Post Harvest Processing of Eastern Redcedar and Hedge-Apple Substrates Affect Nursery Crop Growth[1]

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Abstract

Eastern redcedar (*Juniperus virginiana* L.) could be a viable container substrate for nursery crop production. It is a local, sustainable resource in regions distant from timber production areas where pine bark (PB) is processed. However, eastern redcedar chips (ERC) as a substrate have been associated with decreased container capacity and increased air space. Manipulating particle size could result in a substrate comparable to the current PB industry standard. Additionally, hedge-apple [*Maclura pomifera* (Raf.) C. K. Schneid.], a common species found in the Great Plains region of the United States, could also be used as a resource for substrate construction. This study evaluated four particle sizes, 4.8, 9.5, 12.7, and 19.1 mm (3⁄16, 3⁄8, ½, and ¾ in) ERC and hedge-apple chips (HAC), and compared them to a PB control in the production of 5 plant species. Plants grown in both ERC and HAC showed few differences in growth based on substrate particle size; when growth was affected, plants grown in 4.8 mm (3⁄16 in) and 9.5 mm (3⁄8 in) particle sizes were larger than those grown in coarser 12.7 mm (½ in) and 19.1 mm (¾ in) material. However, both ERC and HAC often produced smaller plants compared to those grown in PB. Results of this study demonstrate that ERC and HAC can be viable substrates or substrate components for some plant species when the trees are processed to small particle sizes, particularly if small plants are an acceptable tradeoff for lower overhead costs.

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

Species used in this study: eastern redcedar (*Juniperus virginiana* L.); hedge-apple [*Maclura pomifera* (Raf.) C. K. Schneid.]; blackeyed-susan (*Rudbeckia fulgida* Aiton var. *fulgida*); maiden grass (*Miscanthus sinensis* Anderss. 'Graziella'); crapemyrtle (*Lagerstroemia* hybrid L. 'Arapaho'; baldcypress [*Taxodium distichum* (L.) Rich.]; redbud (*Cercis canadensis* L.).

Significance to the Nursery Industry

Pine bark (PB) supplies have declined in recent years with a subsequent cost increase. Also, as fuel prices have risen, so have transportation costs. Many growers use PB as a primary substrate component. Therefore, the increase in price and decreased availability strain nursery production operations, particularly those distant from timber production regions, such as the Great Plains. Eastern redcedar (*Juniperus virginiana*) and hedge-apple (*Maclura pomifera*) are tree species found abundantly in the Great Plains due to their broad adaptability. Previous experiments with eastern redcedar chips (ERC) have shown that this species can be a viable nursery substrate component. However, its use is associated with decreased container capacity. Manipulation of particle sizes via post-harvest processing in other wood substrates (clean chip residual, WholeTree, pine tree substrate) has resulted in greater container capacity. The objective of this study was to determine if processing ERC and hedge-apple chips (HAC) to create material of various sizes would render a substrate with more container capacity and less air space than substrates evaluated in previous studies. This study suggests that both ERC and HAC can be used as primary substrate components, with 4.8 and 9.5 mm (3⁄16 and 3⁄8 in) material having closer physical properties to PB. While plants grown in PB usually were larger and had more shoot dry weight, most plants grown in ERC and HAC were still of marketable size and quality.

Introduction

In many regions of the United States the nursery industry requires large quantities of PB-based substrate material to meet their production needs. Unfortunately, PB is becoming a limited resource due to decreased timber production (12). This has led to a demand for alternatives to PB that are sustainable, locally available, and adaptable to pre-existing machinery. Eastern redcedar (*Juniperus virginiana*) and hedge-apple (*Maclura pomifera*; also known as Osage-orange) are two common trees in the Great Plains that could meet these requirements for substrate material in the container-grown nursery production industry. Both species are noted for their adaptability to marginal areas and harsh site conditions which has led to their wide scale use in windbreaks (6, 14). Unfortunately this adaptability, in the case of eastern redcedar, has led to wide scale expansion into native grasslands and cattle ranges resulting in both economic and ecological concerns (5, 10, 14). The only effective control for eastern redcedar expansion is prescribed burns (3, 4, 15). Another quality both trees have in common is that their wood is known to be resistant to decay due to anti-fungal chemicals (1, 7, 17, 18). This decay resistance could help substrates avoid shrinkage, which can cause unfavorable changes in substrate physical properties over a production cycle.

A study on ERC as a substrate component replacing portions of PB in a standard nursery mix has shown increased airspace and decreased container capacity (from the beginning of production) as ERC content increases (16).

[1]Received for publication February 27, 2012; in revised form August 17, 2012. This research was supported by the United States Department of Agriculture – Agriculture Research Service – Floriculture and Nursery Research Initiative, James L. Whitten Building 1400 Independence Ave., S.W. Washington DC, 20250. Contribution no. 12-342-J from the Kansas Agricultural Experiment Station.

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Manipulation of physical properties by increasing or decreasing particle size could result in substrates with more suitable airspace and container capacity for container-grown plant production. Previous work has explored particle size of wood based substrates (2, 8, 11), though they have been focused on a species of pine (loblolly pine, *Pinus taeda*). In a study with clean chip residual (~ 50% wood-based substrate; 2), five substrates consisting of four 100% wood-based products of various sizes [9.5, 12.7, 19.1, and 31.8 mm (⅜, ½, ¾ and 1¼ in)] as well as a PB control were used in the production of five woody species [loropetalum (*Loropetalum chinensis* var. *rubrum*), butterfly bush (*Buddleja davidii* 'Black Knight'), crapemyrtle (*Lagerstroemia indica* 'Hopi' and *Lagerstroemia* × *fauriei* 'Natchez') and azalea (*Rhododendron indicum* 'Mrs. G.G. Gerbing')]. Results showed that plants grown in 12.7 and 9.5 mm (½ and ⅜ in) substrate material were similar in size to those grown in a PB control and that plants grown in these smaller sized particles had greater growth compared to plants grown in larger size particles [19.1 and 31.8 mm (¾ and 1¼ in)]. In a greenhouse study with WholeTree (greater than 80% wood-based substrate; 8), annual plants [marigold (*Tagetes patula* 'Little Hero Yellow') and petunia (*Petunia* × *hybrida* 'Dreams Pink')] were grown substrates composed entirely or in part of WholeTree chips, processed to one of 3 hammer mill screen sizes [4.8 mm (3⁄16 in), 6.4 mm (¼ in) or 9.5 mm (⅜ in)] and mixed with peatmoss at 20 or 50% (by vol). The study reported that all marigold plants were marketable at 34 days after planting and that there were no differences in flower number. However, petunia plants did not grow as well in a 4:1 WholeTree substrate, which the authors attributed to nitrogen immobilization early in production. Physical properties of substrates used in this study indicated high air space and low container capacity in entirely WholeTree or 4:1 WholeTree treatments, though 1:1 ratios of WholeTree to peatmoss provided similar physical properties to the control peatlite treatment. In an extensive study with pine tree substrate mixes (11), the authors found that growth of marigold (*Tagetes erecta* 'Inca Gold') was similar to a control peatlite treatment when coarsely ground pine tree substrate (no hammer milling, chipping only) was mixed with finely ground pine tree substrate [4.8 mm (3⁄16 in)]. In a second experiment, the authors evaluated 27 substrate mixes (various amounts of screen sizes, organic amendments and sand) and demonstrated that substrates composed of coarsely ground pine tree substrate could be amended with finely ground pine tree substrate or other materials to produce plants of similar quality to industry standard peatlite and PB substrates.

Adjustment of particle size for ERC substrate could increase container capacity resulting in increased growth comparable to plant growth in PB. This study compares both ERC and HAC to a PB control to determine if these tree species can be used as nursery substrates as well as to determine which particle size ERC and HAC is best for producing plants comparable to those grown in PB.

Materials and Methods

Eastern redcedar chips were obtained from whole trees harvested in Barber Co., KS that had aged for six months prior to grinding (Queal Enterprises, Pratt, KS). Those chips were further processed in a hammer mill (Model 30HMBL, C.S. Bell Co., Tiffin, OH,) to pass a 4.8, 9.5, 12.7, or 19.1 mm (3⁄16, ⅜, ½, and ¾ in) screen on April 5, 2010. Hedge-apple chips were harvested near Wichita, KS, by a local power company and similarly processed. Eastern redcedar chips, HAC and a PB (SunGro, Bellevue, WA) control were then blended with sand to make a series of five wood:sand (80:20, by vol) substrate mixes. Substrates were pre-plant incorporated with 1.2 $kg \cdot m^{-3}$ (2 $lb \cdot yd^{-3}$) micronutrient package (Micromax, Scotts, Marysville, OH) and controlled release fertilizer at 8.6 $kg \cdot m^{-3}$ (14.5 $lbs \cdot yd^{-3}$ 14-14-14, 8 to 9 month release Osmocote Classic, Scotts, Marysville, OH). Two-gallon containers (7.4 liter #2 Squat Classic C1000S, Nursery Supplies Inc., Fairless Hills, PA) were then filled and planted with one liner per container of black-eyed susan (*Rudbeckia fulgida* var. *fulgida*; Creek Hill Nursery, Leola, PA; 72 cell pack), maiden grass (*Miscanthus sinensis* 'Graziella'; Emerald Coast Growers, Pensacola, FL; 64 cell pack), crapemyrtle [*Lagerstroemia* × 'Arapaho'; Cedar Valley Nurseries, Ada, OK; 6.4 × 6.4 × 10.2 cm (2.5 × 2.5 × 4 in) 24 count Rootmaker® liners, Rootmaker, Huntsville, AL], and baldcypress [*Taxodium distichum*; one-year-old seedlings grown at the John C. Pair Horticulture Research Center, Haysville, KS; seed collected from Ingram, TX; grown in Hummert plant bands with holes, 5.1 × 5.1 × 15.2 cm (2 × 2 × 6 in), Hummert International, Earth City, MO] on April 28, 2010. Containers were placed on an outdoor gravel container pad and irrigated daily via overhead sprinklers supplying 2.54 cm (1 in) of water daily. Redbud (*Cercis canadensis*; seedlings grown at the John C. Pair Horticulture Research Center; seed collected from center) were planted on the same date but with two seedlings per container that were thinned to one seedling 42 days after planting (DAP; June 9, 2010). Redbud seedlings had been grown in a community flat and were removed and potted immediately. Redbuds were transferred later to the container pad after they were allowed to harden off in the greenhouse until 15 DAP (May 13, 2010).

Data collection began on May 13, 2010, 15 DAP, and continued once every 4 weeks (42, 70, 105, 126 and 154 DAP) until termination on September 29, 2010, except blackeyed-susan and maiden grass, which were harvested earlier on August 11, 2010 (105 DAP). Data collected included pH and electrical conductivity (EC) using the pour-thru technique (19). Leaf greenness as measured with a SPAD-502 Chlorophyll Meter (Minolta Camera Co., Ramsey, NJ), and growth indices [(widest width + perpendicular width + height) ÷ 3] were measured at 15, 42, 70, and 105 DAP. Leaf greenness was measured with the average of four newly matured leaves per plant. Shoot and root dry weight was recorded at the conclusion of the study by drying in a forced air oven (Model SC-400, The Grieve Co., Round Lake, IL) at 71C (160F) for 7 days. Substrate physical properties ($n = 3$) were determined using North Carolina State University porometers (Raleigh, NC), which measured substrate air space, container capacity, substrate bulk density, and total porosity (9). Leaf samples ($n = 4$) of maiden grass, crapemyrtle, and redbud 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). Foliar N was determined by combustion analysis using 1500 N analyzer (Carlo Erba, Milan, Italy). Remaining nutrients were determined by microwave digestion with inductively coupled plasma-emission spectrometry (Thermo Jarrel Ash, Offenbach, Germany). Data were analyzed using the Waller-Duncan K-ratio T Test (SAS version 9.1, SAS Institute

Inc., Cary, NC). The experimental design was a randomized complete block design with five substrate treatments and eight single plant replications per treatment. Each primary substrate component (ERC or HAC) and each plant species in these substrates were considered separate experiments for the purpose of analysis and compared to the same species grown in the PB control.

Results and Discussion

All substrates were within recommended ranges for total porosity and bulk density (20; Table 1). Container capacity of PB was greater than the recommended range (68.8%; recommended range is 45 to 65%) while the smaller particle sizes (4.8 and 9.5 mm; 3⁄16 and 3⁄8 in) of ERC and 4.8 mm (3⁄16 in) HAC were acceptable. Container capacity values for all other substrates (larger particle sizes) were lower than recommended. Airspace values for PB were lower than recommended, whereas airspace values of the two largest particle size substrates (12.7 and 19.1 mm; ½ and ¾ in) were higher than recommended. The incorporation of 20% sand could have played a role in the low container capacity and high air space of coarse substrates, however, use of 20% sand is an acceptable and common industry practice in the Great Plains where the extra weight assists with fewer container blow-overs in frequent high winds. Added weight is particularly important in wood-based substrates as they typically weigh less than PB. Acceptable substrate airspace values were achieved with the two smallest particle sizes (4.8 and 9.5 mm; 3⁄16 and 3⁄8 in). Substrate shrinkage values for all ERC treatments were the same as for PB while shrinkage values for all HAC treatments were higher than PB, particularly for the 4.8 mm (3⁄16 in) size. This is surprising since HAC is considered to be a decay resistant wood (18). However, 2.3 mm (0.1 in) of shrinkage would likely have little effect on substrate physical properties and plant growth. For particle size distribution, the 12.7 mm (½ in) screen size produced an ERC substrate most similar in particle size distribution to PB, whereas the largest screen size (19.1 mm; ¾ in) produced an HAC substrate most similar to PB (Table 2). These attributes of alternative substrates are important to understand in order to manage crops based on substrate properties and crop requirements. Crops needing little water could be grown in a coarser substrate while crops that need a significant amount of water could be produced in a substrate with high container capacity. Crops could then be grouped according to substrate type (water requirements) and shade, allowing for better water management in the nursery. Alternatively, if the desired crop needs to maintain a certain size (ex. shipping or pruning), substrates can be used to either increase growth (greater container capacity) or restrain it (greater air space).

Substrate pH was higher for all HAC particle size treatments than for PB throughout the study with the exception of 4.8 mm (3⁄16 in) at 126 DAP and 4.8, 9.5 and 12.7 mm (3⁄16 , 3⁄8, and ½ in) at 154 DAP (Table 3). The same was true

Table 1. Physical properties of alternative substrates composed of tree species [eastern redcedar (ERC) and hedge-apple (HAC)] processed to various particle sizes in a hammer mill and a pine bark control substrate.[z]

Substrates[y]	Total porosity[x]	Container capacity[w]	Air space[v]	Bulk density[u]	Shrinkage[t]
	(% vol)			(g·cm^{-3})	mm
			ERC		
Pine bark	73.5a[s]	68.8a	4.7e	0.52a	0.4[ns]
4.8 mm (3⁄16 in) ERC	70.2b	50.1b	20.2d	0.45b	0.8
9.5 mm (3⁄8 in) ERC	70.1b	40.1c	29.9c	0.46b	0.2
12.7 mm (½ in) ERC	70.0b	35.2d	33.9b	0.45b	0.3
19.1 mm (¾ in) ERC	69.0b	29.9e	40.1a	0.47b	0.5
			HAC		
Pine bark	73.5a	68.8a	4.7d	0.52a	0.4c
4.8 mm (3⁄16 in) HAC	68.3c	52.3b	16.0c	0.51a	2.3a
9.5 mm (3⁄8 in) HAC	66.3d	36.7c	29.6b	0.50a	1.2b
12.7 mm (½ in) HAC	71.5b	36.6c	34.9a	0.43b	1.6b
19.1 mm (¾ in) HAC	68.3c	33.3d	34.9a	0.46b	1.4b
Recommended[r]:	50–85	45–65	10–30	0.19–0.70	

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

[y]Substrate treatments were: ERC = *Juniperus virginiana* chips, pine bark, or HAC = *Maclura pomifera* chips. Substrates mixed on v:v basis with each treatment containing 80% wood to 20% sand.

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

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

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

[u]Bulk density after forced-air drying at 105C for 48 hr.

[t]Difference between final substrate level and initial substrate level measured from the top the container.

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

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

[ns]Means not significantly different.

Table 2. Particle size analysis of alternative substrates composed of tree species [eastern redcedar (ERC) or hedge-apple (HAC)] processed to various particle sizes in a hammer mill and a pine bark control substrate.

	Substrate^z				
		ERC			
Particle size range:	Pine bark	4.8 mm (3⁄16 in)	9.5 mm (3⁄8 in)	12.7 mm (½ in)	19.1 mm (¾ in)
Coarse^y	27.3b^x	20.1c	33.8a	27.5b	33.8a
Medium	40.1c	50.8a	45.5b	44.4b	34.5d
Fine	32.7a	29.2a	20.7b	28.1a	31.7a
		HAC			
Coarse	27.3c	15.5d	37.1ab	44.2a	33.7bc
Medium	40.1c	51.4a	43.7b	40.6bc	39.9c
Fine	32.7a	33.2a	19.2bc	15.2c	26.4ab

^{z}Substrate treatments were: ERC = *Juniperus virginiana* chips, pine bark, or HAC = *Maclura pomifera* chips. Substrates mixed on v:v basis with each treatment containing 80% wood to 20% sand.

^{y}Coarse = 2.00 mm and greater [sieve opening (mm) 6.30 and 2.00]; Medium = less than 2.00 and greater than 0.5 mm [sieve opening (mm) 0.71 and 0.5]; Fine = less than 0.5 mm [sieve opening (mm) 0.25, 0.11, and pan].

^{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).

for ERC through 70 DAP, after which they were similar. In general, pH of the wood-based substrates was higher than is typically recommended for container production (20). Electrical conductivity for all treatments was generally within recommended ranges (0.8 to 1.5 mmho·cm^{-1}; 20) throughout the study (data not shown).

Black-eyed susan. Growth indices at termination (105 DAP) were similar for plants grown in ERC and PB except for smaller plants grown in 12.7 mm (½ in) ERC (Table 4). Shoot dry weight (SDW) of plants grown in PB was similar to plants grown in the two smallest particle sizes of ERC, whereas SDW of plants grown in the two largest particle sizes were lower than for PB. Plants grown in HAC were smaller (growth index and SDW) than plants grown in PB, but were not different among particle sizes. Leaf greenness (measured with the SPAD Meter) for plants grown in PB, ERC and HAC were similar at each measurement date (data not shown).

Maiden grass. Results for maiden grass indicated that the highest growth indices and SDW were in PB and 4.8 mm (3⁄16 in) alternative substrates (either species; Table 4). Larger particle sizes of ERC or HAC yielded smaller plants, though they were still marketable. Tissue nutrient content did not reveal any toxicities or deficiencies (data not shown).

All woody plants. All woody species were grown for 154 days. Between 105 and 154 DAP a period of high winds and summer heat occurred which resulted in dieback of some woody plant species. This is reflected in decreased growth indices between 105 and 154 DAP.

Crapemyrtle. Growth indices (both 105 and 154 DAP) and SDW of crapemyrtle was highest in PB, while plants grown in ERC substrates were the same, but were less than in PB (Table 4). At 105 DAP plants grown in ERC were, on average, 19% smaller than plants grown in PB (range 17 to 23%), but by 154 DAP that gap had decreased to 12% (range

Table 3. Change of substrate pH over time in alternative substrates composed of tree species [eastern redcedar (ERC) or hedge-apple (HAC)] processed to various particle sizes in a hammer mill and a pine bark control substrate, as determined with the pour-through method.

Substrates^z	15 DAP^y	42 DAP	70 DAP	105 DAP	126 DAP	154 DAP
Pine bark	6.0b^x	6.1b	6.3c	6.8^{ns}	6.6^{ns}	7.3^{ns}
4.8 mm (3⁄16 in) ERC	6.9a	7.3a	6.8b	6.8	6.9	7.2
9.5 mm (3⁄8 in) ERC	6.9a	7.2a	7.2ab	7.0	6.9	7.2
12.7 mm (½ in) ERC	6.9a	7.2a	7.0ab	6.9	6.7	7.1
19.1 mm (¾ in) ERC	7.1a	7.4a	7.3a	7.2	6.8	7.5
Pine bark	6.0b	6.1c	6.3c	6.8c	6.6b	7.3b
4.8 mm (3⁄16 in) HAC	6.8a	6.9b	6.7b	7.3b	7.1ab	7.4b
9.5 mm (3⁄8 in) HAC	7.0a	7.0b	6.7ab	7.3b	7.2a	7.6ab
12.7 mm (½ in) HAC	7.0a	7.1ab	6.9ab	7.6a	7.4a	7.7ab
19.1 mm (¾ in) HAC	7.0a	7.4a	7.1a	7.6ab	7.2a	7.9a

^{z}Substrate treatments were: ERC = *Juniperus virginiana* chips, pine bark, or HAC = *Maclura pomifera* chips. Substrates mixed on v:v basis with each treatment containing 80% wood to 20% sand.

^{y}DAP = days after planting

^{x}Means within column and location followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests $\alpha = 0.05$ (n = 4).

^{ns}Means not significantly different.

Table 4. **Growth of black-eyed susan (*Rudbeckia fulgida* var. *fulgida*), maiden grass (*Miscanthus sinensis* 'Graziella'), crapemyrtle (*Lagerstroemia* 'Arapaho', baldcypress (*Taxodium distichum*) and redbud (*Cercis canadensis*) in alternative substrates composed of tree species [eastern redcedar (ERC) or hedge-apple (HAC)] processed to various particle sizes in a hammer mill and a pine bark control substrate.**

	Black-eyed susan		Maiden grass		Crapemyrtle			
					Growth index			
Substrate[z]	Growth index[y] 105 DAP	Shoot dry weight[x]	Growth index 105 DAP	Shoot dry weight	105 DAP	154 DAP	Shoot dry weight	Root dry weight[w]
Pine bark	49.4a[v]	70.7a	108.5a	142.7a	53.7a	47.1a	42.1a	12.3[ns]
4.8 mm (3⁄16 in) ERC	49.7a	65.2ab	105.5ab	100.6b	41.4b	41.1b	26.8b	10.0
9.5 mm (3⁄8 in) ERC	44.7ab	60.2ab	97.4bc	85.9bc	44.8b	41.9b	30.6b	11.8
12.7 mm (1⁄2 in) ERC	41.0b	52.3b	100.8abc	76.4c	44.5b	42.5b	24.7b	12.7
19.1 mm (3⁄4 in) ERC	46.7ab	54.9b	92.9c	70.8c	42.7b	40.4b	24.1b	10.7
Pine bark	49.4a	70.7a	108.5a	142.7a	53.7a	47.1a	42.1a	12.3[ns]
4.8 mm (3⁄16 in) HAC	40.8b	57.1b	100.5ab	113.2b	45.0b	42.3bc	26.4b	10.6
9.5 mm (3⁄8 in) HAC	37.5b	53.6b	94.2b	75.3dc	44.3bc	46.1ab	35.2ab	17.8
12.7 mm (1⁄2 in) HAC	35.4b	46.0b	81.6c	68.6dc	42.5bc	40.2c	25.6b	14.1
19.1 mm (3⁄4 in) HAC	40.5b	55.7b	93.2b	89.6c	41.1c	41.6c	27.0b	13.4

	Baldcypress						Redbud	
	Growth index		Caliper (mm)					
	105 DAP	154 DAP	105 DAP	154 DAP	Shoot dry weight	Root dry weight	Growth index 154 DAP	Shoot dry weight
Pine bark	78.1[ns]	55.0[ns]	14.8a	17.0[ns]	68.9[ns]	80.8[ns]	40.5[ns]	24.6[ns]
4.8 mm (3⁄16 in) ERC	75.2	60.7	13.9ab	15.4	67.0	88.0	46.5	35.7
9.5 mm (3⁄8 in) ERC	73.8	61.8	13.3b	15.1	69.2	69.0	38.1	26.2
12.7 mm (1⁄2 in) ERC	74.1	59.8	12.7b	14.6	66.5	77.2	55.3	27.2
19.1 mm (3⁄4 in) ERC	73.6	63.2	13.7ab	15.0	64.5	96.5	39.8	24.3
Pine bark	78.1a	55.0[ns]	14.8a	17.0a	68.9a	80.8[ns]	40.5[ns]	24.6b
4.8 mm (3⁄16 in) HAC	66.3b	55.5	13.4b	15.2b	51.8b	52.5	48.7	35.2ab
9.5 mm (3⁄8 in) HAC	64.5b	57.7	13.5b	14.5b	47.2b	60.9	39.6	26.4ab
12.7 mm (1⁄2 in) HAC	67.6b	59.3	13.0b	14.0b	47.3b	88.0	41.6	29.4ab
19.1 mm (3⁄4 in) HAC	68.0b	56.9	12.9b	14.2b	45.3b	79.9	48.9	42.3a

[z]Substrate treatments were: ERC = *Juniperus virginiana* chips, pine bark, or HAC = *Maclura pomifera* chips. Substrates mixed on v:v basis with each treatment containing 80% wood to 20% sand.

[y]Growth index = [(height + width 1 + width 2) / 3]. Measured in cm.

[x]Shoots were harvested at the container surface and oven dried at 70C for 48 h. Weight is measured in grams.

[w]Roots were washed of substrate and oven dried at 70C for 48 h. Weight is measured in grams.

[v]Means within column and location followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests $\alpha = 0.05$ (n = 8).

[ns]Means not significantly different.

10 to 14%). However, it is important to note that the difference between PB and ERC SDW was significantly greater than growth index at 37% (range 27 to 43%). While the difference in growth index was not great, SDW revealed that plants grown in all particle sizes of ERC were less dense and perhaps less marketable. Root dry weight (RDW) was the same for all treatments indicating a healthy root system for plants grown in both PB and ERC. Analysis of foliar nutrient content of plants grown in ERC substrates did not reveal any abnormalities (data not shown).

Growth indices of crapemyrtle grown in HAC at 105 and 154 DAP was highest in PB and generally decreased as particle size increased (Table 4). Data for plants grown in HAC is similar to that of plants grown in ERC in that at 105 DAP plants were 19% smaller than those grown in PB (range 16 to 23%) and 10% smaller at 154 DAP (range 2 to 15%). Like the plants grown in ERC, plants grown in HAC had significantly less SDW (32%; range 16 to 39%) than plants grown in PB. Root dry weight of crapemyrtle grown in HAC was also similar across all treatments. Foliar nutrient content of crapemyrtle grown in HAC was generally normal with the exception of higher than expected levels of Fe, though no toxicity symptoms were present on plants grown in the study (data not shown).

Baldcypress. At termination, there were no differences in growth index, caliper, SDW, or RDW of baldcypress grown in ERC (Table 4). At 105 DAP caliper varied among substrates, however, those differences were not present at termination. Growth indices of baldcypress grown in HAC were greatest in PB at 105 DAP, however by 154 DAP, there were no differences. Caliper of baldcypress was greatest in PB at both 105 and 154 DAP, though all particle sizes of HAC were similar. Shoot dry weight at study termination was greatest in PB, but there were no differences in RDW. We suspect that the loss of treatment separation was likely a result plant dieback due to environmental stress as all measured growth index values decreased from 105 to 154 DAP. At study termination, PB substrates produced plants with the highest caliper growth and the highest SDW among all treatments.

Redbud. Regardless of substrate (ERC or HAC), redbud seedling growth index, caliper, and RDW were similar among treatments (data not shown). Shoot dry weight of

Table 5. **Leaf greenness of redbud (*Cercis canadensis*) grown in alternative substrates composed of tree species [eastern redcedar (ERC) or hedge-apple (HAC)] processed to various particle sizes in a hammer mill and a pine bark control substrate.**

	Leaf greenness[z]					
Substrate[y]	**15 DAP[x]**	**42 DAP**	**70 DAP**	**105 DAP**	**126 DAP**	**154 DAP**
Pine bark	33.0a[w]	34.0a	33.8a	35.2ab	33.8b	38.9b
4.8 mm (3⁄16 in) ERC	27.0c	22.9c	26.6b	32.7b	35.0b	38.7b
9.5 mm (3⁄8 in) ERC	26.8c	24.3cb	37.7a	34.9ab	37.3ab	40.9ab
12.7 mm (1⁄2 in) ERC	25.6c	24.0c	37.9a	34.9ab	36.5ab	38.5b
19.1 mm (3⁄4 in) ERC	29.3b	29.6ab	36.4a	38.8a	40.6ab	46.7a
Pine bark	33.0a	34.0a	33.8[ns]	35.2[ns]	33.8[ns]	38.9[ns]
4.8 mm (3⁄16 in) HAC	28.2b	26.5b	31.3	33.4	33.2	38.4
9.5 mm (3⁄8 in) HAC	27.3b	27.3b	34.6	35.5	34.9	42.1
12.7 mm (1⁄2 in) HAC	27.2b	28.7b	33.7	35.2	36.6	40.1
19.1 mm (3⁄4 in) HAC	27.6b	30.7ab	35.4	35.2	36.3	41.8

[z]A measure of leaf chlorophyll content using a SPAD-502 Chlorophyll Meter (Minolta Camera Co., Ramsey, NJ).

[y]Substrate treatments were: ERC = *Juniperus virginiana* chips, pine bark, or HAC = *Maclura pomifera* chips. Substrates mixed on v:v basis with each treatment containing 80% wood to 20% sand.

[x]DAP = days after planting.

[w]Means within column and location followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests α = 0.05 (n = 8).

[ns]Means not significantly different.

seedlings grown in ERC were the same for all particle size treatments, however, seedlings grown in HAC were largest in the 19.1 mm (3⁄4 in) particle size whereas seedlings in the PB substrate were the smallest (Table 4). Leaf greenness for redbud grown in ERC was greatest in PB at 15 DAP (Table 5). However, by the final harvest (154 DAP), plants grown in 19.1 mm (3⁄4 in) ERC had the greatest leaf greenness. Leaf greenness of redbud seedlings grown in HAC were not different across treatments from 70 DAP to final harvest. Tissue nutrient analysis on redbud did not reveal any toxicities or deficiencies (data not shown).

In general, for crops evaluated in this study, at both 105 and 154 DAP for woody and herbaceous species certain trends were observed. Growth index and SDW were higher in PB than ERC or HAC substrates. Within ERC or HAC the various screen sizes often produced similarly sized plants. When particle size did influence plant growth, smaller plants were generally produced in substrates with the larger particle sizes. These results are similar to the findings of other experiments with wood-based substrates using different particle sizes. Work by Boyer et al. (2) with several particle sizes of clean chip residual (9.5, 12.7, 19.1, and 31.8 mm; 3⁄8, 1⁄2, 3⁄4 and 1¼ in) showed that clean chip residual and PB were comparable. However larger screen sizes had higher air space values, and lower container capacity values, which was cited as an explanation for some growth effects. Similarly, Jackson et al. (11) passed pine tree substrate through 4.8, 6.4, 9.4, or 15.9 mm (3⁄16, ¼, 3⁄8, 5⁄8 in) screens and showed plant growth decreased with increasing screen size. Data in this study also demonstrated that container capacity decreased with increasing screen size for both ERC and HAC. Studies comparing WholeTree substrate and clean chip residual in combination with PB demonstrated that the addition of PB improved the physical characteristics of these substrates (13). Other studies blended PB and ERC at different proportions to grow baldcypress, silver maple (*Acer saccharinum* L.), and chinese pistache (*Pistacia chinensis* L.; 16). Plant growth was similar in substrates containing up to 20% ERC compared to PB. At higher levels of ERC plants grew less. In this experiment, despite differences in SDW and growth indices, RDW for all species was not significantly affected by ERC at any particle size. Therefore these alternative substrates have the capacity to produce plants with a larger root system per unit of above ground biomass than the PB substrates.

Both ERC and HAC can be used as primary substrate components, for some species. However, of the two species utilized for substrate construction, ERC tended to produce plants most similar to PB. The majority of plants grown in this study were marketable at termination, with perhaps the exception of crapemyrtle. Use of these materials as a primary substrate component could alleviate some of the shipping costs and availability issues associated with PB as a primary substrate component. The financial savings from use of ERC or HAC could offset the decrease in growth associated with them compared to PB. Use of either ERC or HAC as a large portion in a substrate blend with PB or other substrates known for higher container capacities (peatmoss) could help to adjust container capacity to the industry standard. Overall, ERC and HAC are promising materials for nursery growers interested in replacing or augmenting PB in substrate mixes.

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