Eastern Redcedar (*Juniperus virginiana*) as a Substrate Component Effects Growth of Three Tree Species[1]

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Abstract

Sustainable and local alternative substrates are being explored for nursery crop production due to concern over pine bark (PB) supplies and costs. This study evaluated a tree species which is weedy in the Great Plains region of the United States, eastern redcedar, processed through a hammer mill equipped with a 19 mm (3/4 in) screen size to create six substrates consisting of 0, 5, 10, 20, 40, and 80% eastern redcedar chips (ERC) and 20% sand; the remaining volume was composed of PB. Each of these substrates were then used to grow baldcypress (*Taxodium distichum*), Chinese pistache (*Pistacia chinensis*), and silver maple (*Acer saccharinum*) under two fertilizer rates: either a 4.5 $kg \cdot m^{-3}$ (7.5 $lbs \cdot yd^{-3}$) low fertilizer rate or a 8.9 $kg \cdot m^{-3}$ (15 $lbs \cdot yd^{-3}$) high fertilizer rate. Substrates composed of 40 and 80% ERC had reduced container capacity, resulting in less growth of all three species. Plants responded similarly to both fertilizer rates suggesting that the limiting factor to plant growth is substrate physical properties. Plants grown in 5–20% ERC were of comparable size and quality to those grown in the control substrate. Therefore, ERC can be recommended as a PB substrate supplement, but not as a full replacement at this time.

Index words: alternative, local, loblolly pine, media, pine bark, substrate, sustainable.

Species used in this study: eastern redcedar (*Juniperus virginiana* L.); loblolly pine (*Pinus taeda* L.); baldcypress (*Taxodium distichum* L. [Rich.]); Chinese pistache (*Pistacia chinensis* L.); silver maple (*Acer saccharinum* L.).

Significance to the Nursery Industry

Pine bark (PB) availability has decreased in recent years due to changes in harvesting practices and demand from competing industries. All the while, an increase in price has resulted from high transportation costs for nursery crop growers in areas distant from timber production. As such, there is a need for alternative substrate materials that are local and sustainable. Eastern redcedar (*Juniperus virginiana*) is a native tree in the Great Plains, which can be used for saw timber, cabinets and mulch, though the percentage of trees harvested for use is small. This species is expanding rapidly across the region due to a lack of natural control (fire), and is associated with negative environmental impacts on native grasslands. Use of eastern redcedar as a substrate could help slow its expansion into the Great Plains while providing a market for the species and a cost effective substrate for local nursery crop growers. This study demonstrated that processed eastern redcedar chips (ERC) can be used up to 20% of the total substrate volume (ERC:PB:sand; 20:60:20; v:v:v) producing plants similar to those grown in a 80:20 PB:sand mix. Incorporation of higher percentages of ERC (40 and 80% ERC) were associated with increased airspace and low container capacity, resulting in less growth with both high and low fertilizer rates in 80% ERC and less growth in the low fertilizer rate at 40% ERC.

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Introduction

Pine bark-based substrates continue to be the industry standard for container production of woody ornamentals throughout the central and eastern United States (20). However, because of decreased timber production and increased demand from competing industries, PB has become less available for the nursery industry with a corresponding increase in price (14). Shipping costs, particularly in regions lacking a pine-based timber industry, compounds this price increase further. This has led to a demand for alternative substrates to supplement or replace PB, particularly in regions that lack native pine species. Eastern redcedar (*Juniperus virginiana*) grows throughout most of the Great Plains region of the United States. Historically kept in check by wild fires, eastern redcedar is aggressively expanding into grasslands and abandoned fields especially in areas where controlled burning is rarely practiced (1, 2, 10). Eastern redcedar is associated with significant decreases in plant species richness, and changes in animal diversity and abundance on grassland mammals and birds (5, 6, 12).

Previous studies have shown that multiple types of pine (*Pinus* sp.) wood can be used as substrate components in a PB-based substrate or as complete replacements (3, 7, 13). Several products made from pine trees [primarily *Pinus taeda* (loblolly pine)] have been evaluated. These products contain various amounts of green material (needles), including pine tree substrate (chipped pine logs), *WholeTree* (whole pine trees), and clean chip residual (all parts of the pine tree excluding the heartwood; 3, 8, 13). Use of eastern redcedar wood as a container substrate has been shown to be viable (11, 16). Chinese pistache (*Pistacia chinensis*) and Indian-cherry (*Frangula caroliniana*) were grown in six substrates composed of varying ratios of ERC and PB with four fertilizer rates. It was demonstrated that Chinese pistache grown in 5, 20, and 40% ERC were comparable in height and shoot dry weight to those grown in 100% PB. Whereas plants grown in 10 and 80% ERC had less height and shoot dry weight compared to those grown in PB (11).

A later study by Murphy et al. (16) evaluated low-value tree species [sweetgum (*Liquidambar styfaciflua*), hickory (*Carya* sp.), and eastern redcedar] in comparison with a peat:perlite and a *WholeTree* substrate for greenhouse production of petunia (*Petunia* × *hybrida* 'Dreams Sky Blue'), vinca (*Catharanthus roseus* 'Cooler Peppermint') and impatiens (*Impatiens walleriana* 'Super Elfin Salmon'). Plants grown in sweetgum and hickory did not perform as well as those grown in ERC, which grew similarly to the control treatments. The authors recommended that growers could amend their greenhouse substrates up to 50% ERC with little to no difference in plant growth.

Use of eastern redcedar as a substrate component for container plant production has not been fully explored and, if successful, could decrease production costs for nursery growers in the Great Plains while simultaneously providing incentive to reduce eastern redcedar populations. However, eastern redcedar has known allelopathic properties and has been shown to inhibit seed germination in some native grass species (17, 18). Allelopathy research has primarily focused on the allelopathic properties of fresh leaves and leaf litter on the soil surface (17, 18). Allelopathic potential of the heartwood and species affected are currently unknown.

The objective of this study was to determine if eastern redcedar can be used as a substrate component for the nursery industry. Treatments were designed to model potential use by nursery crop growers who may substitute portions or completely replace PB as the primary component in an 80:20 PB:sand (by vol) substrate.

Materials and Methods

Eastern redcedar chips (ERC) used in this study were harvested from felled trees allowed to age for six months in the area around Barber County, KS (Queal Enterprises, Pratt, KS). Trees were processed into chips using a horizontal woodgrinder (Rotochoper, St. Martin, MN). Further processing occurred through a hammer mill (A.W.W. Grinder Inc., Model 5-2 0-4, Wichita, KS) to pass a 19 mm (3/4 in) screen on May 18, 2009. Eastern redcedar chips were then blended with PB (SunGro, Bellevue, WA) and sand, in six ratios (by vol) resulting in six substrate treatments. All substrates contained 20% sand and ERC consisting of 0, 5, 10, 20, 40, or 80%. The remaining volume was PB. Each substrate blend was pre-plant incorporated with 0.68 $kg{\cdot}m^{-3}$ (1.5 $lbs{\cdot}yd^{-3}$) micronutrient package (Micromax, The Scotts Company, Marysville, OH) and either a low 4.5 $kg{\cdot}m^{-3}$ (7.5 $lbs{\cdot}yd^{-3}$) fertilizer rate or a 8.9 $kg{\cdot}m^{-3}$ (15 $lbs{\cdot}yd^{-3}$) high rate of controlled release fertilizer (19-6-12, 8 to 9 month release, Osmocote Classic, The Scotts Company, Marysville, OH) to make 12 substrates.

The study was conducted at the John C. Pair Horticultural Research Center (Haysville, KS) on three woody tree species, with each species treated as a separate experiment. Chinese pistache and baldcypress (*Taxodium distichum*) seedlings (one year old seedlings grown at the John C. Pair Horticulture Research Center in plant bands with holes, 5.1 × 5.1 × 15.2 cm (2 × 2 × 6 in) (Hummert Int., Earth City, MO) were transplanted into #3 containers (Olympian Heavy weight-Classic 1200, Nursery Supplies Inc., Fairless Hills, PA) on May 20, 2009. A third woody species, silver maple (*Acer saccharinum*), was planted from seed (Lincoln Oaks Nursery, Bismarck, ND) on June 9, 2009, using #2 containers (Olympian Heavy Weight C200, Nursery Supplies Inc., Fairless Hills, PA). Three silver maple seed were planted per container and germinated in a shade house before being moved to the production area in full sun 14 days later. Plants were thinned to one plant per container at 35 days after planting (DAP). Chinese pistache and silver maple were terminated on September 9, 2009 (113 DAP and 92 DAP, respectively). Baldcypress was terminated 7 days later (120 DAP).

Substrate pH and electrical conductivity (EC) were determined at 15, 29, 43, 57, 71, 85, 99, and 113 DAP using the pour-through technique (19) on baldcypress only. Substrate shrinkage was determined by calculating the difference between the distance from the top of the container to the substrate surface at 15 and 113 DAP. Leaf greenness (an indirect measurement of leaf chlorophyll content) was quantified using a SPAD-502 Chlorophyll Meter (Minolta Camera Co., Ramsey, NJ) at 15, 29, 43, 57, 71, 85, 99, and 113 DAP on Chinese pistache based on the average of four newly matured leaves. Stem caliper [measured 15.24 cm (6 in) above the substrate surface] and plant height were measured 113 DAP for all species. Shoot and root dry weights of all species were recorded at the conclusion of the study by drying in a forced air oven (model SC-400, The Grieve Co., Round Lake, IL) at 70C (158F) for 7 days. Leaf samples (four replications per treatment) of Chinese pistache were analyzed (Brookside laboratories, New Knoxville, OH) for nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), Magnesium (Mg), sulfur (S), boron (B), iron (Fe), manganese (Mn), copper (Cu), and zinc (Zn) with inductively coupled plasma-emission spectromertry (Thermo Jarrel Ash, Offenbach, Germany). Foliar N was determined by combustion analysis using 1500 N analyzer (Carlo Erba, Milan, Italy).

Substrates were analyzed for particle size distribution by passing a 100 g (3.5 oz) air-dried sample through a series of sieves. Sieves were shaken for 3 min with a Ro-tap (Ro-tap RX-29, W.S. Tyler, Mentor, OH) sieve shaker (278 oscillations per minute, 159 taps per minute). Substrate air space, container capacity, bulk density, and total porosity were determined by using a NCSU Porometer (9) using 347.5 cm^3 (21.2 in^3) samples in a 7.6 cm (3 in) aluminum cylinder with four replications.

The experimental design was a randomized complete block design with a factorial arrangement of treatments. Treatments were replicated eight times (baldcypress, Chinese pistache) or six times (silver maple). Data were subject to ANOVA with means separation using the Waller-Duncan K-ratio T Test (version 9.1 SAS Institute Inc., Cary, NC).

Results and Discussion

Substrate pH did not differ based on fertilizer rate, thus pH was analyzed based on the main effects of ERC content (Table 1). Substrate pH of 80% ERC was consistently the highest at each date and was always ≥ 7.30. Substrate pH generally decreased with decreasing ERC content. Treatments with 0 and 5% ERC typically had the lowest pH. Over time, substrate pH became more similar with the pH of substrates containing large percentages of PB, increasing at each measurement date most likely due to the high alkalinity of irrigation water (270 ppm $CaCO_3$). Electrical conductivity for all treatments was generally within recommended ranges (0.8 to 1.5 $mmho{\cdot}cm^{-1}$; 20) throughout the study (data not shown).

Physical properties varied based on ERC content (Table 2). Air space was within recommended ranges (10 to 30%)

Table 1. **Change of substrate pH over time in substrates composed various combinations of pine bark and eastern redcedar, as determined with the pour-through method.**

Substrate[z]	15 DAP[y]	29 DAP	43 DAP	57 DAP	71 DAP	85 DAP	99 DAP	113 DAP
0% ERC:80% PB	5.7cd[x]	5.1e	5.9de	6.3d	6.3d	7.0c	6.8c	7.2cb
5% ERC:75% PB	5.5d	5.0e	5.8e	6.2d	6.5cd	6.8c	7.0b	6.9d
10% ERC:70% PB	5.5d	5.4d	6.0d	6.3d	6.6cd	7.0c	7.0cb	7.0dc
20% ERC:60% PB	5.8c	6.1c	6.3c	6.6c	6.9b	7.3b	7.1b	7.2cb
40% ERC:40% PB	6.8b	6.9b	6.8b	7.0b	7.0b	7.4b	7.5a	7.3b
80% ERC:0% PB	7.7a	8.2a	7.6a	7.3a	7.4a	7.6a	7.7a	7.5a

[z]Substrate treatments were: PB = pine bark, ERC = eastern redcedar chips. Substrates mixed on volume basis with each treatment containing 20% sand. Species used for this measurement was baldcypress.

[y]DAP = days after planting.

[x]Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests α = 0.05 (n = 4).

except 5 and 10% ERC, which were slightly below recommendations (9.1 and 8.2 respectively; 20). However, the highest airspace was in 80 and 40% ERC, which were greater than the other substrate blends. Container capacity was within recommended ranges for all substrates containing 40% ERC or less. The lowest container capacity was in 80% ERC (39.3%), which was below the recommended range of 45 to 65% (20). This is similar to other studies conducted on wood-based substrates that showed increasing airspace and decreasing container capacity with increasing percentages of wood-based components in a substrate blend (4, 7, 13). Substrates containing 0, 5, 20, and 40% ERC had the highest total porosity while 80 and 10% ERC had the lowest. However all substrates were within the recommended levels of 50 to 85% (20). Bulk density was within recommended ranges for all substrates. There were no differences in substrate shrinkage, indicating ERC-based substrates do not decompose significantly over a one-season production cycle.

Increases in airspace and corresponding decreases in container capacity are linked to the differences in particle size distribution (Table 3). There was a higher proportion (43.8%) of coarse material (2 mm or larger) in 80% ERC than in substrates containing 0, 5, 10, or 20% ERC. Medium sized particles (between 2.00 and 0.5 mm) were highest in substrates containing ≤ 20% ERC. The least amount of medium particles was in 80% ERC. There were no differences between substrate fine particles (less than 0.5mm). Substrates composed of 80 and 40% ERC had coarser particles and decreased medium size particles. This corresponds to the increase in airspace and decrease in container capacity in these substrates. Pores in 40 and 80% ERC substrates were larger and held less water.

Baldcypress. Each growth measurement of baldcypress was significantly affected by fertilizer rate ($p < 0.001$ except height, described below; Table 4). However, while fertilizer rate had an effect on height ($p < 0.0027$), substrate treatments did not. Within a fertilizer rate, caliper was similar in substrates containing up to 40% ERC, but decreased at 80% ERC. Shoot dry weight for the low fertilizer rate was similar up to 20% ERC, then decreased at both 40 and 80% ERC. The high fertilizer rate produced plants with similar shoot dry weight up to 40% ERC, but less shoot dry weight at 80% ERC. Root dry weights of plants grown in both the

Table 2. **Physical properties of substrates composed of various combinations of pine bark and eastern redcedar.**

Substrates[t]	Air space[zy] (% vol)	Container capacity[w] (% vol)	Total porosity[w] (% vol)	Bulk density[v] (g/cm3)	Shrinkage[u] (mm)
0% ERC:80% PB	12.6c[s]	63.0b	75.5a	0.51bc	1.1[ns]
5% ERC:75% PB	9.1cd	66.5a	75.6a	0.50c	0.7
10% ERC:70% PB	8.2d	62.0b	70.2b	0.52b	0.7
20% ERC:60% PB	10.4cd	63.9ab	74.3a	0.51bc	0.8
40% ERC:40% PB	20.8b	55.2c	75.9a	0.51bc	0.6
80% ERC:0% PB	29.9a	39.3d	69.1b	0.58a	0.8
Recommended ranges[r]	10 to 30	45 to 65	50 to 80	0.19–0.70	

[z]Analysis performed using the North Carolina State University porometer.

[y]Air space is volume of water drained from the sample / volume of the sample.

[x]Container capacity is (wet wt. – oven dry wt.) / volume of the sample.

[w]Total porosity is container capacity + air space.

[v]Bulk density after forced-air drying at 105C for 48 h.

[u]Shrinkage is the difference in substrate from the top of the container to the media surface at the beginning of the experiment and at termination.

[t]Treatments were: PB = pine bark, ERC = eastern redcedar chips. Substrates mixed on volume basis with each treatment containing 20% sand.

[s]Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests (α = 0.05, n = 3).

[r]Recommended ranges as reported by Yeager et al. (2007).

[ns]Means not significantly different.

Table 3. Particle size analysis of substrates composed of various combinations of pine bark and eastern redcedar.

U.S. standard sieve no.	Sieve opening (mm)	Substrate[z]					
		0% ERC: 80% PBz	5% ERC: 75% PB	10% ERC: 70% PB	20% ERC: 60% PB	40% ERC: 40% PB	80% ERC: 0% PB
1/4"	6.3	2.2b[yx]	2.7ab	2.2b	2.9ab	4.1ab	7.4a
10	2.0	22.4b	20.6b	24.0b	21.1b	25.3b	36.0a
25	0.71	30.3[ns]	29.1	29.3	28.7	29.0	27.3
35	0.5	12.4a	12.5a	12.0a	12.3a	11.6a	8.3b
60	0.25	23.4[ns]	24.5	23.0	24.4	21.8	14.7
140	0.11	8.0[ns]	9.2	8.2	9.2	7.3	5.2
pan	0.0	1.0bc	1.4a	1.3a	1.5a	1.0b	0.8c
Coarse[w]		24.9b	23.3b	26.2b	24.0b	29.4ab	43.8a
Medium		42.7a	41.6ab	41.4ab	41.0ab	40.6b	35.6c
Fine		32.4[ns]	35.0	32.5	35.0	30.0	20.6

[z]Substrate treatments were: PB = pine bark, ERC = eastern redcedar chips. Substrates mixed on volume basis with each treatment containing 20% sand.

[y]Numbers represent the percent of the total material within that screen size.

[x]Percent weight of sample collected on each screen, means within row followed by the same letter are not significantly different based on waller-duncan K ratio t tests at $\alpha = 0.05$ (n = 3).

[w]Coarse = 2.00 mm and greater; Medium = less than 2.00 and greater than 0.5 mm; Fine = less than 0.5 mm.

[ns]Means not significantly different.

Table 4. Growth of three tree species in substrates composed of various combinations of pine bark and eastern redcedar.

Species[u]	Substrate[t]	Plant height (cm)[z]		Caliper (mm)[y]		Shoot dry weight (g)[x]		Root dry weight (g)[w]	
		Fertilizer level[v]							
		Low	High	Low	High	Low	High	Low	High
Baldcypress 120DAP[r]	0% ERC:80% PB	113.0[ns]	116.5[ns]	20.4ab[s]	22.0a	87.7a	126.4ab	109.8ab	161.4a
	5% ERC:75% PB	114.7	117.4	21.0a	22.0a	94.8a	125.0ab	131.9a	121.6ab
	10% ERC:70% PB	115.4	119.4	20.7ab	23.0a	90.0a	135.3a	97.2bc	154.8a
	20% ERC:60% PB	116.3	118.9	19.9ab	22.4a	86.6a	128.3ab	95.9bc	160.1a
	40% ERC:40% PB	109.1	127.4	19.0b	21.3a	72.7b	116.4b	69.1cd	136.8a
	80% ERC:0% PB	103.7	113.7	15.2c	18.3b	48.5c	79.7c	50.2d	84.0b
Chinese pistache 113DAP	0% ERC:80% PB	110.0a		1.6[ns]	1.7ab	94.7a	114.9a	54.6a	
	5% ERC:75% PB	115.4a		1.7	1.7ab	94.9a	123.0a	68.8a	
	10% ERC:70% PB	120.0a		1.7	1.9a	113.4a	138.7a	64.3a	
	20% ERC:60% PB	116.8a		1.6	1.8a	95.6a	129.1a	56.1ab	
	40% ERC:40% PB	113.2a		1.6	1.8ab	74.4b	116.6a	51.4ab	
	80% ERC:0% PB	95.0b		1.5	1.5b	57.4b	79.2b	34.8b	
Silver maple 92DAP	0% ERC:80% PB	26.8ab[s]		4.5ab	5.7a	3.0ab	4.9a	2.2ab	3.6a
	5% ERC:75% PB	24.5b		4.7ab	5.6a	2.9b	4.4a	2.4ab	3.7a
	10% ERC:70% PB	27.5ab		5.3a	5.2a	4.0a	4.2a	3.2a	2.7ab
	20% ERC:60% PB	29.8a		4.9ab	5.6a	3.2ab	4.9a	2.8a	3.7a
	40% ERC:40% PB	23.7b		4.2b	4.9a	1.6c	3.6ab	1.4b	2.7ab
	80% ERC:0% PB	12.9c		2.4c	2.4b	0.5d	0.4b	0.4c	0.3b

[z]Plants were measured from the top of the substrate to the apical meristem.

[y]Plants were measure six inches from the top of the substrate.

[x]Shoots were harvested at the container surface and oven dried at 70C for 48 h.

[w]Roots were washed of substrate and oven dried at 70C for 48 h.

[v]Substrates were pre-plant incorporated with either a low ($4.5\ kg \cdot m^{-3}$) or high ($8.9\ kg \cdot m^{-3}$) rate of controlled release fertilizer (Osmocote, The Scotts Company, Marysville, OH; 19-6-12). Significant differences based on fertilizer rate are separated by High and Low, measurements that are not significantly different between fertilizer treatments are not separated.

[u]Species were baldcypress (*Taxodium distichum*), Chinese pistache (*Pistacia chinensis*) and silver maple (*Acer saccharinum*).

[t]Substrate treatments were: PB = pine bark, ERC = eastern redcedar (Juniperus virginiana) chips. Substrates mixed on volume basis with each treatment containing 20% sand.

[s]Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests $\alpha = 0.05$ (n = 8 for baldcypress and Chinese pistache; n = 6 for silver maple).

[r]DAP = days after planting.

[ns]Means not significantly different.

low and high fertilizer rates showed a similar trend with substrates composed of 80% ERC producing the least amount of growth.

Chinese pistache. Height of Chinese pistache did not vary by fertilizer rate but did by ERC treatment (Table 4). Plants growing in substrates containing 40% ERC or less were similar in height, whereas the substrate containing 80% ERC produced shorter plants. Caliper was affected by fertilizer rate, but was not affected by substrate treatment in the low fertilizer rate. Caliper for plants grown in the high fertilizer rate were only different between 10 and 20% ERC when compared to 80% ERC. The reduction in plant height was reflected in shoot dry weight in the both fertilizer rates. Root dry weight was influenced by ERC content but not by fertilizer rate. A trend toward decreased root dry weight based on increased ERC content favored substrates containing less ERC (0 to 10%) with the least root dry weight at 80% ERC. This data is similar to baldcypress. Less growth occurred when plants were grown in 80% ERC. When fertilizer rate influenced growth, the initial reduction typically occurred at 40% ERC. Leaf greenness as indicated by the SPAD meter did not differ based on substrate or fertilizer level past 43 DAP (data not shown).

Leaf tissue of Chinese pistache was also analyzed for nutrient content. As expected, foliar N content was greater in the high fertilizer rate, but was unaffected by ERC content (Table 5). Foliar N content was below the recommended range (15) in the low fertilizer rate, which could have been caused by too low of a rate or by leaching in such a porous substrate. Phosphorus content was unaffected by fertilizer rate, however, the highest P content was found in plants growing in 80% ERC. Potassium content was also unaffected by fertilizer rate. Although foliar K content was affected by ERC content, there appeared to be no clear trend. Micronutrients were within or above recommended ranges (data not shown) suggesting that nutrient absorption were not negatively affected by ERC content.

Silver maple. Silver maple was chosen for evaluation as an assay due to its quick plant growth and susceptibility to micronutrient deficiencies, though there was not enough plant growth across all treatments by the termination of the experiment to sample for foliar nutrient content. Plant height at 92 DAP was not affected by fertilizer rate, but was greatly reduced when growing in 80% ERC substrate (Table 4). Seedling caliper was greater in the high fertilizer rate, however, there was a decrease in caliper when plants were grown in 80% ERC. Shoot and root dry weights showed the same trends. Plants grown in low fertilizer maintained a relatively similar shoot and root dry weight through 20% ERC, with subsequent decreases at 40% and again at 80% ERC. Plants growing in the high fertilizer rate maintained similar shoot and root dry weights through 40% ERC, with a drop in weight at 80% ERC. These trends in growth are similar to those seen in baldcypress and Chinese pistache.

The observed decrease in growth associated with 80% ERC and, to a lesser extent, 40% ERC is likely linked to the corresponding increases in airspace and decreases in container capacity associated with both substrates. It is likely that plants grown in 80 and 40% ERC are more prone to water stress due to the lower water holding capacity in those substrates. These results are consistent with the results of experiments using clean chip residual which also demonstrated less growth in plants as percent wood content increased (3, 4). Plants grown at a high fertilizer rate in 40% ERC fared better in terms of growth when compared to plants grown with low fertilizer in 40% ERC substrates. However even at the higher fertilizer rate plants grown in 40% ERC were frequently smaller than plants grown in less ERC at the same fertilizer rate. This shows that while elevating the fertilizer rate does have an effect, the trends within each fertilizer rate remained the same: a decrease in growth at 40% ERC, and again at 80% ERC. This differs however, from studies using chipped pine logs in which decreased growth was attributed to N-immobilization (13). It was shown that plants grown in chipped pine tree substrate had less growth compared

Table 5. Foliar nutrient content of Chinese pistache (*Pistacia chinensis*) grown in substrates composed various combinations of pine bark and eastern redcedar 113 days after planting.

	N (%)		P (%)	K (%)
	Fertilizer level[y]			
Substrates[z]	Low	High		
0% ERC:80% PB	1.96[x]	2.53[ns]	0.19b[w]	1.11ab
5% ERC:75% PB	1.86	2.45	0.19b	1.11ab
10% ERC:70% PB	1.78	2.30	0.16b	1.00b
20%: ERC:60% PB	2.00	2.40	0.19b	1.12ab
40% ERC:40% PB	1.82	2.22	0.18b	1.19a
80% ERC:0% PB	1.89	2.14	0.23a	1.11ab
Sufficiency range[v]:	2.13 to 2.81%		0.16 to 0.25%	1.02 to 1.58%

[z]Substrate treatments were: PB = pine (*Pinus* sp.) bark, ERC = eastern redcedar (*Juniperus virginiana*) chips. Substrates mixed on volume basis with each treatment containing 20% sand.

[y]Substrates were pre-plant incorporated with either a low (4.5 kg·m⁻3) or high (8.9 kg·m⁻3) rate of controlled release fertilizer (Osmocote, The Scotts Company, Marysville, OH; 19-6-12). Significant differences based on fertilizer rate are separated by High and Low, measurements that are not significantly different between fertilizer treatments are not separated.

[x]Tissue analysis performed on the most recently mature leaves. N = nitrogen, P = phosphorous, K = potassium.

[w]Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests $\alpha = 0.05$ (n = 4).

[v]Sufficiency range published by Mills and Jones (1996).

to peat-lite within the same fertilizer rate. However, when plants grown in chipped pine log substrate were compared with plants grown in a peat-lite substrate with 100 mg·L^{-1} less nitrogen the plants had comparable growth (13). While the current study did not evaluate N-immobilization in the substrate, foliar N content was similar at each fertilizer rate. Additionally, the low fertilizer rate had lower than recommended levels of foliar N. The combination of low water holding capacity and a lower than optimal amount of available N from the low fertilizer rate is likely the reason for less growth in 40% ERC in the low fertilizer rate.

There was no apparent effect on plant growth due to allelopathic chemicals within the eastern redcedar wood. Eastern redcedar chips used in this experiment did not contain any green material (scales), which has been the main focus of allelopathic studies. Allelopathic effects of eastern redcedar on species other than grasses are unknown (17, 18). Eastern redcedar used in this experiment could have contributed to decreased growth in higher concentrations of ERC due to allelopathy, possibly synergizing with the low container capacity resulting in decreased growth. However, the low container capacity alone seems more compelling based on this data. Other studies on wood-based artificial substrates showed that decreasing the particle size increased water holding capacity and plant growth when compared to larger particle sizes (4, 13). Manipulation of particle size could adjust ERC so that it could increase container capacity and thus increase growth.

Eastern redcedar processed through a 19 mm (3/4 in) screen is a viable substrate component replacing up to 20% of the PB in a substrate for woody nursery crops in an outdoor production setting. While it can supplement PB, it cannot replace it as a primary substrate component without resulting in less growth for some woody species. However, while use of ERC did result in less plant growth in 40 and 80% ERC, the decrease in overhead costs due to using a less expensive substrate component could offset this loss while still producing marketable plants.

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