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Article

Producing Cherry Tomatoes in Urban Agriculture

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Abstract: Agriculture in urban and urbanizing areas will be increasingly critical to enhancing food security and food sovereignty, creating income, strengthening social interactions, and improving health outcomes in cities. We used three roofs, a hydroponic system, an aquaponic system, and field rows in an urban environment to grow six dwarf tomato cultivars: 'Micro Tom', 'Red Robin', 'Sweet 'n' Neat', 'Terenzo', 'Tiny Tim', and 'Tumbler.' We measured the marketable yield and non-marketable yield, mass of non-marketable tomatoes exhibiting defects, and the content of 12 mineral nutrients in fruits. We found the productivity often varied among cultivars within a cropping system. 'Terenzo' and 'Tumbler' were always some of the most productive cultivars, whereas 'Micro Tom' was normally among the least productive cultivars. The production from 'Red Robin', 'Tiny Tim', and 'Sweat 'n' Neat' was more variable, sometimes producing high, moderate, or low mass. The mineral content was especially variable across the cultivars and we did not identify cultivars that were consistently high or low in mineral content across systems, indicating that the mineral content was highly influenced by a genotype x environment interaction. The amount of 5 minerals differed across cultivars in aquaponics, 9 differed in hydroponics, and 6–12 differed in the roof systems. A high-yielding cultivar should be selected first and production methods can then be modified to maximize the nutrient content.

Keywords: aquaponic; extensive green roof; field rows; hydroponic; minerals; nutrients; yield

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1. Introduction

The global population has grown rapidly, and urban residents will constitute 68% of the global population by 2050 [1]. The United States (U.S.) is no exception to this urban growth. For example, at least 17% of the total U.S. population resides on 2% of the country's total land area in the Northeast U.S., which is known as the Northeast Megalopolis and spans from Washington, D.C. to metropolitan Boston, MA [2]. Urbanization and population growth in the Northeast, which is the most highly urbanized region in the U.S., has led to a decline in the agricultural land base [3]. This decline necessitates the development of intensive farming practices that are adapted to an increasingly urbanized environment, production on increasingly marginal lands, and the displacement of agricultural production to other parts of the U.S. or world. However, population growth also represents an opportunity for farmers to meet increasing demand for local foods and value-added specialty products that serve the needs and tastes of a region's diverse population. Immigration is a source of population growth and diversity in the U.S. and more than eight million immigrants and an estimated eight million children of immigrants that were born in the U.S. live in the Northeast Megalopolis, which represents 30% of the total population of this region [4,5]. A large percentage of immigrants are settling in urban areas. For example, Hispanics represent an average of 56% of the student body in the four largest public-school districts in Massachusetts [6]. Hispanics constitute the largest ethnic/immigrant group in the Northeast and continental U.S. Recent immigration from Asia to the U.S. is increasing at a greater rate than Hispanics [7]. The Northeastern U.S. is also a destination for immigrants from Africa: New York State has the largest African population in the U.S. and Maryland the fourth largest. This human diversity means diverse tastes in food and demand for specialty crops in the region.

Agriculture in urban and urbanizing areas will be increasingly critical to enhancing food security and food sovereignty, creating a primary or secondary source of income, strengthening social interactions, and improving health outcomes in cities [8–10]. Whereas most urban farms and gardens are small compared to their peri-urban and rural counterparts, their number is growing, yield of fruits and vegetables per unit area can be much higher, and, in aggregate, they could fulfill a significant proportion of local need for fresh produce [11–13]. New England's food plan, the 50 by 60 plan, calls for expanding production to 230,000 acres of urban and suburban land to meet 50% of the regional food demand locally by 2060 [14]. Commodity crops requiring large spaces will continue to be grown in more rural areas outside of cities, but the mapping of multiple cities has shown the potential space within cities for specialty crops [15–17]. This mapping often uses satellite imagery to identify outdoor space for soil-based production at ground level and on rooftops; innovative urban cropping systems can also include soilless production and indoor spaces [18]. However, space, labor, and other start-up and input costs can be high within cities, so many urban farms may generate little, if any, revenue ([19]; Richardson, unpublished data). Urban farmers are often faced with the trade-off of maximizing social benefits to the community and enhancing food security or maximizing profit.

An urban farmer's goals influence their production strategies and may include growing crops that (1) meet the needs of the most vulnerable community members, (2) cater to niche specialty and ethnic markets by producing culturally appropriate food for the local population and immigrant groups, and/or (3) are widely consumed across cultures. Tomatoes (*Solanum lycopersicum* L.), which originated in Latin America, are one crop that can be included in all these strategies because of their popularity as fresh fruit and in affordable processed products across cultures. For example, they are the second most commonly consumed vegetable in the U.S. [20], which, in part, is attributed to Asian and Hispanic immigration to the United States [21]. Asian, Hispanic, and African countries are some of the world's largest producers, consumers, and exporters of tomatoes [22]. Tomatoes are routinely grown in urban spaces because of the availability of many cultivars that are tolerant of urban heat, are productive and hardy across urban cropping systems, and are profitable. Tomatoes are also a nutrient-dense food containing vitamins, minerals, and carotenoids, which are associated with a lower risk of some cancers, cardiovascular disease, and macular degeneration [23–25], but nutrient content can differ due to production environment and genotype [26].

As urban agriculture expands to meet the health and food demands of the urban population, so does the need for crop trials in urban spaces that identify varieties, cultivars, and species of crops that are best suited for these environments and how these environments influence the nutrient content of crops [27–29]. Common cropping systems in urban environments include: (1) soilless growing, such as hydroponics and aquaponics, which are usually indoor and use nutrient-rich water to grow crops; (2) soil-based growing, which often takes the form of raised beds, home gardens, and community gardens, which may include protective structures such as low and high tunnels; and (3) outdoor growing in soilless media on green roofs and in pots or containers. These systems vary in their temperatures, lighting, sources of nutrients, and cultural practices, which may influence the quantity and quality of the crops that are produced. The goals of this study were to investigate six cultivars of dwarf, determinate cherry tomatoes that were produced in six common urban cropping systems for one growing season to determine which cultivars resulted in the highest yield of marketable and non-marketable fruits and to report the differences in the mineral content of the fruit. We selected cherry tomatoes because of their popularity as fresh fruit, high fruit production, availability of dwarf cultivars that are ideal for small growing spaces, and our experience that heavy rains often cause larger fruiting tomatoes to split.

2. Materials and Methods

2.1. Systems and Tomato Cultivars

We used six cropping systems at four locations: (1) the 1858 m^2 green roof at the University of the District of Columbia's (UDC) Van Ness campus; (2) the green roof at the Farm at 55 M Street (Washington, DC, USA); (3) a concrete rooftop at the Station (Alexandria, VA, USA); and (4) UDC's 58 ha Firebird Farm (Beltsville, MD, USA). We planted tomatoes at Firebird Farm in three systems: (1) outdoors in a field row, (2) in a hydroponic Dutch bucket system within a high tunnel, and (3) in a decoupled aquaponic Dutch bucket system parallel to the hydroponic system. We grew tomatoes in these systems for two to three years from 2017 to 2019 to collect data and adjust methodology, but report data solely from 2019 because the variable methods prevent comparisons across years. We purchased seeds of six cherry tomato cultivars: 'Terenzo', 'Tumbler', 'Tiny Tim', 'Micro Tom', 'Red Robin', and 'Sweet 'n' Neat' (Totally Tomatoes, Randolph, WI, USA), selecting dwarf determinate cultivars because urban growing systems are often space-limited.

2.1.1. UDC's Green Roof Planter Boxes (Hereafter "Green Roof Planters")

We used 24 planter boxes that each had a surface area of 0.9 m^2 and depth of 46 cm. Green roof planters were positioned around the roof's periphery and filled to a depth of approximately 30 cm with rooflite® semi-intensive green roof media (Skyland USA, Landenberg, PA, USA). The boxes were only partially filled to prevent exceeding the weight-bearing limit of the roof. A total of four sets of six boxes were along three edges of the roof: two on the south, one on the west, and one on the north. We randomly assigned the six tomato cultivars to the six boxes in each set, with each box containing two plants of the same cultivar planted 91 cm apart. This created a randomized complete block design with each block being a set of six boxes and each box being a replicate. Drip irrigation was used as needed to supplement rain-water. We fertilized plants biweekly with 3.7 mL fish waste emulsion (Alaska Fish Fertilizer 5–1–1) in 0.95 L of water for each plant. Fish waste emulsion is a common organic fertilizer that is used in urban production and reportedly contains minerals such as calcium, magnesium, sulfur, iron, copper, zinc, and other trace elements.

2.1.2. The Farm at 55M Street Pots (Hereafter "M Street Roof Pots") and The Station Roof Pots (Hereafter "Station Roof Pots")

At each location we planted individual plants in 18.9-L (5-gallon) pots with a mix of 0.11 kg of Super K Organic Fertilizer 3-4-7 (Fertrell Company, Bainbridge, PA, USA) per 3.8 L of all-natural compost (Veteran Compost, Aberdeen, MD, USA). The plants of each tomato cultivar were planted individually in four pots, with each pot being a replicate. We arranged the pots in two parallel rows on either side of a drip irrigation line using a completely randomized design.

2.1.3. Firebird Farm Field Row (Hereafter "Farm Row")

We planted four replicates of each tomato cultivar in a single tilled field row using a completely randomized design, with each plant being a replicate. The plants were spaced 61 cm and watered with a manually-operated drip tape system as needed. We fertilized the plants biweekly with 3.7 mL fish waste emulsion (Alaska Fish Fertilizer 5–1–1) in 0.95 L of water for each plant.

2.1.4. Firebird Farm Aquaponics (Hereafter "Aquaponics")

The aquaponics system is as previously described in [29]. Briefly, we aligned 24 Dutch buckets in a single row with 55.9 cm separating the center of one bucket with another. The 11-L Dutch buckets were filled with perlite that was layered on 7.6 cm of hydroton clay pebbles. Each Dutch bucket contained one plant of each of the six tomato cultivars, with four replicates of each cultivar. We completely randomized the positions of the 24 plants within the row. This aquaponic system was within a high tunnel that was covered with double-layered polyethylene film (Sun Master® Infrared Anti-Condensate Thermal Greenhouse Film, Farmtek, Dyersville, IA, USA). We irrigated the tomato plants twice daily from a storage reservoir with blue tilapia wastewater that was supplemented with iron. We maintained electrical conductivity within the fish system between 1.0 and 2.0 mS/cm during the fruiting period by adjusting fish feed. We maintained pH between 6.00 and 7.00 using calcium carbonate and potassium hydroxide to increase pH as needed.

2.1.5. Firebird Farm Hydroponics (Hereafter "Hydroponics")

The hydroponic system was parallel to the aquaponic system in the high tunnel and the layout of plants was the same as previously described for aquaponics. We irrigated tomato plants in the hydroponic system twice daily from a storage reservoir with 10–5–14 (N-P-K) MaxiGrow solution (General Hydroponics, Santa Rosa, CA, USA) for the first 5 days, then used 5–15–14 (N-P-K) MaxiBloom solution (General Hydroponics, Santa Rosa, CA, USA) thereafter. We determined the concentration of fertilizer by measuring electrical conductivity and then added additional fertilizer as necessary to match the electrical conductivity in the aquaponic reservoir. We raised pH with potassium hydroxide, as needed, to match the pH in the aquaponic reservoir.

2.2. Plant Productivity

We planted tomato seeds in trays with potting soil in a greenhouse on 3 April 2019. Plants were transferred on 26 April 2019 to 10.1-by-10.1 cm containers and then transplanted to site locations on 20–21 May 2019. Soil on the tomato plants' roots was removed in a tap water bath before planting into aquaponic and hydroponic systems. We examined plants for pests and diseases and treated them with neem oil or PyGanic® (MGK, Minneapolis, MN, USA) when necessary. We harvested fully ripe fruit twice weekly at all sites from 23 May 2019 until 25 October 2019, except at the Station Farm which was shut down 1 August 2019 due to mites. We counted and weighed the total ripe marketable fruit and ripe non-marketable fruit for each replicate. An individual fruit was determined to be marketable if it could reasonably be included in a box of cherry tomatoes at a farmers' market (i.e., free from rot, disease, feeding damage, and other major physical damage). Of the non-marketable fruit mass, we also separately determined the percentage that had one of the following defects: (1) splitting; (2) diseased; (3) rot; (4) fed upon, mostly by insects; (5) fed upon by mites; (6) discolored; (7) poor texture; (8) wrinkled; or (9) other problems (a catch-all category for rarer defects). The defect categories were not mutually exclusive. For example, a tomato with splitting and discoloration would be included in both defect categories. The green roof had multiple plants per replicate in a system, so we divided the total count and mass from all the harvested fruit by the number of plants to calculate count and mass on a per-plant basis.

We collected samples for mineral analysis from three biological replicates of each cultivar at each location between 8 July 2019 and 5 August 2019, except in the field row which was excluded because of disease afflicting the fruit. We stored samples immediately in a freezer at −80 °C until they were shipped on ice to New Age Laboratories (South Haven, MI, USA). New Age Laboratories analyzed content of 12 mineral nutrients, including boron (B), calcium (C), copper (Cu), iron (Fe), potassium (K), magnesium (Mg), manganese (Mn), sodium (Na), phosphorus (P), sulfur (Si), and zinc (Zn), by inductively coupled plasma optimal emission spectrometry [30]. Results are presented on a dry matter basis.

2.3. Statistical Analyses

We analyzed differences in number and mass of marketable and non-marketable fruit and minerals across cultivars within a cropping system with separate general linear models (PROC GLM; [31]). Additionally, we analyzed the percentage of non-marketable fruit in each of the nine defect categories with separate general linear models (6 cropping systems × 9 defect categories = 54 possible models). In a limited number of cases, we dropped a cultivar from analysis because of insufficient sample size. We used base-10 log and square-root transformations on data when necessary to meet assumptions of normality prior to analysis. In two instances, data still were not normally distributed after transformations, so we used the F-approximation of the Friedman test and associated rank-sum multiple comparison test [32]. We used the Tukey–Kramer means separation test for all analyses to determine which means differed ($p < 0.05$). Means for non-transformed data are presented in the results.

3. Results

3.1. Plant Productivity

The number and mass of marketable and non-marketable fruit differed among cultivars in all cropping systems except for the number and mass of non-marketable fruit in the M Street roof pots. The relative order of cultivars from most to least productive were similar for number of marketable fruit and mass of marketable fruit, and number of non-marketable fruit and mass of non-marketable fruit, so we present full results for the two measures of mass only. We also mostly do not present results for the nine defect categories because (1) data for 34 of 54 possible general linear models were lacking (indicating that the defect was not a problem at a site); (2) when enough data were present for analysis, results were usually non-significant (in 14 of 20 cases); and (3) in the six models where defects were different across cultivars, a Tukey–Kramer means separation test failed to find differences in pairs of the means, except in one instance.

There was a large amount of variance in the mass of marketable fruit that were collected in aquaponics and green roof planters and the cultivars in these systems produced a similar mass of fruits (Table 1). However, in the other systems 'Terenzo' and 'Tumbler' were always among the most productive cultivars, whereas 'Micro Tom' was normally among the least productive. Production from 'Red Robin', 'Tiny Tim', and 'Sweat 'n' Neat' was more variable, sometimes producing high, moderate, or low mass. On average, cultivars produced a higher mass in the M Street roof pots, followed by the green roof planters and hydroponic system, and relatively low mass in the aquaponics system, farm row, and Station roof pots, but we did not statistically analyze differences among systems because they are not true replicates (Table 1).

Table 1. Mean mass, in grams, of marketable cherry tomatoes per plant across six cultivars and six systems. Means with different letters within a row are different (Tukey–Kramer means separation test, $p < 0.05$).

System	Cultivar						*p*	System Average
	'Terenzo'	'Tumbler'	'Sweet 'n' Neat'	'Tiny Tim'	'Red Robin'	'Micro Tom'		
Aquaponic	456	706	488	332	336	.	0.02	464
Hydroponic	2011 a	1740 a	578 b	386 b	218 b	100 b	<0.01	871
Farm row	671 ab	1548 a	212 b	70 b	49 b	47 b	<0.01	450
Green roof planters	1259	1375	1047	1089	526	753	<0.01	1019
Station roof pots	664 a	495 ab	147 ab	561 ab	233 ab	27 b	<0.01	369
M Street roof pots	3299 a	3908 a	835 bc	1390 ab	655 bc	81 c	<0.01	1765
Cultivar average	1393	1629	551	637	336	181		

The lowest mass of non-marketable fruit was collected from aquaponics and the M Street roof pots and cultivars in these systems produced a similar mass of non-marketable fruit (Table 2). On average, cultivars produced a higher mass of non-marketable fruit in the farm row followed by the Station roof pots, but we did not statistically analyze the differences among systems because they are not true replicates (Table 2). Plants in the field row were afflicted by disease, leading to low marketable yield and high non-marketable yield of fruit. The plants in the Station roof pots were heavily infested with mites, which led to this site being shut down sooner than the others, low marketable yield, and high non-marketable yield of fruit. The amount of rot differed among the cultivars in this system ($F5 = 14.2$, $p < 0.01$), with 'Micro Tom', 'Red Robin', and 'Sweat 'n' Neat' producing the most rotted fruit and 'Terenzo', 'Tumbler', and 'Tiny Tim' producing the least. Whereas 'Micro Tom' was the lowest producing cultivar of non-marketable fruit in most systems, it was among the highest in the green roof planters. All the cultivars except for 'Micro Tom' produced a relatively high mass of non-marketable fruit in the Station roof pots.

Table 2. Mean mass (percentage of non-marketable mean mass of the total mean mass), in grams, of non-marketable cherry tomatoes per plant across six cultivars and six systems. Means with different letters within a row are different (Tukey–Kramer means separation test, $p < 0.05$).

System	Cultivar						p	System Average
	'Terenzo'	'Tumbler'	'Sweet 'n' Neat'	'Tiny Tim'	'Red Robin'	'Micro Tom'		
Aquaponic	107 (19)	132 (16)	39 (7)	51 (13)	44 (12)	.	<0.01	75
Hydroponic	121 b (6)	503 a (22)	116 b (17)	51 b (12)	81 b (27)	43 b (30)	<0.01	157
Farm rows	4207 a (86)	3096 ab (67)	765 b (78)	1193 b (94)	710 b (94)	63 c (57)	<0.01	1742
Green roof planters	882 ab (41)	1175 a (46)	465 bc (31)	227 c (17)	266 bc (34)	570 abc (43)	<0.01	588
Station roof pots	1025 a (61)	1239 a (71)	904 ab (86)	1088 a (66)	797 ab (77)	72 b (72)	<0.01	888
M Street roof pots	101 (3)	181 (4)	149 (15)	125 (8)	252 (28)	28 (26)	0.12	144
Cultivar average	1064	1054	406	456	358	139		

The cultivars producing a high mass of non-marketable fruit varied in aquaponics, hydroponics, green roof planters, and M Street roof pots (Table 2). 'Tumbler' was consistently one of the highest producers of non-marketable fruit, as was 'Terenzo' in all the systems except hydroponics. This may partially be attributed to the fact that these cultivars often produce the most total fruit (marketable + non-marketable). The percentage of non-marketable fruit compared to the total fruit production is often moderate to low compared to the other cultivars, indicating in these cases that the large mass of non-marketable fruit is likely because of the high mass of the total fruit production and not because these cultivars produce a lot of non-marketable fruit compared to other cultivars (Table 2). However, 'Terenzo' and 'Tumbler' produced the highest percentage of non-marketable fruit in the aquaponic system, and 'Tumbler' also produced the highest percentage in the green roof planters, which indicates in some cases that the relative amount of non-marketable fruit to total fruit may be higher than other cultivars.

3.2. Minerals

The amount of 5 minerals differed across cultivars in aquaponics, 9 differed in hydroponics, 6 differed in green roof planters, all 12 differed in the Station roof pots, and 7 differed in the M Street roof pots (Table 3). In 17 cases where the nutrients were different across cultivars, we did not find differences in means through a Tukey–Kramer means separation test. We focus on the 21 cases where a Tukey–Kramer means separation test found differences in pairs of means (Table 3). Most nutrients were relatively similar across cultivars in aquaponics, except 'Red Robin' had less sodium than other cultivars ('Micro Tom' was not tested because of inadequate sample size). Nutrients were also relatively similar in hydroponics, but there were some notable differences: 'Micro Tom' had the highest iron content and 'Sweet 'n' Neat' had among the lowest amounts of boron, iron, potassium, and sodium. Of the three nutrients that differed among cultivars in the green roof planters, 'Red Robin' and 'Sweet 'n' Neat' had among the highest nutrient content in all three cases, whereas 'Tumbler' had lower amounts of calcium and sulfur ('Terenzo' was not tested because of inadequate sample size). 'Red Robin', 'Sweet 'n' Neat', and 'Micro Tom' usually had the highest nutrient content in the Station roof pots and 'Terenzo', 'Tiny Tim', and 'Tumbler' often had lower nutrient content, except 'Tiny Tim' was particularly high in sodium and there are some other exceptions to this pattern. 'Micro Tom' was highest in boron in the M Street roof pots and that cultivar and most of the others were also relatively high in copper, iron, and sulfur, except 'Terenzo' and 'Tiny Tim' had lower amounts of three of the four nutrients.

Table 3. Mean mg/kg of minerals that differed in cherry tomatoes across six cultivars in five systems. Means with different letters within a row are different (Tukey–Kramer means separation test, $p < 0.05$).

System	Mineral	Cultivar						*p*
		'Micro Tom'	'Red Robin'	'Sweet 'n' Neat'	'Terenzo'	'Tiny Tim	'Tumbler'	
Aquaponic	Boron	.	4.7	5.8	4.7	6.3	6.8	0.34
	Calcium	.	1290	1320	1170	1245	1300	0.95
	Copper	.	4.0	4.1	4.0	2.9	4.5	0.04
	Iron	.	34.0	32.3	52.3	42.7	63.0	<0.01
	Magnesium	.	2060	2180	1857	1600	2033	0.07
	Manganese	.	8.8	8.9	6.7	6.9	8.5	0.11
	Phosphorous	.	5880	6240	4767	4043	5253	0.02
	Potassium	.	29,800	31,933	29,433	29,300	35,000	0.15
	Silicon	.	123.0	137.7	91.1	83.6	109.3	0.13
	Sodium	.	451 ab	374 b	469 ab	930 a	533 ab	<0.01
	Sulfur	.	1353	1417	1283	1071	1420	0.02
	Zinc	.	2.6	0.9	2.9	8.3	4.5	0.10
Hydroponic	**Boron**	8.1 a	4.3 ab	3.0 b	2.6 b	3.9 ab	3.5 ab	<0.01
	Calcium	2513	934	1187	931	1094	818	0.01
	Copper	8.3 a	5.0 ab	4.2 ab	4.4 ab	3.6 b	4.1 ab	<0.01
	Iron	51.7 a	26.0 b	25.7 b	23.0 b	20.0 b	23.3 b	<0.01
	Magnesium	2357	2053	1917	2297	1793	2063	0.03
	Manganese	11.5	10.1	8.4	9.2	7.7	9.8	0.17
	Phosphorous	4940	5967	5153	5223	5573	5370	0.36
	Potassium	30,600 ab	31,000 ab	26,633 b	31,767 ab	32,633 a	33,000 a	<0.01
	Silicon	84.1	130.7	145.7	121.7	121.0	94.1	0.02
	Sodium	712 ab	323 ab	282 b	344 ab	909 a	308 ab	<0.01
	Sulfur	1980	1547	1387	1683	1387	1437	0.10
	Zinc	4.0	9.6	8.1	15.3	12.7	13.3	0.01
Greenroof planters	Boron	12.7	12.3	10.7	.	10.9	10.2	0.15
	Calcium	3367 a	2440 ab	2740 ab	.	2610 ab	1434 b	<0.01
	Copper	6.7	6.5	9.3	.	6.7	6.2	0.53
	Iron	43.0	56.7	53.7	.	48.0	43.0	0.05
	Magnesium	1897	2007	1887	.	1435	1328	<0.01
	Manganese	16.3	18.0	17.0	.	17.0	18.0	0.22
	Phosphorous	4967	5720	5220	.	4605	4380	0.06
	Potassium	27,500	25,633	24,500	.	24,900	24,450	0.61
	Silicon	46.6 b	110.3 ab	120.6 a	.	76.7 ab	75.6 ab	<0.01
	Sodium	915	1189	1157	.	2030	1247	0.25
	Sulfur	2157 ab	2480 a	2293 ab	.	1555 b	1703 b	<0.01
	Zinc	27.7	40.7	39.0	.	28.5	30.5	0.01
Station roof pots	Boron	11.0	8.8	8.9	8.7	7.6	10.3	0.04
	Calcium	2353 a	2100 ab	1763 abc	972 abc	1623 bc	754 c	<0.01
	Copper	6.6 a	4.4 ab	3.8 b	2.4 b	2.6 b	2.6 b	<0.01
	Iron	47.3 a	45.3 a	42.3 ab	29.0 c	28.7 c	33.3 bc	<0.01
	Magnesium	2093 a	2027 a	1763 ab	1247 bc	1113 c	1413 bc	<0.01
	Manganese	13.7 a	16.3 a	12.7 a	7.2 b	7.1 b	8.7 b	<0.01
	Phosphorous	6033 ab	6313 a	5460 ab	4447 b	4480 b	4550 ab	<0.01
	Potassium	34,200	34,033	33,633	27,700	27,833	30,833	<0.01
	Silicon	56.6	60.5	58.8	34.1	46.5	33.4	0.01
	Sodium	434 b	354 b	437 b	385 b	782 a	349 b	<0.01
	Sulfur	2436 a	2353 a	2100 ab	1450 b	1447 b	1560 b	<0.01
	Zinc	25.3	30.7	28.3	21.0	18.3	24.0	<0.01
M Street roof pots	**Boron**	13.0 a	7.6 b	8.5 b	7.8 b	7.8 b	8.2 b	<0.01
	Calcium	3667	2297	2070	1900	2100	1510	0.01
	Copper	7.2 a	3.5 ab	4.1 ab	3.1 b	3.3 ab	4.6 ab	<0.01
	Iron	89.7 a	50.0 ab	51.3 ab	38.7 b	40.7 b	42.3 ab	<0.01
	Magnesium	2547	2217	2017	2140	1530	2073	0.02
	Manganese	24.3	20.0	22.7	17.0	12.7	16.7	0.15
	Phosphorous	6040	6533	6797	5917	5723	6030	0.37
	Potassium	32,467	35,300	31,633	35,167	33,833	37,000	0.42
	Silicon	12.0	11.3	6.3	6.7	13.3	7.3	0.47
	Sodium	585	453	460	348	918	292	<0.01
	Sulfur	1903 ab	1903 ab	2330 a	1837 ab	1457 b	1737 ab	<0.01
	Zinc	17.7	28.7	31.0	18.7	17.0	17.3	0.02

4. Discussion

We tested yield and aspects of fruit quality of six tomato cultivars that were produced in six urban systems. The systems were an aquaponic and hydroponic system within the same high tunnel, three roof systems (two using pots and one using planters), and a field row. Productivity and nutrients of fruit varied among cultivars within a system, but 'Terenzo' and 'Tumbler' frequently produced the highest marketable mass of fruits. 'Tumbler' was previously reported as having good fruiting and as a popular cultivar in the Northeast U.S. [33], but there is a lack of information on 'Terenzo.' Although 'Tumbler' and 'Terenzo' may seem like ideal cultivars based on yield, their nutrient content, like the other cultivars that we tested, was probably heavily influenced by a genotype by environment interaction. The nutrients of all the crops can be influenced by genotype and environment, but the variability that we and others measured (e.g., [26,34]) indicate that tomato nutrients may fluctuate more readily than some other crops. For example, we measured minerals in six strawberry cultivars in almost all the same systems that were used in this study and found that only three minerals differed across cultivars in aquaponics (compared to five in tomatoes), four differed in hydroponics (nine in tomatoes), and two differed in green roof planters (six in tomatoes) [29]. We also measured minerals in genotypes of *Hibiscus sabdariffa* L. and found no genotype by environment interaction, although the amount of minerals was separately influenced by genotype and environment [28].

Given the ability of production methods to influence nutrients in tomatoes, it seems reasonable to select a high-yielding cultivar of cherry tomatoes first and then modify production methods to maximize nutrient content of that cultivar. A second consideration in urban production should be disease and pest resistance of tomato cultivars. We did not include pests and diseases in our results because there was no variability among cultivars. However, plants in aquaponics and hydroponics were the only ones that were inflicted with powdery mildew, so that should be considered when selecting a cultivar for these soilless systems. An unknown disease severely impacted production in the open field row and mites and aphids were present in every system, but especially soilless systems (mites and aphids) and green roof pots (mites). The overall productivity of a cropping system can also be a consideration when selecting the urban production methods for tomatoes and the green roof planter boxes and one location of pots on a rooftop (M Street) surprisingly outperformed the soilless systems, farm row, and another set of pots on a rooftop (the Station). These results should be interpreted with caution since this was a one-year study and the farm row and the Station roof pots were afflicted by disease and mites, respectively. Multiple years of crop trials would be needed to determine which systems consistently yield more tomatoes and which ones consistently have problems. However, some of our results pertaining to cropping systems are informative. Of the two soilless systems, production in hydroponics was higher than aquaponics, which is a result we also saw in our strawberry trials and may be due to nutrient availability in commercial hydroponic fertilizers versus fish waste [29]. Also, where and how pots are situated on roofs can lead to drastically different outcomes, such as in this study. Pots at M Street were situated on a green roof media, which lowered the surrounding temperature. Additionally, the tomato roots grew out of the drainage holes at the bottoms of pots and into the green roof, which likely provided additional benefits that the tomato plants that were confined to their pots on a warmer concrete surface at the Station did not receive. The warmer environment at the Station also may have led to higher plant stress, making plants susceptible to the mite infestation that occurred [35]. Environmental stress and mites can influence the nutrient composition of tomatoes [35], so this may explain why this site was the only one where all 12 of the minerals varied among cultivars.

One outstanding question with urban agriculture is whether it is economically profitable. All cultivars that we tested produced relatively low yields because they were dwarf varieties, although our reported yields in most systems are higher than those from indoor production of 'Tiny Tim' and 'Red Robin' under artificial lighting [36]. Also, 'Terenzo' and 'Tumbler' produced larger yields than determinate and indeterminate non-dwarf cultivars in greenhouses [37,38]. However, multiple dwarf plants may be needed for their yield to be comparable to non-dwarf cultivars that are grown in open fields [38]. Dwarf varieties may be most useful in small home spaces or in for-profit enterprises with dense plant spacing but could have more limited uses if economic profit is the primary concern. The best solution for obtaining a better yield of cherry tomatoes in urban agriculture systems is using high-yielding cultivars, which also needs to be accompanied with research to determine the production techniques that maximize yield in each system.

We highlight some traits of cherry tomato cultivars when they are grown in urban systems, but future studies could include a market analysis to see which ones are most preferred by consumers, more research to identify ideal cultivars for each major urban cropping system, measures of fruit flavor and color, and measurements of other nutrients, including vitamins and carotenoids. Vitamins and carotenoids confer some of the health benefits that are ascribed to tomatoes but are also likely to be influenced by production methods [26,34]. Maximizing nutritional benefits of urban crops is of utmost importance to urban populations.

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