Particle Size Affects Physical and Chemical Properties of 100% Pine Bark Horticultural Substrate

by

Evan Taylor Ware

A thesis submitted to the Graduate Faculty of
Auburn University
In partial fulfillment of the
Requirements for the Degree of
Master of Science

Auburn, Alabama
May 7, 2017

Keywords: nursery, container-grown, pH

Approved by

D. Joseph Eakes, Chair, Professor, Horticulture
Jeff L. Sibley, Professor, Horticulture
Carolyn W. Robinson, Associate Professor, Horticulture
J. David Williams, Professor and Head, Horticulture

Abstract

Pine bark is the most commonly used substrate component for container plant production in the southeastern United States, with some growers using 100% pine bark. Substrate physical and chemical properties directly affect the finished container-grown plant product. This study was developed to determine if there is a feasible way for growers to alter substrate physical and chemical properties to better suit the needs of the specific horticultural crop they are producing. Physical and chemical characteristics from locally sourced pine bark milled through two different screen sizes [0.50 inch (1.3 cm) and 0.75 inch (1.9 cm)] were compared the un-milled bark nuggets, as well as a standard substrate mix. Data showed that decreasing the particle size of a 100% pine bark substrate through milling does change physical and chemical properties. In this study, air space decreased as particle size decreased, water holding capacity increased as particle size decreased, total porosity increased as particle size decreased, and electrical conductivity and pH decreased as particle size decreased. This study suggests that producers can use milling to create a sustainable and cost-effective management of 100% pine bark substrates required for container-grown plant production.

Index words: nursery, container-grown, pH

Acknowledgements

I owe many thanks to many people for their help throughout my time at Auburn University. Thank you to Dr. Joe Eakes for helping me navigate the ups and downs of my research and graduate school experience in general. Thank you for taking the time to get to know my interests and goals so that you could better advise me and give me opportunities to develop needed skills to achieve my goals. Thank you to Dr. Jeff Sibley, Dr. Carolyn Robinson, and Dr. Dave Williams for all of your insight and support throughout this project.

Thank you to my fellow graduate students who helped me with this study, as well as the numerous students and staff members that helped me with my first project. Thanks to Beth Clendenen for your constant friendship, support, and encouragement. Thank you to Anthony Bowden for your unconditional love, support, and friendship; thank you for all of your hands-on help and for sharing your knowledge on a variety of subjects.

Thank you to my grandparents, Al Picinich, Ferne Picinch, and Mary E. Ware for all of your support throughout my time as a graduate student. I wouldn’t have been able to do this without you all! Thank you to my parents, James Ware and Lissa Ware, for believing in me, supporting me, and being proud of me. Thanks to my sister Jordan for your support and for keeping me smiling.

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CHAPTER I

INTRODUCTION

The greenhouse and nursery industry has grown exponentially in size and economic impact for decades. The gross market value of greenhouse and nursery crops sold in the U.S. during 2014 reached $13.8 billion, up almost two billion from just five years earlier. In Alabama alone, greenhouse and nursery crop sales totaled almost $243 million in 2014 (U.S. Department of Agriculture, 2015). Over the last forty years, production of nursery crops has slowly shifted from field production to container production, with about 60% of the industry currently growing plants in containers (Yeager et al., 2013). A container-grown plant root system is limited in volume and depth of substrate when compared to field-grown crops. Therefore, even if a native soil works well for field production, if this same soil is used for container production, the soil will remain saturated post watering and drainage. Saturated soils in container production result in poor root aeration and reduction of overall plant growth (Bilderback, 1980). The inability to use mineral soils for container production has led the industry to use soilless substrates in container-grown nursery crops. The need for improvements in container production has changed the way nursery plants are grown, there by requiring new management protocols to be developed for irrigation, fertilization, and pest control (Yeager et al., 2013). The rise of container-grown plant production has created a surge in research to identify best management practices for resource management and container substrates (Bilderback, 1999; Fain et al., 2000; Jackson et al., 2010).

Container-grown plant production operations require less acreage than traditional field production, can create year-round planting and marketing, and allow for finished products to be shipped to a diverse array of markets. Although there are many benefits of container plant production, container nurseries require diligent management of many production factors (Dunwell and Vanek, 2013). One of the most important production factors is the type of substrate used, which will vary from site to site and by plant type. Many terms exist to describe substrates including soil, media, soilless media, potting mix, artificial media, manufactured topsoil, and substrate; however, the terms are confusing and often inaccurate. The term "substrate" avoids confusion and accurately describes the entire rhizosphere within containers (Yeager et al., 2013).

The most commonly used substrate components in the southeastern United States are pine bark, sand, and milled sphagnum peat moss (Yeager et al., 2013). Pine bark is the dominant substrate component in the southeast, with some growers using 100% pine bark rather than a mixture of components. Growers must know how physical properties of pine bark vary with regard to particle size and distribution, and how these changes then affect plant growth. Knowledge of these physical changes will allow growers to make educated decisions as to which size of bark should be used in substrate blends so that the composition allows for the standardization of water and nutrient management practices optimizing production.

LITERATURE REVIEW

Horticultural Container Substrates

The main purposes of a container substrate are to serve as physical support for the plant, and to store oxygen, water, and nutrients needed for plant growth (Klingaman, 1975). Growers of greenhouse and nursery crops use primarily soilless substrates for container plant production, which are made of both organic and inert components, rather than mineral soils. Successful growers must be aware of physical and chemical properties inherent in these substrates. As such, small differences in the components of substrates can cause significant changes in plant growth and overall quality, due to alteration of substrate water holding capacity, structure, texture, and other physical and chemical properties. The factors of water holding capacity, air space for roots, and mineral storage capacity to meet plant needs (Jozwik, 2000) are especially important to consider in container plant production due to the limited water and nutrients available in the restricted volume of the container and the substrate it holds. Ideal substrates are reproducible, the substrate components are readily available, and are free of pathogens, weeds, and pests (Reinikainen, 1993).

There are many different choices of components available to growers when deciding what will make up a container substrate. While the standard substrate components used in the eastern U.S. are pine bark, sand, and milled sphagnum peat moss, alternatives being used include coconut coir (shredded coconut husks), composted animal wastes, composted cotton gin waste, composted hardwood bark, rice hulls, and tree or wood-based substrates (Awang and Ismail, 1997; Hidalgo et al., 2006; Jackson et al., 2005; Jackson et al., 2010; Murphy et al., 2010; Sharkawi et al., 2014; and Tyler et al.,1993). Different substrate components may vary in texture, physical structure, and availability by nursery location. Therefore, each individual grower must choose a mixture that will allow for production of the highest quality plant at the lowest possible cost (Pokorny, 1979). Cost, availability, ease of handing, and reproducibility are four classic criteria that influence substrate component selection (Avent, 2003). The need for cost effective, uniform substrates that can be incorporated into standardized fertility and water management programs continues to be a driving force behind research addressing needs in the horticulture industry.

Physical and Chemical Properties of Container Substrates

The suitability of a container substrate is mainly determined through the quality of the finished product or plant grown in the substrate (Verdonck and Gabriëls, 1988). The physical and chemical properties of the substrate, directly affects the finished plant product. A suitable substrate must be composed structurally in a way that plant roots can penetrate throughout the substrate, which allows for adequate extraction of oxygen, water, and nutrients, in addition to serving as an anchor for the plant (Reinikainen, 1993). Due to frequent and heavy applications of fertilizer and water needed to maintain optimal plant growth in a container, growers must be aware of the physical and chemical properties of the substrate used (Brown and Pokorny, 1975).

The Best Management Practices (BMP) Guide for Producing Nursery Crops (Yeager et al., 2013) provides recommendations for substrate selection and outlines the desirable physical and chemical properties of horticultural substrates. Ranges for desired physical properties of container substrates after irrigation and drainage are: total porosity 50 to 85%, air space 10 to 30%, water holding capacity 45 to 65%, and bulk density 0.19 to 0.70 g/cc.

Physical properties of container substrates are often determined with The North Carolina State University Porometer (Fonteno et al., 1995). Numerous methods exist to determine chemical properties of leachate extracted from substrates including the pour-through nutrient extraction procedure (Wright, 1986), bulk solution displacement (Nelson and Faber, 1986), and saturation extraction (Warncke, 1986). Nutrients available to container-grown crops can be estimated by how well the leachate conducts electricity, as electrical conductivity (EC) increases proportionally with the dissolved salts present.

The pour-through extraction procedure does not require the removal of substrate from containers to send to laboratories, as do other methods, which allows chemical properties to be determined without disturbing plant roots. First, container plants are watered to container capacity and left for an hour or until container capacity is reached. Additional water is poured through the substrate, which displaces the water in the perched water table at the bottom of the container. EC and pH are determined from the leachate collected (Wright, 1986). Bulk solution displacement requires an acrylic column (5 cm in diameter and 60 cm tall) with a no.11 rubber stopper fitted with a plastic tubing connector for drainage inserted into the bottom of the column. Glass filter paper is placed over the stopper and about 1000 cm^3 of substrate packed into the column (100 cm^3 at a time, compacted with a rubber stopper connected to a wooden dowel). Sufficient packing of substrate prevents channeling of displacing fluid. A volume of 250 ml of displacing solution (0.5% aqueous potassium thiocyanate in 50% ethanol) is added on top of the substrate. Bulk solution (the aqueous liquid phase of the substrate and its solutes, consisting of ions dissociated from the surfaces of substrate particles) is extracted and collected from the base of the column, and solution chemical properties are determined (Nelson and Faber, 1986). The saturation extraction method involves mixing 500 cm^3 of substrate with deionized water until it is just saturated. After equilibrating for 1.5 hours, pH is determined in the saturated medium and the solution is extracted with a vacuum filter. All subsequent analyses are then done on the extracted solution (Warncke, 1986).

Peat Moss

Sphagnum peat moss, one of the most commonly used substrate components among nursery and greenhouse producers in the U.S., is imported mostly from Canada with some coming from Florida, where sphagnum moss decomposes and accumulates in bogs. Peat is harvested through vegetation removal above the water-line of bogs, followed by the creation of a ditch to lower the water table so that the exposed peat will dry. Once dry, large vacuum harvesters or other large equipment is used to harvest the peat (Daigle et al., 2001). Labor costs of harvesting along with environmental concerns for this slowly renewable resource have caused the price of peat moss to rise. As the price for peat moss continues to rise, pine bark has been used as a peat moss substitute in the preparation of container substrates (Lu et al., 2006). In pine bark substrates, a fine grade of milled pine bark (with up to 19% of the bark particles passing through a 0.42 mm screen) is used as the organic amendment for the substrate, rather than peat moss (Pokorny, 1979). Peat moss still remains a standard in nursery and greenhouse production within the U.S. However, increasing labor and fuel costs and environmental concerns have some members of the industry looking elsewhere for cheaper and more readily available peat substitutes.

Bark Substrates

Since the 1970s, the horticulture industry has been using tree bark, a by-product of the lumbermill and papermill industries, as a component for container substrates (Gartner et al., 1973; Pokorny, 1979; Wright and Browder, 2005). Softwood bark is widely used as the main component in most horticultural substrates, with pine bark comprising as much as 75 to 100 percent of container substrates in the eastern U.S. (Lu et al., 2006). While pine bark is preferred in the southern region of the U.S., various hardwood barks have also been used as substrate components for growers in northern and midwestern areas of the US without access to access to adequate quantities of pine bark (Buamscha et al., 2007; Gartner et al., 1973).

Pine bark is harvested from logs in the debarking process prior to lumber or pulpwood production and then processed by hammer-milling and screening in order to reduce bark particle sizes to ranges suitable for a variety of uses, including use as a substrate for plant growth. One benefit of creating specific particle sizes through the milling of pine bark is that this material is reproducible, which allows for a standardized product. Milled pine bark, with 70 to 80% of the particles in the range of 1/40 to 3/8 inches (0.64 to 9.52 mm) in diameter and 20 to 30% of the particles smaller than 1/40 inch (0.64 mm), is referred to as “pine bark fines” and provides a satisfactory particle size ratio for container substrates (Pokorny, 1979). If the bark particle size is too coarse, water retention may be insufficient, whereas if there is an excess of fine particles, surplus water is retained, reducing oxygen in the substrate. Pine bark does not have to be composted before use as a horticultural substrate. However, many pine bark suppliers may age their product (stockpiling it for 3 to 18 months after hammer-milling). The aging or weathering of pine bark enhances its wettability. However, no differences have been reported in plant quality when fresh pine bark and aged pine bark are compared as substrates (Harrelson et al., 2004, Pokorny, 1979).

Recently, several factors have affected the availability of pine bark for horticultural use in the Southeastern U.S. Increases in fuel and electricity costs have increased demand for pine bark and other wood by-products for use as energy sources. Several pulp/paper mills have been closed in the southeast (Sibley, personal communication, 2017) which has decreased tree harvests and subsequent supply of pine bark byproducts. The demand for pine bark as a landscape mulch has also increased. Production of landscape mulch is less costly, requiring less labor to produce (less milling and screening) and commands a greater demand and price in the retail market than pine bark fines. Other uses affecting availability of pine bark include: use as poultry house or animal bedding, insulation, biofilters, and use in park and recreation areas. In addition, the amount of trees being harvested and debarked is not related to demand from use in horticulture, whereby availability at any given time is liable to change depending on demand for lumber and pulpwood (Lu et al., 2006).

Wood-based Substrates

Due to concerns of long-term availability of peat moss and pine bark for container substrates, research examining alternative substrates has increased. Wood residues make up a large source of soilless container substrates, and are generally secondary products of the sawmill and lumber industries. The availability of wood by-products depends on regional industries and availability. Lack of substrate consistency and availability make long-term use of sawmill and lumber by-products as long-term substrate components especially difficult for large production operations. To help address this issue, research on the production of wood-based substrates specifically for horticultural use has increased (Jackson, 2008; Murphy et al., 2010).

Recently, one of the most researched areas for wood-based container substrates has been focused on using the whole tree, where wood, bark, limbs, and needles are pulverized for use, rather than using solely the bark of pine trees for substrate composition. Laiche and Nash (1986) created two pine tree substrates for evaluation – one made from pine park with a considerable amount of pine tree wood added to it, and a second made from needles, twigs, bark and wood. Plant growth of three woody landscape species was highest in 100% pine bark compared to the whole pine tree type substrate (Laiche and Nash, 1986).

In 2005, Wright and Browder reported that Japanese holly (*Ilex crenata*), azalea (*Rhododendron spp.*), and marigold (*Tagetes patula*) could be grown in a fully pulverized 100% pine wood substrate made from the bole of debarked loblolly pines (*Pinus taeda*). Further research (Wright et al., 2006) evaluated growth of 27 woody ornamental species in a container substrate made of ground pine chips and suggested that with adjustments to fertility, fresh ground pine chips could replace pine bark as a container substrate component.

Fain et al. (2008) investigated the potential use of processed whole pine trees (referred to as *WholeTree*) as a container substrate. Freshly harvested, 8 to 10 year-old loblolly pine (*Pinus taeda*), slash pine (*P. eliottii)*, and long leaf pine (*P. palustris)* were chipped with a wood chipper to pass through a 0.374 inch (9.5 mm) screen. Annual vinca (*Catharanthus roseus)* grown in *WholeTree* were smaller than plants grown in 100% pine bark. However, there were no difference in plant growth indices between 100% pine bark and *WholeTree* substrates. Results from this study suggest that *WholeTree* substrates have the potential to replace pine bark as an alternative and sustainable substrate for the growth of short-term crops. Following initial research, *WholeTree* has been used as the substrate mix for Young's Plant Farm, one of the largest herbaceous nursery operations in the U.S., with multiple locations in Alabama and North Carolina (Fain, personal communication, 2017).

Summary

Even with a recent trend of research seeking alternative, more sustainable substrate components, pine bark remains the most used substrate component within the Southeastern U.S. Pine bark substrates vary widely in physical and chemical characteristics depending on location harvested, processing procedure, and other components mixed into the substrate. This study aims to determine the physical and chemical characteristics of 100% pine bark substrate from locally sourced pine trees, milled through different screen sizes. A link between particle size and physical and chemical properties can help local growers better understand the characteristics of pine bark as a substrate component. This knowledge can in turn lead to better yields and plant quality, in addition to more sustainable and cost-effective management of inputs required for plant production.

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CHAPTER II

EFFECT OF PARTICLE SIZE ON PHYSICAL AND CHEMICAL PROPERTIES OF 100% PINE BARK PLANTING SUBSTRATES

Abstract

Pine bark is the most commonly used substrate component for container plant production in the southeastern U.S., with some growers using 100% pine bark. Substrate physical and chemical properties directly affect the finished container-grown plant product. This study was developed to determine if there is a feasible way for growers to alter substrate physical and chemical properties to better suit the needs of the specific horticultural crop they are producing. Physical and chemical characteristics from locally sourced pine bark milled through two different screen sizes [0.50 inch (1.3 cm) and 0.75 inch (1.9 cm)] were compared to un-milled bark nuggets, as well as a standard substrate mix. Data showed that decreasing the particle size of a 100% pine bark substrate through milling does change physical and chemical properties. In this study, air space decreased as particle size decreased, water holding capacity increased as particle size decreased, total porosity increased as particle size decreased, and electrical conductivity and pH decreased as particle size decreased. This study suggests that producers can use milling to create a sustainable and cost-effective management of pine bark substrates required for container-grown plant production.

Index words: nursery, container-grown, pH

Significance to Industry

Pine bark is the most frequently used substrate component for container plant production in the southeastern U.S., yet there are concerns with regard to future availability for the Green Industry. Physical and chemical properties of pine bark can vary widely depending on many factors. Particle size is one property of pine bark that can easily be altered by growers through milling and screening. Growers need to know how the physical and chemical properties are altered by particle size, in order to optimize the correct particle size for pine bark substrate components needed for increased plant yields and quality. Results from this study determined that air space decreases as pine bark particle size decreases, water holding capacity increases as particle size decreases, total porosity increases as particle size decreases, and electrical conductivity and pH decrease as particle size decreases. Using this information, a grower can obtain milled pine bark of different screen sizes in order to change the physical and chemical properties of a 100% pine bark substrate to optimize levels needed for container-grown plant production.

Introduction

The greenhouse and nursery industry has grown exponentially in size and economic impact for decades. The gross market value of greenhouse and nursery crops sold in the U.S. during 2014 reached $13.8 billion, up almost two billion from just five years earlier. In Alabama alone, greenhouse and nursery sales totaled almost $243 million in 2014 (U.S. Department of Agriculture, 2015). Over the last 40 years, production of nursery crops has slowly shifted from field production to container production, with about 60% of the industry currently growing plants in containers (Yeager et al., 2013). A container-grown plant root system is limited by substrate volume and depth when compared to field-grown crops. Even if a native soil works well for field production, if this same soil is used for container production, it will remain saturated post watering and drainage. Saturated soils in container production result in poor root aeration and reduction of overall plant growth (Bilderback, 1980; Bilderback et al., 2005.). The inability to use mineral soils for container production has led the industry to develop and use soilless substrates in container-grown nursery crops. The need for improvements in container production has changed the way nursery plants are grown, thereby requiring new management protocols to be developed for irrigation, fertilization, and pest control (Yeager et al., 2013). The rise of container-grown plant production has created a surge in research to identify best management practices for resource management and container substrates (Bilderback, 1999; Fain et al., 2000; Jackson et al., 2010).

Container-grown plant production operations require less acreage than traditional field production, can create year-round planting and marketing, and allow for finished products to be shipped to a diverse array of markets. Although there are many benefits of container plant production, container nurseries require diligent management of many production factors (Dunwell and Vanek, 2013). One of the most important production factors is the type of substrate used, which will vary from site to site and by plant type. Many terms exist to describe substrates including soil, media, soilless media, potting mix, artificial media, manufactured topsoil, and substrate; however, the terms are confusing and often inaccurate. The term "substrate" avoids confusion and accurately describes the entire rhizosphere within containers (Yeager et al., 2013).

The most commonly used substrate components in the southeastern U.S. are pine bark, sand, and milled sphagnum peat moss (Yeager et al., 2013). Pine bark is the dominant substrate component in the Southeast, with some growers using 100% pine bark rather than a mixture of components (Lu et al., 2006). Growers must know how physical properties of pine bark vary with regard to particle size and distribution, and how these changes then affect plant growth. The objective of this study was to determine how the alteration of particle size affects physical and chemical properties of a 100% pine bark substrate. Knowledge of these physical and chemical changes can allow growers to make educated decisions as to which particle size or blend of particle sizes of pine bark should be used in 100% pne bark substrates so that the composition allows for the standardization of water and nutrient management practices optimizing production.

Materials and Methods

Large pine bark nuggets [1 in to 3 in (2.54 cm to 7.62 cm)] were obtained from Pineywoods Mulch Company, Alexander City, AL 35010. Pine bark nuggets were then processed through a swinging hammer-mill (Williams Patent Crusher & Pulverizer Co., St. Louis, MO 63102) on 24 June 2016. Two screen sizes were used: 0.50 in (1.3 cm) and 0.75 in (1.9 cm).

A completely randomized design evaluating four treatments, including a standard control of pine bark nuggets from the Paterson Greenhouse Complex (Auburn, AL, 36849) was initiated on 14 June 2016. The pine bark nuggets at the Paterson Greenhouse are used in substrate mixes at Auburn University to perform research and grow market-ready plants on a regular basis. Remaining treatments were composed of 100% milled pine bark run through the two screen sizes, along with whole pine bark chips that were not processed through the hammer-mill.

Two methods were used to determine physical properties [substrate air space (AS), water holding capacity (WHC), and total porosity (TP)]. The North Carolina State University (NCSU)

Porometer was used to determine physical properties of the 100% milled pine bark and the Paterson Greenhouse pine bark nugget control (Fonteno et al., 1995).

Due to the large particle size of the whole pine bark chips, the cores necessary for the NCSU Porometer method could not be uniformly packed, so The Bucket Method, outlined in the Best Management Practices: Guide for Producing Nursery Crops (Yeager et al., 2013), was modified and used to determine AS, WHC, and TP for all bark sizes, including the whole pine bark chips. The amount of water held in a standard three-gallon container (Nursery Supplies, Inc., Chambersburg, PA 17201), 1.18 in (3 cm) from the top of the container**,** was measured to be 9.58 L. Four three-gallon (11.4 L) containers, drainage holes sealed with gorilla tape (The Gorilla Glue Company, Sharonville, OH 45241), were filled to a height of 9.45 in (24 cm), or 1.18 in (3 cm) from top of container, with each substrate [milled pine bark processed through a 0.5 in (1.3 cm) screen, milled pine bark processed through a 0.75 in (1.9 cm) screen, whole pine bark chips, and the control pine bark nuggets from Paterson Greenhouse Complex]. An extra sealed three-gallon container was filled with 5.5 lbs (2.49 kg) of sand and dropped from 6 in (15.24 cm) above the top of each container five times to uniformly pack the substrate.

Each of the 16 three-gallon (11.4 L) containers were placed on an overturned six-inch (15.2 cm) nursery container inside a five-gallon (18.9 L) bucket. Water was slowly added to each three-gallon (11.4 L) container until the substrate was saturated and a thin film of free water was present on the substrate surface. The containers were left to sit for 30 min so that the substrate was completely saturated. The volume of water added to each substrate was recorded, and the drainage holes of the three-gallon (11.4 L) containers were cut open and the water was drained into the five-gallon (18.9 L) buckets. Drained water was collected and measured (Ingram et al., 1990; Yeager et al., 2013).

Bulk densities (BD) were determined from the same samples used to determine physical properties using the NCSU Porometer Method (for the milled pine bark and Paterson Greenhouse Complex's pine bark nuggets), and were obtained from 21.2 in^3 (347.5 cm^3) samples dried at 60°C (140° F) in a forced air oven for 96 hours. Particle size distribution (PSD) was determined by 100g oven-dried samples through a series of sieves. Sieves were shaken for five minutes with a Ro-Tap (Ro-Tap RX-29, W.S. Tyler, Mentor, OH 44060) sieve shaker. The particle fraction remaining on each sieve and amount passing through the smallest sieve and caught in the receiver pan were weighed and volume determined (Brown and Pokorny, 1975).

Leachates were obtained using the Virginia Tech Pour Through Method, and values for pH and electrical conductivity were measured (Wright, 1986). Studies were conducted at the Paterson Greenhouse Complex at Auburn University, AL 36849. All data was analyzed using analysis of variance and mean separation using the JMP statistical package (SAS Institute, Cary, NC).

Results and Discussion

Physical properties. Due to the variety of greenhouse crops grown and substrate components available locally at affordable costs, there is no set standard on how to best develop a substrate for container production; however, there are published optimal ranges for air space (AS), total porosity (TP), water holding capacity (WHC), and bulk density (BD) (Yeager et al., 2013). Substrate AS percentages of the pine bark milled through the 0.50 in (1.3 cm) and 0.75 in (1.9 cm) screens were within optimal ranges (10 to 30%) (Yeager et al., 2013) (Table 2.1). Values for AS values were between 23 and 28% for the milled pine bark substrates, while AS for the Paterson Greenhouse pine bark nuggets was higher than recommended at 45%. TP for all treatments were determined to be within the recommended range of 50-85%, ranging from 55-

83% for all substrates. Both the WHC values for the Paterson Greenhouse pine bark nuggets and the whole pine bark nuggets were determined to be below optimal recommendations. WHC values for the milled pine bark treatments were found within recommended ranges with the bark milled through the 0.50 in (1.3 cm) screen at 59.5% and the 0.75 in (1.9 cm) screen at 50.0%. Pine bark milled through the 0.50 in (1.3 cm) screen and pine bark milled through the 0.75 in (1.9 cm) screen both fell within recommended ranges for AS, TP, and WHC. Bulk density values were slightly below the optimal range (0.19-0.70 g/cc) for both milled pine barks and the Paterson Greenhouse pine bark nuggets.

A modified version of the Bucket Method was used in addition to the NC State Porometer method to determine physical characteristics of each treatment (including the whole pine bark nuggets, which were too large to be able to be accurately and consistently packed into the porometer equipment) (Table 2.2). While the Bucket Method is a good tool for growers to use on site to estimate physical properties of container substrates, it is not as accurate as the NCSU Porometer. Values for AS, TP and WHC determined through the bucket method were different from those determined through the NCSU Porometer Method. However, AS increased as particle size increased, WHC decreased as particle size increased, and TP increased as particle size increased.

Analyses of particle size distribution were broken down into three texture sizes: coarse (greater than 2.0 mm), medium (0.5 mm to 2.0 mm), and fine (0.00-0.50 mm) (Table 2.3). There were no differences in the amount of fine particles for the pine bark screened through the 0.75 in (1.9 cm) screen and the Paterson Greenhouse Complex pine bark nuggets. Differences were recorded in the amount of fine particles between all other treatments, with the amount of fine particles ranging from 0.8 to 17.9%. Fine particles affect container substrate WHC, as substrates with a higher percentage of fine particles will often hold too much water, while substrates with fewer fine particles tend to dry out more quickly (Bilderback et al., 2005). There were differences in the amount of medium particles of all treatments, ranging in amounts from 1.3 to 52.5%. Differences were recorded between all treatments in the amount of coarse particles, which allow for aeration in substrates. Coarse particles for all treatments ranged from 29.6 to 97.9%. The whole pine bark had the largest percentage of coarse particles (97.8%), followed by the Paterson Greenhouse Complex nuggets (60.0%), pine bark milled through the 0.50 in (1.3 cm) screen (29.1%), and pine bark milled through 0.75 in (1.9 cm) screen (51.5%). Coarse particles made up the largest fraction of each treatment, except for the pine bark milled through the 0.50 in (1.3 cm) screen, where medium particles were greatest. Out of the two milled pine barks, the pine bark that was milled through the 0.75 in. screen was most similar in particle size distribution to the standard Paterson Greenhouse pine bark nuggets.

pH and EC. Substrate pH was within the BMP recommended range of 4.5 to 6.5 for all substsrates (Yeager, et al., 2013). Between the whole pine bark nuggets, pine bark milled through the 0.50 in (1.3 cm) screen, and pine bark milled through the 0.75 in (1.9 cm) screen, pH decreased as particle size distribution decreased (Table 2.4). EC increased as particle size distribution increased over all susbstrates. All EC values were above the range recommended by the BMP (0.8-1.5 mmhos/cm) and ranged from 2.0 mmhos/cm to 3.8 mmhos/cm. Recent research suggests that certain herbaceous annuals and perennials may have higher nutritional requirements and a need for substrate EC measurements of 1.0 to 2.5 mmhos/cm, indicated in Table 2.4. The EC measurements for all treatments except for the whole pine bark nuggets were within this range for heavy feeding annuals and perennials (ranging from 1.9 to 2.5 mmhos/cm).

Conclusion

A 0.25 in (0.64 cm) difference in screen size affected particle size distribution (PSD), which was different for the two substrates milled through the 0.50 in (1.3 cm) screen and the 0.75 in (1.9 cm) screen. This difference in PSD appears to have influenced differences in the substrate physical properties (AS, WHC, and TP), and confirms that changing the particle size of a 100% pine bark substrate can influence the substrate's physical properties. Data indicate that AS decreases with decreasing particle size, WHC increases with decreasing particle size, and TP increases as particle size decreases. EC and pH are affected by a change in particle size as well, as data show pH and EC decreasing with decreasing particle size. Both milled 100% pine bark substrates had physical properties that were within the ranges recommended by the Best Management Practices Guide for Producing Container-Grown Plants (Yeager et al., 2013). Results from this study suggest that a grower would be able to change physical and chemical properties of a 100% pine bark substrate to levels needed for successful growth of a certain container-grown plant through altering substrate particle size and distribution.

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Table 2.1. Physical properties of three substrates containing 100% pine bark determined using the NCSU Porometer.[z]

Substrate	Air space[y] (% vol)	Water holding capacity[x] (% vol)	Total porosity[w] (% vol)	Bulk density[v] ($g \cdot cm^{-3}$)
Screened through 0.75 inch (1.9 cm)	27.4 b[u]	50.0 b	77.5 b	0.16 b
Screened through 0.50 inch (1.3 cm)	22.8 a	59.5 a	82.3 a	0.16 b
Paterson Greenhouse[t]	45.4 c	31.9 c	77.3 b	0.17 a
Recommended ranges[s]	10-30%	45-65%	50-85%	0.19-0.70

[z]Analyses performed using the North Carolina State University porometer (http://www.ncsu.edu/project/hortsublab/diagnostic/porometer/).

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

[x]Substrate water holding capacity is (wet weight - oven dry weight)/volume of the sample.

[w]Total porosity is substrate water holding capacity + air space.

[v]Bulk density after forced-air drying at 60 C (140.0F) for 96 hrs; 1 $g \cdot cm^{-3} = 62.4274\ lb \cdot ft^{-3}$.

[u]Means within columns followed by the same letter are not significantly different based on Tukey's Studentized Range Test, $\alpha = 0.05$ (n=6).

[t]Pine bark from Paterson Greenhouse Complex, delivered from Pineywoods Mulch Company, Alexander City, AL on 14 June 2016. Used as a substrate component for research and production operations at Auburn University, Auburn, AL.

[s]Recommended ranges as reported by Yeager et al., 2013. Best Management Practices Guide for Producing Container-Grown Plants.

Table 2.2. Physical properties of four substrates containing 100% pine bark determined using a Modified Bucket Method.[z]

Substrate	Air space[y] (% vol)	Substrate water holding capacity[x] (% vol)	Total Porosity[w] (% vol)
Whole pine bark	55.26 c[v]	8.2 b	55.3 b
Screened through 0.75 inch (1.9 cm)	39.2 b	7.47 b	46.7 a
Screened through 0.50 inch (1.3 cm)	25.6 a	21.9 a	47.3 a
Paterson Greenhouse[u]	43.6 bc	5.18 b	48.9 a
Recommended ranges[s]	10-30%	45-65%	50-85%

[z]Analyses performed using a modified version of the Bucket Method.

[y]Air space is volume of water drained from the sample(mL) / total container volume (mL).

[x]Substrate water holding capacity is percent porosity - percent air space.

[w]Total porosity is water added to saturate substrate (mL) / total container volume (mL).

[v]Means within columns followed by the same letter are not significantly different based on Tukey's Studentized Range Test, $\alpha = 0.05$ (n=4).

[u]Pine bark from Paterson Greenhouse Complex, delivered from Pineywoods Mulch Company, Alexander City, AL on 14 June 2016. Used as a substrate component for research and production operations at Auburn University, Auburn, AL.

[s]Recommended ranges as reported by the Best Management Practices Guide for Producing Container-Grown Plants (Yeager et al., 2013).

Table 2.3. Particle size distribution analysis of four 100% pine bark substrates determined using a RoTap Shaker®.

Texture[z]	**Screened through 0.50 inch (1.3 cm)**	**Screened through 0.75 inch (1.9 cm)**	**Paterson Greenhouse pine bark nuggets**	**Whole nugget pine bark**
Fine	17.6 a[y]	12.0 ab	8.1 b	0.8 c
Medium	51.6 a	36.0 b	31.7 b	1.3 c
Coarse	29.1 c	51.5 b	60.0 b	97.8 a

[z]Coarse = greater than 2.0 mm (0.8 in); Medium = 0.5-2.0 mm; Fine = 0.00-0.50 mm.
Grades adopted from Jackson et al., 2009.

[y]Means within rows followed by the same letter are not signiicantly different based on Tukey's Studentized Range Test, α = 0.05 (n=6).

Table 2.4. Solution pH and electrical conductivity (EC) for four 100% pine bark substrates.[z]

Substrate	pH	EC (mmhos/cm)[y]
Whole nugget pine bark	5.6a[x]	3.8a
Screened through 0.75 inch (1.9 cm)	5.3ab	2.1ab
Screened through 0.50 inch (1.3 cm)	5.1bc	2.0b
Paterson Greenhouse pine bark nuggets	4.8c	2.6ab
Recommended ranges[w]	4.5-6.5	1.9-2.5

[z]pH and EC of solution determined using the Virginia Tech Pour Through Method (Wright, 1986).
[y]1 mmhos/cm = $1 mS \cdot cm^{-1}$.

[x]Means within column followed by the same letter are not significantly different based on Tukey's Studentized Range Test, $\alpha = 0.05$ (n=6).

[w]Recommended ranges as reported by the Best Management Practices Guide for Producing Container-Grown Plants (Yeager et al., 2013).

CHAPTER III

FINAL DISCUSSION

Soilless substrates are one of the most important factors that growers have to manage when producing container-grown plants. With nearly all of plant production taking place in containers (Yeager et al., 2013), it is important for growers to be able to alter substrate properties to better suit the needs of whichever crop they are growing. Pine bark is the most commonly used substrate component in the southeastern U. S.; if growers know how particle size affects the chemical and physical properties of pine bark substrates, they can use this information to create a more suitable substrate for use in their growing operation. Being able to alter the chemical and physical properties of pine bark can help growers to produce higher quality plants.

Based on the results of this study, a grower could run pine bark through a series of different screen sizes of a hammer mill to change the chemical and physical properties of a 100% pine bark substrate to better suit specific container-grown crops. Data from this study indicate air space (AS) decreases with decreasing particle size, water holding capacity (WHC) increases with decreasing particle size, and total porosity (TP) increases as particle size decreases. Substrate electrical conductivity (EC) and pH are affected by a change in particle size as well, as data showing substrate pH and EC decreasing with decreasing particle size. Both milled 100% pine bark substrates had physical properties within the ranges recommended in the Best Management Practices Guide for Producing Container-Grown Plants (Yeager et al., 2013).

This study was limited to the use of only two hammer mill screen sizes. Further work should be done using a wider range of screen sizes to be sure that the links noted between physical and chemical properties and particle size in this study are seen on a larger scale in a wider range of substrate particle sizes. Further work should also be performed on alternative substrates that have been deemed appropriate for container-grown production through research to see if particle size has an affect on the properties of alternative substrates as well.

To further this study, multiple crops should be grown in the various screened bark sizes, and results should be analyzed to see how the finished product compares to what would be expected due to the ideal physical and chemical substrate properties outlined in the Best Management Guide for Producing Container-Grown Plants (Yeager et al., 2013).

During this study was completed, the data recorded for WHC using the modified Bucket Method was much lower than the WHC determined using the NCSU Porometer. Guidelines for performing the Bucket Method were drawn from the Best Management Practices Guide for Producing Container-Grown Plants (Yeager et al., 2013). In the Best Management Practices Guide for Producing Container-Grown Plants, the protocol for the Bucket Method does not have any mention of weighing the saturated substrates, and then drying the substrate before taking final measurements. If the substrate were weighed, dried, and weighed again, the WHC of a substrate could be accurately calculated. Due to the substrate still being saturated with water when measurements were taken, the calculations for WHC using the Bucket Method were slightly off. Since the substrate was still saturated, the water collected and measured at the end of this method was not an accurate measurement, as much of the water was still being held within the AS of the substrate. This methodology caused WHC calculations to be slightly inaccurate compared to the WHC values determined through the NCSU Porometer Method.

The Bucket Method is a method that was developed for growers to use on site at their growing operation to check that physical properties of substrates are appropriate for the type of plant being produced. Most growers do not have a forced air dryer, and would not be able to completely dry substrate out while performing the Bucket Method on site, so the step of drying is left out. For this reason, we speculate that WHC determined through the Bucket Method will not be accurate, even if growers diligently follow the protocol outlined in the BMP Guide for Producing Container-Grown Plants.

We speculate that there may be a way for growers to more accurately determine WHC for substrates on site at growing operations, but further work will be needed to verify an improved protocol. A small sample of substrate could be run through the Bucket Method as outlined in the BMP Manual, then weighed, dried in a oven at relatively low temperature (no more than 200 °F), and weighed again. This small sample will need to be of a known volume, and then the amount of water held per gram of substrate could be calculated. This calculation could then be used to determine the amount of water being held in the rest of the samples, and can be taken into consideration in order to have more accurate calculations for WHC.

The EC ranges for the pine bark substrates in this study were all relatively high, especially since no fertilizer had been added to the 100% pine bark. If EC levels are already high, this could cause problems when attempting to grow plants in the substrate that need to be fertilized. While EC levels are high for all substrates, it was noted that EC decreased with decreasing particle size. These trends were not expected, since surface area increases as particle size decreases, which would increase cation exchange capacity (CEC) and lead us to expect EC to increase as particle size decreases. Further research should include analyses of CEC of each substrate to possibly better understand why the EC of 100% pine bark with no charge is so high, and why EC has decreased as particle size decreased.

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