Identification of Promising Heirloom Tomato Varieties for Production in Hawaii

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KEYWORDS. high-tunnel, market class, screen house, tropical

ABSTRACT. **Heirloom tomatoes have been shown to have a large price premium. However, in Hawaii, many do not have the appropriate disease tolerance packages and quality to be useful in the local market. We tested 29 tomato cultivars from three different market classes in two field trials from 2020 to 2021. Hybrid heirlooms had the greatest yields; traditional heirlooms had the highest quality. Introducing new lines to Hawaii will help farmers react to increasing disease pressure while still allowing for high marketable yields and creating an opportunity for price premiums.**

Historically the tomato industry has operated within distinct market domains—fresh and processing (US Department of Agriculture 1983, 1991)—which has facilitated targeted research tailored to the specific needs of each supply chain. A major goal of 20th-century breeding was to develop cultivars that could endure postharvest handling throughout the supply chain (Klee and Tieman 2018). The tomato market was disrupted in the early 1980s, largely instigated by celebrity chefs and food critics (Joseph et al. 2017), which helped change consumer preferences, focusing them on heirloom types (Blanca et al. 2015). Recently, interest in improving flavor and fruit quality has received increased attention (Gao et al. 2019; Hightower 1972; Klee and Tieman 2018; Saliba-Colombani et al. 2001; Tieman et al. 2017; Zhao et al. 2019). In Hawaii, there has been interest in understanding the importance of the local market, in particular for tomato, because of a large proportion of the local market (Xu et al. 2015; Yang and Leung 2020). However, although there have been consistent increases in prices for organic, there have been inconsistent price effects for local (Xu et al. 2015; Yang and Leung 2020).

Demand for heirloom tomatoes has increased over time as they became the poster child for regional cuisine and as consumers sought more diversity in their produce. Although heirloom tomatoes have acquired numerous colloquial definitions, such as 1) being at least 50 years old, 2) being open pollinated, or 3) specific to a region with a traceable ancestry, there is no official botanical classification or accreditation system in place (Harland and Larrinua-Craxton 2009). The notion of what constitutes as heirloom in the fresh market has evolved, with sources arriving at an informal definition in terms of a cultivar's traceable ancestry, age, and pollination status (Casañas et al. 2017; Male 1999; Watson 1996; Zeven 1998). Consumers have come to associate the term heirloom with colorful, atypically shaped, and flavorful tomatoes (Dwivedi et al. 2019). Because of the stark contrast between these characteristics and the typical commercial prototype, heirloom tomatoes have evolved into a specialty subclass within the fresh market (Grassbaugh et al. 1999; Jordan 2007; Joseph et al. 2017). New hybrid cultivars are often promoted as having heirloom-like fruit quality with modern production traits. Without established standards and regulations, the heirloom-like insignia has evolved into a phenotypic descriptor rather than a designation of heritage, genetics, or pedigree.

Although the sociocultural debate on what genuinely qualifies as an heirloom tomato may continue for years, it is possible to examine the properties that distinguish this unique market class quantitatively. The economic value attributed to heirloom tomatoes requires objective quality assurance in their labeling, with prior studies of heirloom germplasm focusing on sourcing desirable traits (Alonso et al. 2011; Dwivedi et al. 2019; Gonçalves et al. 2009; Panthee et al. 2013a; Rodríguez-Burruezo et al. 2005). We evaluated the productivity of cultivars from three market classes—traditional heirloom (TH), heirloom hybrid (HH), and commercial hybrid (CH)—to identify the most promising cultivars and market class for Hawaiian markets.

Materials and methods

Hawaii field trials

THs (cultivars recognized as heirlooms), HHs (hybrids marketed as having heirloom-like characteristics or an heirloom parent, sometimes under names such as "hyloom"), and CHs (conventionally marketed hybrids) were evaluated in field trials at the University of Hawaii research stations on Oahu in 2020 and 2021 (Table 1). To reduce the severity of pests and diseases, field tests were conducted at each location in high-tunnel screenhouses. Experiments were conducted in an augmented design to maximize accessions from each market class (Federer and Raghavarao 1975; Healy et al. 2015). An overview of the germplasm screened is presented in Table 2. Although neither experimental site was certified, management practices used during each study followed USDA National Organic Program standards. The first trial was held at the Waimanalo Research Station (lat. 21°20′7.872″N, long. 157°42′53.2188″W) in a 139-m^2 modified cold frame (model 1100; Conley's, Montclair, CA, USA) from Aug 2020 to Jan 2021. Seedlings were grown in a greenhouse at the University of Hawaii Manoa (Honolulu, HI, USA) using organic management practices and were treated with a 2% fish emulsion solution (Aqua Power™ 5-1-1; JH Biotech, Ventura, CA, USA) 1 week before transplanting. The research plot was tilled in Jul 2020, and

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Table 1. Field passport for two field trials conducted in Hawaii during 2020 and 2021.

Variable	Field trial 2020	Field trial 2021
Location	Waimanalo Research Station	Magoon Research Station
GPS coordinates	Lat. 21°20′7.872″N, long. 157°42′53.2188″W	Lat. 21°18′26.748″N, long. 157°48′35.208″W
Elevation	24 m above sea level	50 m above sea level
Name of farm or institute	The University of Hawaii at Manoa	The University of Hawaii at Manoa
Street address	41-698 Ahiki Street, Waimanalo, HI 96795, USA	2727 Woodlawn Drive, Honolulu, HI 96822, USA
Year	2020–21	2021–22
Transplanting date	7 Aug–15 Sep 2020	29 Jun 2021
First harvest date	2 Oct–16 Nov 2020	21–25 Aug 2021
Last harvest date	10-Week harvest period	10-Week harvest period
Annual rainfall (mm)	1397	3846
Annual temperature (minimum–maximum °C)	20–28	21–24
Soil description	Waialua, very-fine, mixed, superactive, isohyperthermic Pachic Haplustolls	Makiki, fine, mixed, active, isohyperthermic Typic Haplustepts
Texture	Silty clay	Clay loam
Management practices	Local extension service recommendations; organic management practices, although the site was not NOP certified.	Local extension service recommendations; organic management practices, although the site was not NOP certified.
Experimental design	RCBD augmented design[i]	RCBD augmented design[i]

[i] Per Federer and Raghavarao (1975).
NOP = National Organic Program; RCBD = randomized complete block design.

five slightly mounded beds (0.9 × 16.8 m^2) were shaped and spaced at 1.5-m centers. The experimental design consisted of five blocks (plot size, 0.9 × 1.5 m^2), where four plants were considered an experimental unit. Seven check varieties were completely randomized within each block, and 17 treatment accessions were distributed among all remaining plots, each replicated once. Within row spacing, plants were offset at 60 cm apart. A single application of Suståne 8-2-4 (Suståne, Cannon Falls, MN, USA) was incorporated into each plot at planting to achieve an N rate of 224 kg·ha^{-1}. The beds were mulched with wood chips obtained locally and installed with two driplines. Plants were supported using roller hook lines attached to two overhead high-tensile wires running along the bed perimeter. Indeterminate varieties were grown to a single stem and trained using the lower and lean method, whereas determinant types were lightly pruned and supported at the primary stem. Pest management was performed as needed and followed local extension recommendations for organic systems.

A second field trial was conducted at Magoon Research Station (lat. 21°18′26.748″N, long. 157°48′35.208″W) from Jun to Nov 2021. A custom-built screenhouse (92 m^2) was constructed onsite and outfitted with overhead cables to facilitate the lower and lean trellising method. Transplants were produced in the same location and managed according to the previous description. The research plot was tilled, and 10 slightly mounded beds (0.6 × 5.4 m^2) were shaped at 1.4-m centers. Within row spacing, plants were offset at 51 cm apart. The experimental design comprised five blocks (plot size, 0.6 × 1.4 m^2) and five plants per experimental unit. Six check varieties were completely randomized within each block, and eight treatment accessions replicated once were distributed among all remaining plots. A total fertilization rate of 224 kg·ha^{-1} N was provided through a split application of 112 kg·ha^{-1} Suståne 8-2-4 at planting, whereas the remaining equivalents were supplied through soluble fertilizer (Aqua Power™ 5-1-1; JH Biotech) treatments during flower set and early harvest. All other cultural management and site preparations for the 2020 study were repeated in 2021, with the exception that all accessions evaluated were indeterminate in growth.

Data collection

Total and marketable yield. Data for yield and marketability were gathered over 10 weeks, as established by the initial harvest of each plot. The fruit were harvested as needed to guarantee that specimens for subsequent shape and quality assessments were at their peak maturity. Qualitative assessments to determine marketability were based on the grading system outlined by Healy et al. (2015). Harvest data were recorded per plot (as kilograms per plant per plot), and marketable weights were estimated at each weighing by multiplying the average fruit weight by the number of unmarketable fruit.

Analysis of tomato fruit morphology and color. Twenty fruit of each accession were harvested at the red-ripe stage (US Department of Agriculture 1991) and analyzed using the Tomato Analyzer (ver. 4.0) for 42 fruit shape and color metrics (Supplemental Table 1). Ten fruit were prepared for longitudinal and transverse imaging (Gonzalo et al. 2009). Fruit images were captured using an Epson Perfection V39 Color Photo & Document Scanner (Epson America, Inc., Los Alamitos, CA, USA). Fruit were harvested for a 10-week period. Harvest time points were established on a per-plot basis, starting on the day of the first harvest. Frequency was as needed, because only red-ripe fruit were used for images and chemical analysis.

Evaluation of fruit physicochemical properties. Fruit prepared for image analysis were examined for the following fruit quality attributes: total titratable acidity (TTA), total soluble solids (reported as a percentage of degrees Brix), and pH. Cross sections of approximately nine fruit were homogenized in a blender, and three

Table 2. Description of germplasm screened in two Hawaii field trials conducted from 2020 to 2021.

Variable	Entry name	Market class
Waimanalo 2020		
Seed source[i]		
NeSeeds	Brandywine Pink	TH
NeSeeds	Black Krim	TH
NeSeeds	Old German	TH
NeSeeds	Costoluto Genovese	TH
NeSeeds	Dr. Wyche's Yellow Beefsteak	TH
NeSeeds	Pamela	CH
NeSeeds	Shining Star	CH
Paramount	24 Karat	HH
Paramount	Pink Smart	HH
Paramount	WS-2507	CH
Paramount	WS-2519	CH
Paramount	Stealth	HH
Paramount	Eto Truss	HH
Paramount	Aurea	HH
Paramount	Grebe	CH
Paramount	Quasimodo	HH
Yuksel Tohum	Farruco	CH
Yuksel Tohum	Nemesis	CH
Yuksel Tohum	Gelidonya	CH
Yuksel Tohum	Eurasia	CH
Seminis	Cypress	CH
Johnny's Select Seed	Skyway	CH
Honolulu 2021		
Seed source		
NeSeeds	Brandywine Pink	TH
NeSeeds	Old German	TH
NeSeeds	Costoluto Genovese	TH
NeSeeds	Pamela	CH
Paramount	Pink Smart	HH
Paramount	Stealth	HH
Paramount	Quasimodo	HH
Yuksel Tohum	Farruco	CH
Johnny's Select Seed	Marnouar	HH
Johnny's Select Seed	Marsalato	HH
Harris Seed	Ginfizz	HH
Harris Seed	Mai tai	HH
Tomato Fest	Ananas Noire	TH
Cornell University	Brandywise	HH

[i] CH = commercial hybrid; HH = hybrid heirloom; TH = traditional heirloom. Seeds were sourced from Seed sources: Johnny's Selected Seeds at https://www.johnnyseeds.com; Osborne Quality Seeds at https://www.osborneseed.com; Burpee Heirloom at https://www.panamseed.com; Paramount Seeds at https://paramountseeds.com; Seedway at https://www.seedway.com; TomaTech-Nirit Seeds Ltd. at https://www.tomatech.com; and Santa Sweets at http://www.santasweets.com.

50-mL aliquots were stored at –20 °C (Supplemental Fig. 1). Before analysis, samples were thawed for 4 h in the refrigerator (4 °C) and then brought to room temperature (20 to 22 °C) (Casals et al. 2019). Each aliquot was rehomogenized and strained with a cheesecloth to remove excess solids. Brix values were estimated using a digital refractometer (model 30051; Sper Scientific, Scottsdale, AZ, USA) with automatic temperature compensation and recorded as the average of three technical replicates. Using the procedures described in Panthee et al. (2013b), TTA was estimated as the percentage of citric acid (CA) by volume, and pH was measured using a mini automatic titrator and pH meter (model 84432; Hanna Instruments, Woonsocket, RI, USA).

Data analysis

All statistical analyses were conducted using the R statistical software (ver. 4.2.0; R Foundation for Statistical Computing, Vienna, Austria). Each environment's total and marketable yield data were calculated as the average kilograms per plant per plot (Supplemental Tables 2–8). As a result of significant variations across sites, each field experiment was analyzed separately. Total and marketable yields were evaluated by fitting a linear mixed model with genotype as the fixed effect and block as the random effect. The R package augmentedRCBD (Aravind et al. 2020) was used to conduct an analysis of variance and least square mean comparisons using Fisher's least significant difference when $P < 0.05$.

Results

During the 2020 and 2021 field trials in Hawaii, 29 cultivars (11 HH, 11 CH, and 6 TH) were tested for total yield (kilograms per plant), marketable yield (kilograms per plant), and quality (Fig. 1).

2020 Trial. In 2020, there were large differences in marketable yield (Tables 3 and 4), with *Skyway*, a commercial hybrid, having the highest yield, whereas *Stealth*, an heirloom hybrid, had the lowest (Table 4). The check cultivars did not perform among the top two groups in this trial, suggesting the large potential for new-cultivar introduction in Hawaii. Cultivars of all market classes had representatives that showed commercially viable yields, and there were few changes in ranking between marketable yields and total yields (Table 4). For the fruit quality traits TTA and Brix (Fig. 2), THs' mean TTA (0.56% CA) was significantly greater than CHs (0.43% CA, $P = 5.12 \times 10^{-10}$) and HHs (0.44% CA, $P = 6.94 \times 10^{-8}$). There was less variation among class means for Brix, with values for CHs (3.93%) roughly equivalent to the mean for THs (3.94%) (Fig. 2). THs had more negatively skewed distributions, whereas the distribution for CHs was positively skewed (Supplemental Table 3). Among the market types, CH was the only group that was significantly different ($P = 0.03$) from HHs.

2021 Trial. In 2021, there were large differences in yield ($P \leq 0.01$; Tables 5 and 6). The HH *Quasimodo* significantly outperformed all other varieties (Table 6). The check cultivars performed much better in this trial compared with experimental treatments

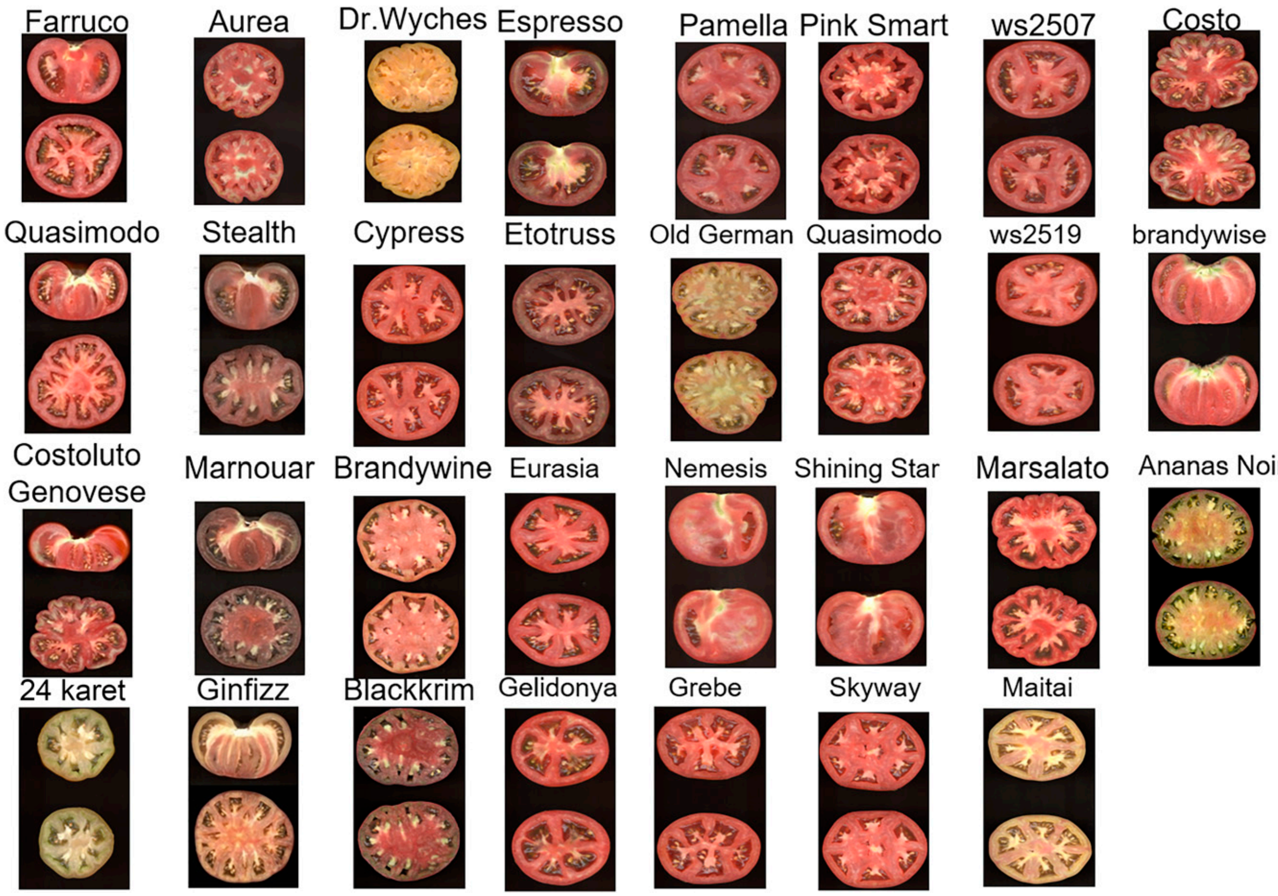

Fig. 1. Cultivars tested in this trial.

(Table 6). Again, there was no clear pattern based on market class with respect to yield, with all market classes represented in good-yielding cultivars. There were also minimal differences in rank between marketable yield and total yield. In 2021, mean comparisons for TTA exhibited a comparable ranking among market classes, with THs having the highest mean (0.73% CA) and CHs having the lowest (0.65% CA) (Fig. 3). Differences among the market classes were seen between THs (0.73% CA) and CHs (0.65% CA; $P = 6.30e^{-3}$), and HHs and CHs (0.71% CA; $P = 0.02$). In contrast, CHs had the highest mean Brix (4.34%), and no significant differences were identified among the market classes. Although the two trials were not compared statistically, trends were observed for the varieties replicated across environments. The HH *Stealth* had the lowest total yield. The TH *Old German* was among the highest yielding lines and it outperformed the two commercial checks included in the trial.

Table 3. Analysis of variance for block- and treatment-adjusted total and marketable yields in the Waimanalo 2020 field trial.

Source of variation	df	*F* value of marketable yield (kg/plant)	*F* value of total yield (kg/plant)
Treatment adjusted			
Block (ignoring treatments)	4	3.51**	4.74**
Treatment (eliminating blocks)	22	2.30**	2.47**
Treatment: check	6	1.50**	1.91**
Treatment: test and test vs. check	16	2.60**	2.68**
Residuals	24	0.32	0.37
Block adjusted			
Treatment (ignoring blocks)	22	2.72**	3.01**
Treatment: check	6	1.50**	1.91**
Treatment: test vs. check	1	11.54**	12.55**
Treatment: test	15	2.62**	2.81**
Block (eliminating treatments)	4	1.20*	1.77**
Residuals	24	0.32	0.37

*, ** Significant at $P < 0.05$ or ≤ 0.01, respectively.

Table 4. Estimated marginal means for total and marketable yield for the Waimanalo 2020 field trial.

Treatment	Market class	Marketable yield (kg/plant)	Total yield (kg/plant)
Cypress	CH	4.95 ± 0.66 a[i]	5.16 ± 0.71 a
Skyway	CH	4.95 ± 0.66 a	5.21 ± 0.71 a
Quasimodo	HH	4.38 ± 0.66 a	4.37 ± 0.71 ab
Grebe	CH	3.81 ± 0.66 ab	4.21 ± 0.71 ab
Old German	TH	2.23 ± 0.66 bc	2.30 ± 0.71 cd
Espresso	HH	2.15 ± 0.66 bc	2.30 ± 0.71 cd
Eurasia	CH	2.13 ± 0.66 bc	2.92 ± 0.71 bc
Farruco[ii]	CH	1.71 ± 0.36 c	2.01 ± 0.38 cd
Nemesis	CH	1.65 ± 0.66 cd	1.93 ± 0.71 c–e
Pamela	CH	1.60 ± 0.36 c	1.73 ± 0.38 cd
Shining Star	CH	1.60 ± 0.36 c	1.91 ± 0.38 cd
Aurea	HH	1.35 ± 0.66 c–e	1.28 ± 0.71 c–f
WS-2519	CH	1.33 ± 0.66 c–e	1.50 ± 0.71 c–f
Gelidonya	CH	1.33 ± 0.36 c	1.55 ± 0.38 c–e
24-Karat	HH	1.18 ± 0.36 dc	1.44 ± 0.38 de
Dr. Wyche’s Yellow Beefsteak	TH	1.15 ± 0.66 c–e	1.46 ± 0.71 c–e
Brandywine	TH	1.14 ± 0.66 c–e	1.92 ± 0.71 c–e
WS-2507	CH	1.01 ± 0.66 c–e	1.07 ± 0.71 c–f
Eto Truss	HH	1.01 ± 0.66 c–e	1.17 ± 0.71 c–f
Costoluto Genovese	TH	0.89 ± 0.66 c–e	1.05 ± 0.71 c–f
Black Krim	TH	0.55 ± 0.36 de	0.79 ± 0.38 ef
Pink Smart	HH	0.52 ± 0.66 c–e	0.61 ± 0.71 d–f
Stealth	HH	0.31 ± 0.36 e	0.32 ± 0.38 f

[i] Lowercase letters shared among values are not significant according to Fisher’s least significant difference (LSD; $P < 0.05$). Means comparisons are relative to the respective column’s trait.
[ii] Check treatments are in bold type. Pairwise comparisons were computed using Fisher’s LSD ($P < 0.05$).
CH = commercial hybrid; HH = heirloom hybrid; TH = traditional heirloom.

Discussion

Total and marketable yields were different among the three market classes (TH, HH, and CH). CHs were among the top-performing lines in both yield metrics in 2020 (Waimanalo), with yields being greatest from this market class found in the determinate types (*Skyway*, *Cypress*, and *Grebe*), suggesting that trellising or pruning techniques may have contributed to the results. We did not restrict the genotypes included to those with disease resistance qualities generally required by local producers (Tomato yellow leaf curl virus and Tomato spotted wilt virus). Consequently, an unexpected finding was the strong performance of the susceptible HH variety *Quasimodo*, which was the top-performing line in 2021 (Honolulu). Furthermore, its total and marketable yields in the 2020 trial were not statistically different from those of the top two CH cultivars. *Ginfizz* was susceptible to disease yet produced consistent and early yields.

Environmental conditions were most likely a significant factor in this study; therefore, additional field studies will be required to make sound recommendations to local growers. The

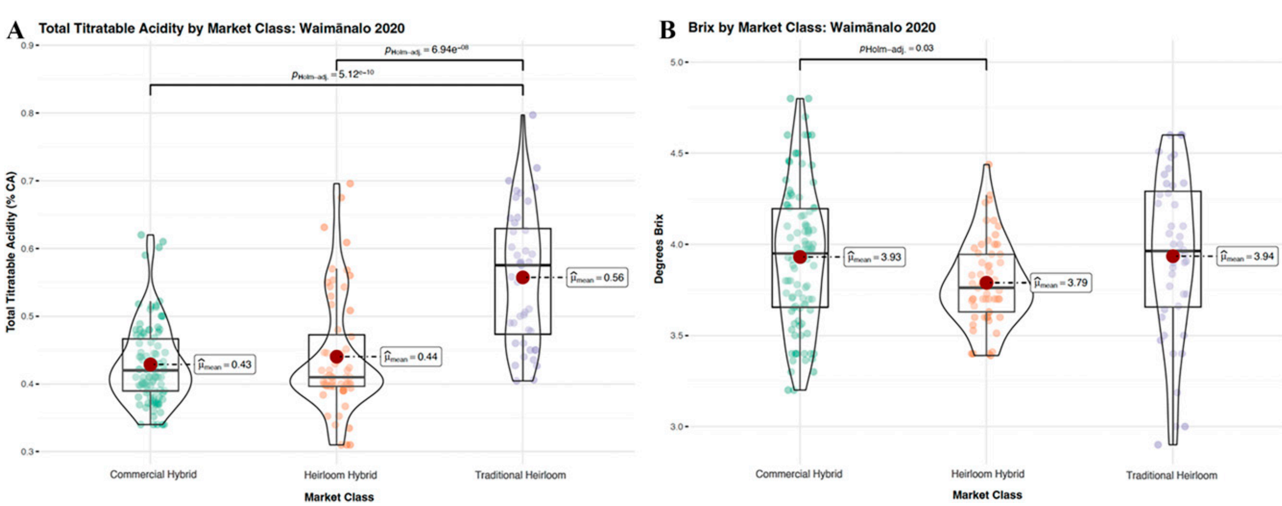

Fig. 2. Mean comparison between Waimanalo 2020 market class values using the Games-Howell test (Holmes adjusted $P < 0.05$) for two fruit quality traits: (A) total titratable acidity [measured as the percentage of citric acid (CA)] and (B) degrees Brix.

Table 5. Analysis of variance for block- and treatment-adjusted total and marketable yields in the Honolulu 2021 field trial.

Source of variation	df	*F* value for marketable yield (kg/plant)	*F* value for total yield (kg/plant)
Treatment adjusted			
Block (ignoring treatments)	4	2.96**	2.66*
Treatment (eliminating blocks)	13	10.83**	14.84**
Treatment: check	5	23.48**	34.18**
Treatment: test and test vs. check	8	2.91**	2.76**
Residuals	20	0.64	0.71
Block adjusted			
Treatment (ignoring blocks)	13	10.97**	14.87**
Treatment: check	5	23.48**	34.18**
Treatment: test vs. check	1	18.22**	13.73**
Treatment: test	7	0.99NS	1.24NS
Block (eliminating treatments)	4	2.50*	2.58*
Residuals	20	0.64	0.71

NS, *, ** Nonsignificant or significant at $P > 0.05$ or 0.01, respectively.

traditional heirloom *Old German* provided the most unexpected findings in both field studies, as its total and marketable yields surpassed several CHs. Although the scale and cultural practices used in the field trials may not be representative of more intensive commercial operations, these results suggest that a comparative economic analysis of specialty market types with varying disease resistance may be a fruitful area of research for cooperative extension in Hawaii.

Heirloom tomatoes have come to personify the preferred fresh-market archetype and command a substantial premium in the marketplace (Healy et al. 2015; Navazio 2012). Many distinctive traits of heirloom fruit are visible cues typically marketed to consumers; however, customers cannot discern between products based on the quality of their internal components. There have been consistent increases in tomato prices as a result of being designated an heirloom (Dwivedi et al. 2019). Therefore, if a tomato has the exterior traits of an heirloom, it will likely be viewed as such, but it may lack the intrinsic quality that customers anticipate. This presents a significant ethical concern regarding heirloom labeling, especially given the consumer demand for heirloom tomatoes (Alexander 2006; Klee & Tieman, 2018; Sydorovych et al. 2013). Given that red tomatoes remain the commercial standard in most markets, the differences in fruit color reflected in heirloom varieties have come to typify the label (Dwivedi et al. 2019; Joseph et al. 2017; Rodríguez-Burruezo et al. 2005). Although postharvest handling and shelf life were not investigated explicitly, they are crucial factors that affect fruit quality and have also influenced historical perceptions of heirloom tomatoes.

Conclusion

There were clear differences among CHs, HHs, and THs as classes; however, individual genotypes within each class performed well, thus providing many options for growers in Hawaii. Although measuring the chemical composition and perception of flavor was outside the scope of our study, it represents an intriguing area for future research and remains an essential

Table 6. Estimated marginal means for total and marketable yield for the Honolulu 2021 field trial.

Treatment	Market class	Marketable yield (kg/plant)	Total yield (kg/plant)
Quasimodo[ii]	HH	7.88 ± 0.51 a[i]	9.26 ± 0.53 a
Ginfizz	HH	4.64 ± 0.95 bc	4.75 ± 1.00 b–d
Old German	TH	4.54 ± 0.51 b	5.12 ± 0.53 b
Pamela	CH	3.34 ± 0.51 cd	3.58 ± 0.53 cd
Farruco	CH	3.32 ± 0.51 cd	4.20 ± 0.53 b–d
Pink Smart	HH	2.94 ± 0.51 cd	3.16 ± 0.53 de
Marsalato	HH	2.57 ± 0.95 c–e	3.17 ± 1.00 b–f
Mai Tai	HH	2.57 ± 0.95 c–e	5.27 ± 1.00 bc
Brandywine	TH	2.52 ± 0.95 c–e	3.09 ± 1.00 b–f
Costoluto Genovese	TH	2.02 ± 0.95 de	2.29 ± 1.00 d–f
Ananas Noire	TH	1.67 ± 0.95 de	2.34 ± 1.00 d–f
Marnouar	HH	1.52 ± 0.51 e	1.60 ± 0.53 f
Stealth	HH	1.49 ± 0.95 de	1.45 ± 1.00 ef
Brandywise	HH	0.87 ± 0.95 e	2.44 ± 1.00 d–f

[i] Lowercase letters shared among values are not significant according to Fisher's least significant difference (LSD; $P < 0.05$). Means comparisons are relative to the respective column's trait.
[ii] Check treatments are in bold type. Pairwise comparisons were computed using Fisher's LSD ($P < 0.05$).
CH = commercial hybrid; HH = heirloom hybrid; TH = traditional heirloom.

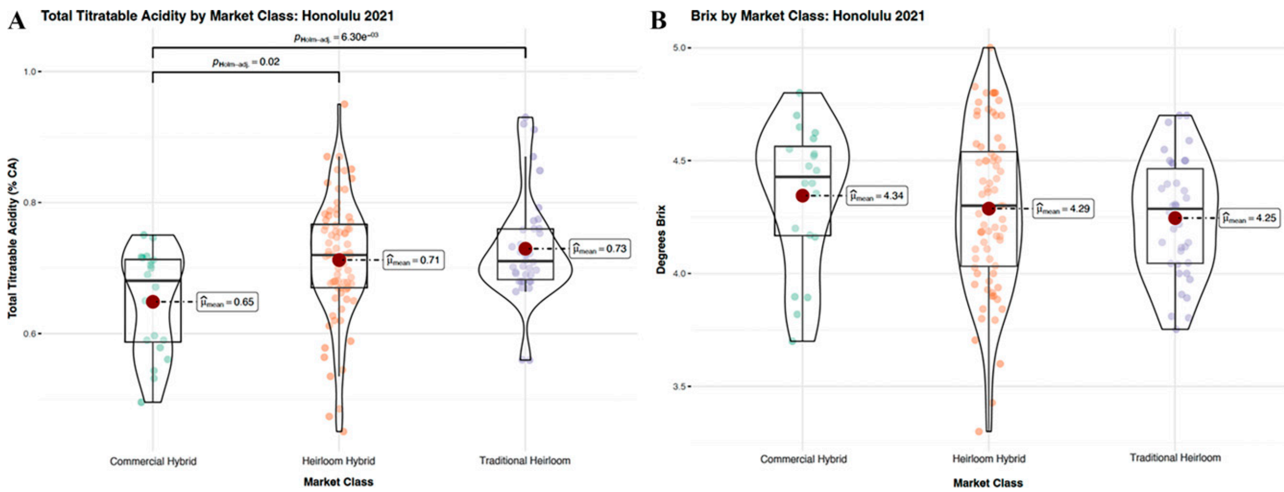

Fig. 3. Mean comparison between Honolulu 2021 market class values using the Games-Howell test (Holmes adjusted $P < 0.05$) for two fruit quality traits: (A) total titratable acidity [measured as the percentage of citric acid (CA)] and (B) degrees Brix.

element required to define the heirloom archetype. The implications of this field of study may provide a spectrum of desirable traits that can be targeted in future breeding programs, can broaden the definitions of what makes a cultivar heirloom, and can enhance ongoing efforts to improve fresh-market tomato quality.

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