical analysis. Data were analyzed using statistical software (SAS version 9.4; SAS Institute Inc., Cary, NC). The yield data were analyzed as a two-way, randomized complete block design, with the production year as the blocking factor. The MIXED procedure was used to determine treatment effects (cultivar, production system, and cultivar × production system). A Bonferroni *P*-value adjustment was used for mean separation at a 5% probability level. The fruit quality analysis also used a complete randomized block design, with subsampling over multiple harvests, and year being the blocking factor. The fruit quality data were analyzed using the MIXED procedure with Kenward–Roger [denominator degrees of freedom (DDFM) = KR] in the MODEL statement to assess production system effects on the fruit quality for both cultivars.

Results and discussion

For 'BHN 589', the HT system produced double the total and marketable fruit number ($P < 0.0001$) when compared with the OF production (Table 1). HT-grown 'Cherokee Purple' tomatoes produced a 2.5 and 3 times greater total and marketable fruit number ($P < 0.05$), respectively, when compared with the OF production (Table 1). When data for both cultivars over the 3 years of the study were aggregated, total and marketable yield (measured in kilograms) of HT-produced fruit were found to be more than double than field-grown fruit ($P < 0.0001$, Table 1). HTs produced a significantly greater percentage marketable fruit number and weight ($P < 0.0001$) for both 'Cherokee Purple' and 'BHN 589' tomatoes (Table 1). This indicates that HT production can reduce the preharvest losses of 'Cherokee Purple' and 'BHN 589' tomatoes, because percent marketability is a direct measure of preharvest losses (Batziakas et al. 2020). Although their incidence was not recorded individually, the primary issues associated with nonmarketable fruit were related to cracking and damage from disease and pests. O'Connell et al. (2012) also found that HT use reduced the incidence of cracking, insect damage, and *Tomato spotted wilt virus*, which led to increased marketability of heirloom tomato fruit.

Tomatoes grown under the two production methods differed little in the measured quality characteristics (Supplemental Table S1). HT-grown 'BHN 589' demonstrated lower FRAP and TA, but greater TSS/TA (Supplemental Table S1). Low TA has been linked to increased temperatures in HTs compared with the OF (Cowan

Table 1. Total and marketable yield of 'BHN 589' and 'Cherokee Purple' tomatoes grown in high-tunnel (HT) and open-field (OF) trials in Olathe, KS, from 2014 to 2016.

	Fruit yield (no./plant)		Fruit yield (kg/plant)[ii]		Marketability (%)[i]	
Treatments	Total	Marketable[i]	Total	Marketable	n	Wt
Production system × cultivar						
'BHN 589'						
HT	56.8 d[iii]	41.9	10.3	8.2	67.5 a	68.9
OF	24.6 b	17.2	5.4	3.8	59.6 b	63.0
'Cherokee Purple'						
HT	42.7 c	28.3	8.3	5.6	61.5 ba	61.8
OF	16.7 a	9.1	4.6	2.5	46.0 c	51.0
Main effects						
Cultivar						
'Cherokee Purple'	29.7	18.7 a	6.4 a	4.0 a	53.7	56.3 a
'BHN 589'	40.7	29.6 b	7.8 b	6.0 b	63.5	66.0 b
Production system						
HT	49.8	35.1 a	9.3 a	6.9 a	64.5	65.3 a
OF	20.7	13.2 b	5.0 b	3.1 b	52.7	57.0 b
Production system[iv]	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cultivar[iv]	<0.0001	<0.0001	0.0089	<0.0001	<0.0001	<0.0001
Productions system × cultivar[iv]	0.0265	NS	NS	NS	0.0497	NS

[i] Marketability was determined by fruit free from cracks, pest damage, rot, and blossom end rot with a diameter larger than 3.8 cm (1.50 inches).
[ii] 1 kg = 2.2046 lb.
[iii] Means in columns within interaction effect and main effect sections followed by the same letter are not significantly different according to a pairwise comparison with a Bonferroni *P*-value adjustment ($P \le 0.05$) within the treatments of cultivar, production system, and their interaction.
[iv] Probability value for the overall analysis of variance F test of the fixed effects using the type III hypothesis test, where $P \le 0.05$. NS = nonsignificant at the $P \le 0.05$ significance level.

et al. 2014). Increased TSS/TA in tomatoes indicates improved eating quality (Xu et al. 2018). HT-grown 'Cherokee Purple' demonstrated lower ORAC and FRAP, and marginally lower TSS (Supplemental Table S1). Cowan et al. (2014) linked the decrease in TSS in HT-grown tomatoes with their increased juice content compared with those grown in the OF. The polyethylene film that covers HTs usually blocks ultraviolet light (Costa et al. 2003), and ultraviolet exposure affects tomato antioxidant content (Toor et al. 2006), which might explain the reduced antioxidant capacity in HT-grown tomatoes.

Based on the data from our trials, the implementation of HT production will benefit growers by increasing overall productivity in addition to having reduced preharvest losses. Preharvest losses are particularly difficult for growers because the cost of supplies and labor to manage the crop has already been invested. The use of the HT system reduces the risk of crop losses and therefore ensures the revenue stream for the grower.

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Supplemental Table S1. Quality attributes of 'BHN 589' and 'Cherokee Purple' tomatoes at harvest (pink maturity stage) grown in high-tunnel (HT) and open-field (OF) trials in Olathe, KS, in 2014 and 2016.

	BHN589			Cherokee Purple		
Quality attribute[i]	**HT**	**OF**	***P* value**	**HT**	**OF**	***P* value**
Redness (a*)	10.6	10.8	NS[ii]	3.5	2.5	NS
Lightness (L*)	55.7	54.5	NS	55.4	54.1	NS
Respiration rate, carbon dioxide ($mg \cdot kg^{-1} \cdot h^{-1}$)[iii]	21.4	20.1	NS	23.1	22.1	NS
Lycopene ($\mu g \cdot g^{-1}$ FW)	3.9	3.4	NS	3.4	4.2	NS
Beta-carotene ($\mu g \cdot g^{-1}$ FW)	2.2	2.2	NS	1.9	2.3	NS
Ascorbic acid ($\mu g \cdot g^{-1}$ FW)[iii]	213	223	NS	204	235	NS
Oxygen radical absorbance capacity, Trolox equivalents ($\mu M \cdot 100\ g^{-1}$ FW)	614	643	NS	522	743	0.001
Ferric reducing ability of plasma, Trolox equivalents ($\mu M \cdot 100\ g^{-1}$ FW)	229	286	<0.001	192	317	<0.0001
Total phenols, gallic acid equivalents ($mg \cdot 100\ g^{-1}$ FW)	16.0	17.4	NS	14.7	15.5	NS
Total soluble solids (%)	4.7	4.8	NS	4.9	5.2	<0.001
Titratable acidity (%)	0.42	0.48	<0.05	0.38	0.41	NS
Total soluble solids/titratable acidity	12.0	10.3	<0.05	13.5	13.0	NS

[i] 1 $mg \cdot kg^{-1}$ = 1 ppm, $\mu g \cdot g^{-1}$ = 1 ppm, 1 g = 0.0353 oz, 1 $mg \cdot 100\ g^{-1}$ = 10 ppm.
[ii] NS = nonsignificant at the $P \leq 0.05$ significance level.
[iii] Respiration rate and ascorbic acid were measured only during the 2016 season.
FW = fresh weight.
Each value represents the mean of measurements obtained from four harvests in 2014 and five harvests in 2016. Nine marketable fruit per replicate were used for the quality assessments.