Teaching Methods

Growth, Cold-hardiness, and Flowering of Sweet Olive, Fortune's Osmanthus, Fragrant Tea Olive, and Holly Tea Olive in Tennessee

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SUMMARY. Production and use of sweet olive (*Osmanthus armatus*), fragrant tea olive (*O. fragrans*), holly tea olive (*O. heterophyllus*), and fortune's osmanthus (*O. xfortunei*) as a landscape plant is currently limited to U.S. Department of Agriculture (USDA) Hardiness Zones 7 to 10, and nursery growers wish to extend the range of these species into colder climates. To provide recommendations to growers and landscapers and inform breeding efforts for cold-hardiness improvement, a replicated trial was conducted in a USDA Hardiness Zone 6b/7a transition zone. Fifteen cultivars and two unnamed accessions representing four species were evaluated for growth, stem necrosis, and flowering in a pot-in-pot production system from 2015 to 2017. One-half of the plants in each cultivar were moved to winter protection each November and returned to the field each May. There were significant differences in growth and cold-hardiness among cultivars. Percent increase in the growth index after three growing seasons for winter-exposed accessions of sweet olive, fortune's osmanthus, fragrant tea olive, and holly tea olive averaged 867%, 1175%, 155%, and 6361%, respectively. Percent stem necrosis in May 2017 for sweet olive, fortune's osmanthus, fragrant tea olive, and holly tea olive averaged 1.1%, 2.7%, 44.8%, and 20.2%, respectively. The most cold-tolerant accessions based on stem necrosis and growth index of winter-exposed plants were 'Kaori Hime', 'Hariyama', 'Shien', 'Head-Lee Fastigate', and 'Rotundifolius' holly tea olive, 'San Jose' fortune's osmanthus, and 'Longwood' sweet olive. Of these cultivars, Kaori Hime, San Jose, and Longwood flowered under winter-exposed conditions. All fragrant tea olive cultivars were damaged by winter exposure. 'Fodingzhu' was the only fragrant tea olive cultivar that flowered each year under winter-exposed conditions. Evaluation and breeding efforts are continuing to extend the range for production and growth of this genus.

The genus *Osmanthus* consists of ≈30 species of evergreen trees and shrubs distributed primarily throughout temperate, subtropical, and tropical China. Fragrant tea olive is the most popular species, with at least 166 named cultivars (Xiang and Liu, 2008). Fragrant tea olive is a common landscape commodity throughout its native range, where it is prized for its

fragrant flowers and leaf extracts used in traditional medicine (Shang et al., 2003). Four groups of fragrant tea olive [Albus, Asiaticus, Aurianticus, and Luteus (a.k.a Thunbergii); Xiang and Liu, 2008] are defined by morphological and phenological traits, including flower color, peduncle length, and flowering time. Other popular species include holly tea olive and fortune's osmanthus, which is a hybrid of fragrant tea olive and holly tea olive. These species have cultivars with diverse plant architecture, leaf forms, and flowering times and are commonly found in landscape plantings throughout USDA Hardiness Zones 7, 8, and 9 in the United States.

Nursery growers wish to extend the range of fragrant tea olive into colder climates throughout the United States and China (Dong, 2010). Production and landscape use currently are limited to USDA Hardiness Zones 7 to 8 for sweet olive, Zones 7 to 9 for holly tea olive, and Zones 7 to 10 for fragrant tea olive. Mature landscape plants of holly tea olive have been observed as far north as USDA Hardiness Zone 6b, indicating that the species may be more cold-hardy than traditionally thought (Dirr, 2009). Cold-hardiness of the hybrid fortune's osmanthus appears to be intermediate to that of its parents (Dirr, 2009), indicating that hybrid breeding may be a promising avenue for improving cold-hardiness in the genus.

Germplasm evaluation and breeding are underway to find species and cultivars suitable for the U.S. market and to incorporate favorable traits into fragrant tea olive. However, there is little replicated trial information on this genus colder than USDA Zone 7. The current evaluation was conducted in a climatic and geographic transition zone in Tennessee on the border of USDA Hardiness Zones 6 and 7 (U.S. Department of Agriculture, 2012).

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
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
16.3871	inch ³	cm ³	0.0610
0.5933	lb/yd ³	kg·m ⁻³	1.6856
28.3495	oz	g	0.0353
(°F - 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

Many of the plants produced in the Zone 6b/7a transition area can be used in landscapes as far south as Zone 8 and as far north as Zone 5 (Fare, 2017). To provide recommendations to growers and landscapers and inform breeding efforts for cold-hardiness improvement, a replicated trial was conducted at the Tennessee State University Nursery Research Center in McMinnville, TN (lat. 35.7°N, long. 85.8°W), from 2015 to 2017.

Materials and methods

Fifteen cultivars and two unnamed accessions representing four species were chosen for the trial (Table 1). Plants were purchased from Nurseries Caroliniana (North Augusta, SC) in Apr. 2015 and immediately potted into 14.6-L containers (C2000; Nursery Supplies, Chambersburg, PA), with the exception of two large fortune's osmanthus cultivars that were potted into 23.0-L containers (C2800; Nursery Supplies). Growing media consisted of pine bark amended with 6.6 kg·m⁻³ 19N–2.1P–7.4K controlled-release fertilizer (Osmocote Pro; Scotts-Sierra Horticultural Products Co., Maryville, OH), 0.6 kg·m⁻³ micronutrient fertilizer (Micro-max; Scotts-Sierra Horticultural Products Co.), 0.6 kg·m⁻³ iron sulfate (Sprint 330; BASF Co., Florham Park, NJ), and 0.2 kg·m⁻³ magnesium sulfate (Epsom salt; PQ Corp., Joliet, IL).

Plants were moved to the trial site 1 May 2015. Trial site consisted of a pot-in-pot production system with 23.0-L socket pots in 4-ft-wide rows separated by 4-ft grassy alleys. The 14.6- or 23.0-L pots containing the plants were placed inside the

Table 1. Sweet olive, fortune's osmanthus, fragrant tea olive, and holly tea olive cultivars represented in McMinnville, TN cultivar trial.^z

Common name	Cultivar	Purchase size (L) ^y	Transplanted 15 May 2015 (L)
Sweet olive	Jim Porter	3.7	14.6
Sweet olive	Longwood	3.7	14.6
Fortune's osmanthus	— ^x	11.4	23.0
Fortune's osmanthus	Fruitlandii	11.4	23.0
Fortune's osmanthus	San Jose	3.7	14.6
Fragrant tea olive	Fodingzhu	3.7	14.6
Fragrant tea olive	Apricot Echo	3.7	14.6
Fragrant tea olive	Beni Kin Mokusei	3.7	14.6
Fragrant tea olive	— ^x	3.7	14.6
Holly tea olive	Goshiki	3.7	14.6
Holly tea olive	Hariyama	0.8	14.6
Holly tea olive	Head-Lee Fastigate	3.7	14.6
Holly tea olive	Kaori Hime	0.8	14.6
Holly tea olive	Ogon	3.7	14.6
Holly tea olive	Rotundifolius	1.6	14.6
Holly tea olive	Shien	1.6	14.6
Holly tea olive	Variegatus	1.6	14.6

^zAll plants were purchased from Nurseries Caroliniana, North Augusta, SC, on 1 May 2015. All plants were purchased as 1-year-old rooted cuttings, except for the fortune's osmanthus, which were 2-year-old rooted cuttings.

^y1 L = 0.2642 gal.

^xSeedling (i.e., not a named cultivar).

socket pots. Native soil was backfilled in socket pots containing 14.6-L pots to steady and insulate pots. The experimental design was a completely randomized design. Within-row spacing was 4 ft. Plants were top-dressed with 72 g of 19N–2.1P–7.4K controlled-release fertilizer (Osmocote Pro) in Aug. 2015 and Apr. and Aug. 2016 and 2017. Drip irrigation was used as needed throughout the growing season.

Six plants of each cultivar were included in the trial. Within each cultivar, one-half of the plants were assigned to a protected overwintering treatment. These plants were removed from the trial site to a 48-ft-long × 24-ft-wide × 10.8-ft-tall covered elliptical coldframe ≈15 Nov. each year of the study. The coldframe was covered with 6-mil clear plastic and provided with supplemental heat via a gas-fired unit heater to maintain at least 39 °F. Protected plants were watered once per week for 10 min; no supplemental irrigation was provided to exposed plants. Protected plants were brought back to the trial site 15 Apr. each year of the study. The study began 15 May 2015 and covered three growing seasons, ending 25 Oct. 2017. Weather data during the study period were collected from the National Environmental Satellite, Data, and Information Service McMinnville, TN Station

[USC00405882 (lat. 35.6723°N, long. 85.7810°W, elevation 940 ft)].

Plants were measured for growth in 2015 (15 May and 20 Oct.), 2016 (16 May and 20 Oct.), and 2017 (22 May and 25 Oct.). Measuring took place in spring after winter damage was manifest in shoots and foliage. Shoot height was measured to the tallest node with foliage. A growth index (GI) was calculated for each plant according to the formula $\pi b r^2$, where b is shoot height in centimeters, $r = 0.5d$, and d is the mean of two perpendicular diameter measurements in centimeters (Lindstrom et al., 2001). Percent increase in GI was determined for each plant by the formula: $[(GI_t - GI_{\text{initial}}) \div GI_{\text{initial}}] \times 100\%$, where GI_{initial} is the GI value at the start of the study period and GI_t is the GI at the time of measurement. Necrotic stem was measured from the first node with foliage to the shoot tip of the tallest three shoots. Percent necrotic stem was determined for each shoot by the formula: percent necrotic stem $\div$ total stem length $\times 100\%$. Total stem length was determined by measuring from the base of the plant to the shoot tip. Flowering was observed every 2 weeks from the onset of flowering of the earliest cultivar to the termination of flowering of the latest cultivar. Numbers of apical and lateral flowers were counted

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Table 2. Surface air temperatures and precipitation in McMinnville, TN, during the winters of 2015–16 and 2016–17.^z

Yr	Month	Mean temp (°F) ^{y,x}	Mean maximum temp (°F) ^w	Mean minimum temp (°F) ^v	Heating degree days (no.) ^u	Cooling degree days (no.) ^t	Highest temp (°F)	Lowest temp (°F)	Duration maximum temp (d) ^s	Duration minimum temp (d) ^r	Total precipitation (inches) ^x
2015	Nov.	56.0	65.5	46.5	279	8	77	21	0	4	5.4
2015	Dec.	53.9	63.6	44.3	357	14	76	26	0	8	8.5
2016	Jan.	37.5	47.1	27.9	853	0	68	9	2	24	5.0
2016	Feb.	44.7	53.3	36.0	590	0	73	18	1	12	8.2
2016	Mar.	57.0	68.3	45.8	275	27	85	29	0	5	2.4
2016	Nov.	54.2	68.6	39.8	328	18	86	20	0	9	5.0
2016	Dec.	43.7	53.8	33.6	663	4	75	17	0	15	8.3
2017	Jan.	48.6	56.8	40.3	510	0	72	5	3	7	4.1
2017	Feb.	52.9	64.0	41.7	343	4	78	20	0	6	2.9
2017	Mar.	54.0	66.6	41.4	353	13	80	17	0	11	6.0

^zAll data collected from the National Environmental Satellite, Data, and Information Service, McMinnville, TN, Station [lat. 35.6723°N, long. 85.7810°W, elevation 940 ft (286.5 m)].

^yMean temperature = the sum of mean daily temperatures for each day in a month divided by the number of days in the month.

^x(°F – 32) ÷ 1.8 = °C, 1 inch = 25.4 mm.

^wMean maximum temperature = the average daily maximum air temperature observed during a calendar month.

^vMean minimum temperature = the average daily minimum air temperature observed during a calendar month.

^uHeating degree days = (65 °F – m) × n, where m = the daily mean temperature and n = number of days in the month.

^tCooling degree days = (m – 65 °F) × n, where m = the daily mean temperature and n = number of days in the month.

^sDuration maximum temp = number of days the daily maximum temperature is less than 32 °F.

^rDuration minimum temp = number of days the daily minimum temperature is less than 32 °F.

on each plant and flower morphology (male, female, or perfect) was noted.

Data analysis was performed using SAS software (version 9.4 for Windows; SAS Institute, Cary, NC). Fisher's exact test of independence was used to determine whether winter mortality was independent of cultivar for winter-exposed accessions. For each treatment (winter-protected or winter-exposed), the general linear model procedure (PROC GLM) was used to partition variance in GI and percent necrotic stem into sources attributable to cultivar and error. Constancy of residual variance was checked using the Brown–Forsythe test. All variables satisfied analysis of variance assumptions except percent growth in 2017. Percent growth in 2017 data were transformed using square root, which alleviated nonconstant variance; non-transformed means are presented in tables and figures for clarity. Means for each cultivar were compared using Tukey's Studentized range test with an $\alpha = 0.05$ significance level.

Results

The minimum temperatures experienced by unprotected plants in the first winter (2015–16) and second winter (2016–17) were 9 and 5 °F, respectively (Table 2). The first winter had 36 d in January and February during which the minimum temperature was below 32 °F. In the second winter, only 13 d in January and February were below 32 °F. There was no day during the study during which minimum temperatures

Table 3. Percent necrotic stem for sweet olive, fortune's osmanthus, fragrant tea olive, and holly tea olive cultivars grown in a winter-exposed pot-in-pot production system in McMinnville, TN.^z

Cultivar	Necrotic stem 2016 (%)	Necrotic stem 2017 (%)
Sweet osmanthus		
Jim Porter	1.8 a ^x	2.1 a
Longwood	0.0 a	0.0 a
Fortune's osmanthus		
— ^y	0.0 a	0.0 a
Fruitlandii	4.3 a	0.0 a
San Jose	1.7 a	8.1 ab
Fragrant tea olive		
Apricot Echo	14.4 a	60.7 ab
Beni Kin Mokusei	0.0 a	29.2 ab
Fodingzhu	— ^w	—
— ^y	0.0 a	10.3 ab
Holly tea olive		
Goshiki	3.2 a	11.3 ab
Hariyama	0.0 a	17.8 ab
Head-Lee Fastigate	0.0 a	0.0 a
Kaori Hime	0.2 a	0.6 a
Ogon	3.8 a	46.0 ab
Rotundifolius	0.0 a	14.0 ab
Shien	0.9 a	0.4 a
Variegatus	1.4 a	71.3 ab

^zStandard deviations for 2016 and 2017 were 8.1 and 12.0, respectively (n = 3 plants/cultivar).

^ySeedling (i.e., not a named cultivar).

^xTukey's mean separation is shown in lowercase letters; for each variable, means with the same letter are not significantly different at the $\alpha = 0.05$ level.

^w'Fodingzhu' was excluded from analysis as only one winter-exposed accession survived the first winter.

went below 0 °F. Both winters were warmer than the 30-year normal (National Oceanic and Atmospheric Administration, 2018). In the first winter, mean maximum and mean minimum monthly temperatures exceeded the 30-year normal by an average of 4.2 and 6.0 °F, respectively. Mean

maximum and minimum monthly temperatures in the second winter exceeded the 30-year normal by an average of 7.0 and 5.0 °F, respectively.

Cultivar was not independent of post-winter mortality ($\chi^2 = 51.0$, $P < 0.01$). 'Fodingzhu' fragrant tea olive had

Table 4. Growth index (GI) for sweet olive, fortune's osmanthus, fragrant tea olive, and holly tea olive cultivars represented in McMinnville, TN, cultivar trial.

Cultivar	GI (cm ³) ^z					
	May 2015 ^y	Oct. 2015	Oct. 2016		Oct. 2017	
			P-I-P ^x	Tent ^w	P-I-P	Tent
– ^v	441,016	949,081	1,154,209	2,025,802	1,723,232	1,947,074
Fruitlandii	227,292	869,684	1,096,517	2,578,391	1,055,609	2,173,583
Beni Kin Mokusei	192,232	99,842	368,659	495,157	154,575	607,042
Ogon	162,689	191,072	182,278	369,668	33,292	418,503
Apricot Echo	94,065	521,376	794,514	1,839,206	157,099	2,811,048
– ^v	76,009	103,593	487,629	894,874	413,026	889,607
Jim Porter	73,302	165,354	157,359	595,224	269,438	643,990
Longwood	32,257	46,478	224,521	247,517	414,091	552,496
San Jose	29,938	258,104	836,659	819,466	883,420	911,852
Fodingzhu	23,817	102,725	– ^u	559,435	–	645,656
Rotundifolius	23,484	147,230	621,190	533,225	632,266	1,137,079
Head-Lee Fastigate	17,935	66,419	219,708	230,088	667,950	536,419
Variegatus	16,238	24,377	65,586	61,215	26,610	45,263
Goshiki	12,974	14,205	73,543	47,523	99,793	83,954
Shien	7,422	47,078	261,313	272,958	482,574	559,216
Hariyama	2,759	6,473	134,399	97,594	276,193	289,390
Kaori Hime	2,170	26,921	305,567	203,520	548,410	287,896

^zGI = πhr^2 , where h is shoot height in cm, $r = 0.5d$, and d is the mean of two perpendicular diameter measurements in centimeters; n = 6 plants/cultivar for 2015 dates, n = 3 plants/cultivar/winter location for 2016 and 2017 dates; 1 cm³ = 0.0610 inch³.

^yAll accessions placed in pot-in-pot (P-I-P) production system in May 2015.

^xP-I-P = plants spent previous winter outdoors in P-I-P.

^wTent = plants spent previous winter in a heated coldframe.

^vSeedling (i.e., not a named cultivar).

^u'Fodingzhu' was excluded from further analysis after only one winter-exposed accession survived the first winter.

significantly greater mortality than any other cultivar, with two of three winter-exposed accessions dying during the first winter (2015–16). One of three winter-exposed 'Jim Porter' sweet olive and one of three winter-exposed 'Beni Kin Mokusei' fragrant tea olive died during the 2017 growing season, likely from very wet conditions after heavy rainfall. Four of six 'Variegatus' holly tea olives died during the study period, split equally between winter-exposed and winter-protected plants. The two 'Variegatus' accessions that died were the only winter-protected plants that died during the study period.

There were significant differences in cold-hardiness among cultivars as measured by percent necrotic stem observed in May of each year (Table 3). Mean percent necrotic stem measured in May 2017 for sweet olive, fortune's osmanthus, fragrant tea olive, and holly tea olive was 1.1%, 2.7%, 44.8%, and 20.2%, respectively. Each species except fragrant tea olive had at least one cultivar with 0% stem death each year.

Initial GI ranged from 2170 cm³ for 'Kaori Hime' holly tea olive to 441,015 cm³ for the unnamed fortune's osmanthus, reflecting the size of these plants at the time of purchase (Table 4).

Table 5. Percent increase in growth index (GI) for sweet olive, fortune's osmanthus, fragrant tea olive, and holly tea olive cultivars represented in McMinnville, TN, cultivar trial.

Cultivar	GI (cm ³) ^z				
	Oct. 2015 ^y	Oct. 2016		Oct. 2017	
		P-I-P ^x	Tent ^w	P-I-P	Tent
Kaori Hime	1,197 a ^u	14,568 a	9,998 a	27,121 a	14,844 ab
Rotundifolius	630 b	2,534 bcd	2,992 bc	2,538 bc	6,300 bc
San Jose	606 b	2,739 bcd	1,703 bc	2,872 bc	1,924 c
Apricot Echo	473 bc	777 cd	2,437 bc	61 c	3,607 bc
Shien	450 bc	3,460 bc	2,770 bc	6,662 bc	6,128 bc
Head-Lee Fastigate	384 cd	1,231 cd	1,974 bc	3,753 bc	4,729 bc
Fodingzhu	293 cde	– ^u d	1,922 bc	– c	2,213 c
Hariyama	203 cde	4,677 b	6,517 ab	9,908 b	20,392 a
Jim Porter	133 de	147 d	703 c	319 c	733 c
Fruitlandii	108 e	382 cd	298 c	364 c	236 c
– ^v	89 e	162 d	282 c	291 c	267 c
Goshiki	58 e	589 cd	530 c	950 c	1,002 c
– ^v	49 e	547 cd	1,224 c	447 c	1,212 c
Variegatus	41 e	294 d	214 c	38 c	102 c
Ogon	32 e	17 d	184 c	–79 c	218 c
Longwood	20 e	729 cd	526 c	1,415 bc	1,211 c
Beni Kin Mokusei	–37 e	109 d	234 c	–19 c	324 c

^zGI = πhr^2 , where h is shoot height in centimeters, $r = 0.5d$, and d is the mean of two perpendicular diameter measurements in centimeters; n = 6 plants/cultivar for 2015 date, n = 3 plants/cultivar/winter location for 2016 and 2017 dates; 1 cm³ = 0.0610 inch³.

^yAll accessions placed in pot-in-pot (P-I-P) production system May 2015.

^xP-I-P = plants spent previous winter outdoors in P-I-P.

^wTent = plants spent previous winter in a heated coldframe.

^vSeedling (i.e., not a named cultivar).

^uTukey's mean separation is shown in lowercase letters; for each variable, means with the same letter are not significantly different at the $\alpha = 0.05$ level.

^u'Fodingzhu' was excluded from further analysis after only one winter-exposed accession survived the first winter.

Final GI for winter-exposed plants ranged from 26,610 cm³ for 'Variegatus' holly tea olive to 1,723,232 cm³ for the fortune's osmanthus seedling. Final GI for winter-protected plants ranged from 45,263 cm³ for 'Variegatus' holly tea olive to 2,811,047 cm³ for 'Apricot Echo' fragrant tea olive.

Percent increase in GI for winter-exposed sweet olive, fortune's osmanthus, and fragrant tea olive after three growing seasons ranged from -18.9% for 'Beni Kin Mokusei' fragrant tea olive to 2871% for 'Longwood' fortune's osmanthus (Table 5). Mean percent increase in GI after three growing seasons for winter-exposed accessions of sweet olive, fortune's osmanthus, and fragrant tea olive were 867%, 1175%, and 155%, respectively. Percent increase in GI for winter-exposed holly tea olive after three growing seasons ranged from -79.3% for 'Ogon' holly tea olive to 27,121% for 'Kaori Hime' holly tea olive (Table 4). Mean percent increase in GI after three growing seasons for winter-exposed accessions of

holly tea olive was 6361%. After 3 years in a winter-exposed pot-in-pot production system, there were significant differences in percent growth increase among cultivars (Table 4). Accessions with the largest growth increase were the holly tea olive cultivars Kaori Hime, Hariyama, Shien, and Head-Lee Fastigate, followed by San Jose fortune's osmanthus, Rotundifolius holly tea olive, and Longwood sweet olive.

Flowers were observed at least once during the study period for all cultivars except Beni Kin Mokusei, Goshiki, and Head-Lee Fastigate. Flowering of trial cultivars lasted from September to November for winter-exposed plants and from September to March or April for winter-protected plants (Fig. 1). Cultivars of sweet olive and fortune's osmanthus bloomed most reliably after winter exposure. Three of four fragrant tea olive cultivars bloomed after the first winter, whereas only one of four bloomed after the second winter. Only one of eight holly tea olive

cultivars flowered after winter exposure. Winter exposure greatly reduced the length of the flowering period and the number of flowers. Length of flowering for winter-exposed sweet olive and fortune's osmanthus was reduced by an average of 45% while flowering time of fragrant tea olive was reduced by an average of 75% compared with winter-protected plants (Fig. 1). Number of flowers was also greatly reduced in winter-exposed plants compared with winter-protected plants for all cultivars except San Jose sweet olive (data not shown).

Flower morphology was variable both between and within species. Both sweet olive cultivars produced perfect flowers, whereas all three fortune's osmanthus cultivars produced male-only flowers. Flowers of 'Hariyama', 'Rotundifolius', and 'Shien' holly tea olive were perfect, whereas 'Kaori Hime', 'Ogon', and 'Variegatus' holly tea olive produced male-only flowers. Morphology and function was difficult to determine for

Fig. 1. Flowering of sweet olive, fortune's osmanthus, fragrant tea olive, and holly tea olive cultivars represented in McMinnville, TN, cultivar trial. Length of flowering period is represented by horizontal bars for winter-protected (dark blue) and winter-exposed (light blue) accessions. Winter-protected plants were placed in a heated coldframe in November and returned to the pot-in-pot production system in April of each year. Winter-exposed plants remained in the pot-in-pot production system year-round; n = 3 plants/cultivar/winter location except 'Fudingzhu' (n = 1 winter-exposed accession), 'Beni Kin Mokusei' and 'Jim Porter' (n = 2 winter-exposed accessions), and 'Variegatus' (n = 1 winter-exposed accession and n = 1 winter-protected accession).

fragrant tea olive, where pistils can range from slightly to completely reduced. Male-only flowers were observed on 'Fodingzhu' throughout the study period, whereas 'Apricot Echo' produced male-only flowers the first winter and perfect flowers the second winter.

Discussion

McMinnville, TN, is in a transition zone between USDA Hardiness Zones 6 and 7, and results from evaluations made in transition zones often can be used over a wide geographic and climatic area (Fare, 2017). The plants in this pot-in-pot production system likely experienced colder conditions than in-ground plants, so these interpretations may be considered conservative for this region.

Although plants in this experiment were all 1-year-old rooted cuttings, there were large differences in initial sizes, as reflected in the initial GI of each plant measured at the onset of the experiment. By the end of the experiment, GI rank among cultivars had changed such that many of the smallest accessions were in the midrange of size. There was no correlation between initial plant size and percent growth increase, supporting the hypothesis that growth increase or lack thereof was due to adaptability in this environment rather than inherent differences in growth rate.

As expected, fragrant tea olive was the least cold-hardy species in the trial. Several of the winter-exposed fragrant tea olive accessions died, and all had some stem death from winter injury. However, there was significant variation among cultivars. On the basis of mortality and stem death, fragrant tea olives in order of least to most cold-hardy were 'Fodingzhu', 'Apricot Echo', 'Beni Kin Mokusei', and the unnamed seedling accession. While two of the three 'Fodingzhu' died the first winter, the single remaining 'Fodingzhu' was the only fragrant tea olive accession to flower each year under winter-exposed conditions even though stem mortality was observed each spring. These differences underscore the need to import and test more fragrant tea olive from China and Japan, where more than 160 cultivars have been named (Xiang and Liu, 2008). Considering that there are only a dozen or

so cultivars available in the U.S. market, substantial progress in recommending cold-hardy selections could be made simply by importing and testing more cultivars. In addition, the hardiness of the seedling over the cultivars indicates that improvement for cold-hardiness can be made by breeding and selecting within the species.

Accessions with the largest growth increase in winter-exposed conditions were the holly tea olive cultivars Kaori Hime, Hariyama, Shien, and Head-Lee Fastigate, followed by San Jose fortune's osmanthus, Rotundifolius holly tea olive, and Longwood sweet olive. Of these cultivars, Kaori Hime, San Jose, and Longwood flowered under winter-exposed conditions. 'Beni Kin Mokusei' fragrant tea olive and 'Ogon' holly tea olive both showed negative increases, meaning stem death and lack of growth made their GI values smaller by the end of the study period than at the beginning.

Three kinds of breeding systems are found within the Oleaceae: hermaphroditism, androdioecy, and dioecy (Hao et al., 2005; Xu et al., 2014). Flowers of sweet olive, fortune's osmanthus, and holly tea olive were perfect (i.e., hermaphrodites possessing functional male and female organs) at all observation points during the study period, whereas fragrant tea olive flowers were perfect or male-only at different times depending on the cultivar. The male-only flowers contained pistillodes with different degrees of degradation compared with true pistils, often making it difficult to classify flower morphology without a microscope (Xu et al., 2014). Evidence for cryptical dioecy, where the hermaphrodite is functionally female, was observed as viable pollen did not naturally dehisce from the anthers of hermaphrodite flowers of 'Apricot Echo' fragrant tea olive. Cultivars producing male-only flowers appear to be more numerous than cultivars that produce hermaphroditic flowers. Nine of 62 fragrant tea olive cultivars studied by Duan et al. (2013) produced hermaphroditic flowers and the remainder were male-only. The presence of both male and hermaphrodite flowers in fragrant tea olive has been interpreted as a step in the evolutionary pathway from hermaphroditism to dioecy (Xu et al., 2014).

Further breeding improvement is necessary in fragrant tea olive to increase cold-hardiness. Many of the 120 cultivars described by Xiang and Liu (2008) (including cultivars that produce hermaphroditic flowers) should be tested at multiple locations in the United States. Producing new fortune's osmanthus hybrids as well as hybrids of fragrant tea olive and sweet olive will provide variation for multi-site testing. The close relationship between tea olive and fringetree (*Chionanthus*) indicates the possibility of wide hybridization as a breeding strategy (Yuan et al., 2010). Tools to select parents and verify hybrids, including molecular markers and a transcriptome data set for identification of important genes, are now available for fragrant tea olive and its relatives (Alexander, 2016; Alexander et al., 2017; Duan et al., 2013; Mu et al., 2014).

In summary, the most-cold tolerant cultivars (based on mortality and stem death) were Kaori Hime, Hariyama, Shien, and Head-Lee Fastigate holly tea olive, San Jose fortune's osmanthus, Rotundifolius holly tea olive, and Longwood sweet olive. Of these cultivars, Kaori Hime, San Jose, and Longwood flowered under winter-exposed conditions. Fragrant tea olive cultivars were the least cold-hardy species based on winter mortality, winter stem damage, and low to negative growth increases. Evaluation and breeding efforts are underway to extend the range for production and growth of this genus.

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