Combined Proceedings IPPS 72:102-110. 2022.

Quantifying the Influence of Moisture Content on Bark Screening for Improved Particle Separation

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Keywords: Greenhouse growing, growing media, material processing, nursery crops, pine bark, screening, soilless substrates

Summary

Historically, tree bark was regarded as a waste product of the timber industry for decades. After lumber harvesting and debarking, bark is often hammer-milled and screened to decrease its particle size for further use. This bark processing is impacted by many variables such as moisture content, which can influence the manufacturing and alter the final product. However, little work has been conducted to quantify moisture contents effect on bark screening. Thus, this study consisted of bark screened at five different moisture contents (50, 55, 60, 65, and 70%) and its yield were quantified and analysed. In general, as moisture content increased, bark that was processed through the screen (unders) had a decrease in yield on a volume and mass basis, whereas bark that did not process through the screen (overs), increased in volume and mass. More fine particles attached to the overs bark; however, this did not largely influence container capacity or air-filled porosity values. Hence, the drier the bark prior to screening resulted in more balanced particle separation.

INTRODUCTION

The timber industry has been heavily relied upon for fuel, building components, and energy, especially prior to the 1970’s (Raviv and Lieth, 2008). Formerly, softwood tree species such as pine or fir, would be harvested and debarked, where the xylem wood would be used for lumber or pulp, and the bark discarded. However, bark accounts for approximately 10% of the tree volume (Bunt, 1988) and is often buried or burned (Naasz et al., 2009). Nevertheless, advances in research discovered more sustainable uses of lumber harvests, particularly in the bark sector. Bark has been known to be used for a variety of commodities, including wood planks and pulpwood for paper products (Harkin and Rowe, 1971), biofuels (Nosek et al., 2016), cork (wine bottles), and in the horticulture industry as a mulch and growing medium (Baker, 1957; Pokorny, 1979; Bunt, 1988).

Once the log is debarked, the bark initially is not suitable for use due to large particle sizes (Pokorny, 1983). Therefore, the bark requires further processing such as aging, hammer-milling, and screening. Previously, Pokorny and Delaney (1975) demonstrated that hammer-milled/screened bark-based substrates that contain a majority of bark particles > 0.60 mm provide suitable horticultural media. Currently, the stripped bark is hammer-milled through screen apertures that often range from 4.0 – 9.5 mm (Fain et al., 2008; Jackson et al., 2009).

With regards to horticultural bark-based substrates, particle size has a tremendous influence on the physical/hydraulic properties, which subsequently impacts plant performance (Fields et al., 2017). A bark with an unbalanced proportion of coarse particles results in insufficient water-holding characteristics, whereas increased percentages of fine bark in a substrate material leads to poor aeration; both of which can be deleterious to containerized crop growth and development (Mathers et al., 2007).

Successful and continued use of screened pine bark depends on consistency, reproducibility, and predicting the proportions of partitioned bark particles on each screen after processing (Pokorny and Henry, 1984). Though biological and mechanical factors can influence the efficiency of bark hammer-milling and screening (Solbraa, 1979), moisture content may have the largest impact on the proportions of bark particle separation (Stewart et al., 2019). Water has high surface tension which frequently results in water remaining adsorbed to bark particle surface areas and internal porosities (Raviv and Lieth, 2008). However, greater moisture contents enable bark particles to more readily “stick” to each other via adhesion/cohesion. Jackson et al. (2010) concluded that the bark moisture content at the time of hammer-milling/screening can influence particle partitioning, where increasing bark moisture contents can decrease the quantity of bark particles screened.

Research is sparse in quantifying particle separation via screening under different initial screening moisture contents. This presents opportunities to 1) identify suitable moisture contents for bark screening and 2) further understand how moisture content at the time of screening influences bark processing yield. We hypothesize that the particle separation efficiency will decrease as moisture content increases.

MATERIALS AND METHODS

Bark Moisture Content Preparation. Fifteen plastic bags were each filled with exactly 0.03 m^3 of aged loblolly pine (*Pinus taeda*) bark (Phillips Bark Processing Co; Brookhaven, MS, U.S.) and sealed shut to ensure no moisture loss. Thereafter, the moisture content (MC) of the collected bark was gravimetrically determined prior to bark screening by weighing, drying (105℃ for 48 h), and reweighing four samples, resulting in a MC of 55% ± 0.01 SD. Therefore, five MC treatments were chosen: 50-, 55-, 60-, 65-, and 70% MC.

To estimate the dry weight of 0.03 m^3 of the pine bark samples, a porometer analysis (Fonteno and Harden, 2010) was conducted on three unscreened bark replicate samples. The total dry weight of the 0.03 m^3 samples were estimated by using bulk density (D_b) values (0.17 $g{\cdot}cm^{-3}$ ± 0.00 SD) and were calculated (4,919 g ± 59 SD). Subsequently, the quantity of water for each MC treatment required to be lost via evaporation (50% MC) or added (55, 60, 65, and 70% MC) was calculated and gravimetrically measured. Treatments contained target weights of 9,838 (50% MC), 10,931 (55% MC), 12,298 (60% MC), 14,055 (65% MC), and 16,397 g (70% MC). For the 50% MC treatment, the bark remained within the plastic bag and the bag was left open for evaporative demand to reduce the MC. The bags were continuously mixed and weighed until the desired weight was reached. For all other treatments, water was added to each bag and was equilibrated 72 h prior to screening. Each MC treatment contained three replicates ($5_{\text{MC treatments}}$ x $3_{\text{replicates}}$ = $15_{\text{total bags}}$). Once all MC treatments attained the desired weights, the treatments were prepared for screening.

Bark Processing. Once equilibrated and ready for processing, three small (~50 g) samples were randomly collected from each bag to measure the MC immediately before screening. The actual MC of the 50, 55, 60, 65, and 70% MC treatments were 52% ± 2 SD, 58% ± 2 SD, 61% ± 5 SD, 65% ± 1 SD, 68% ± 1 SD, respectively.

From each bag (replicate), 0.014 m^3 of bark was removed and placed in a 0.03 m^3 container and was immediately processed. The bark passed through a continuous flow screen (CF-1; Gilson Company Inc. Model; Lewis Center, OH, U.S.) fitted with a 6.3 mm aperture screen, set to 569 revolutions per minute, and screen level was maintained at 5° inclined slope. The bark particles passed through the screen at a rate of 56.21 $cm^3 min^{-1}$.

Measurements. All bark that was passed through the screen will be referred to as 'unders' and all bark that did not pass through the screen will be referred to as 'overs' for the remainder of this paper. Multiple measurements were assessed during and immediately after each replicate of 0.014 m^3 of bark was processed in MC treatments: The time it took for all the bark to be fed through the screen, the mass (g) of the overs and unders, and the volume (m^3) of the overs and unders. After the bark replicate within each MC treatment was processed, the bark was placed in a plastic bag and sealed to prevent moisture loss.

Physical Properties. Substrate physical properties, [container capacity (CC), air space (AS), total porosity (TP), and D_b] were measured via porometers of each over and under replicate within all MC treatments after screening. Thereafter, each replicate within the MC treatments was measured for its particle size distribution by sieving three, 100 g dry substrate replicates through a Ro-Tap shaker (Rx-29; W.S. Tyler, Mentor, OH, U.S.) for five min with a column of stacked sieves with aperture sizes of 6.3, 2.0, 0.7, 0.5, 0.3, and 0.1 mm, with a catch pan at the bottom.

Data Analysis. All data presented in tables and figures with corresponding statistical analysis was analysed in JMP Pro (16.2.0; SAS Institute, Inc.; Cary, NC, U.S.) utilizing Analysis of variance (ANOVA) and Tukey's Honestly Significant Difference at the $\alpha = 0.05$ significance level. Pearson correlation coefficient values were also calculated in JMP Pro (16.2.0) to correlate screening parameters across different types of measured yield.

RESULTS AND DISCUSSION

Physical Properties. There were slight differences observed across CC values within unders, where 55% unders held more than 65% unders (**Table 1**; $p = 0.0239$). However, there were no differences observed in overs CC values (**Table 1**; $p = 0.4820$). All unders ranged within recommended nursery substrate standards for water holding capacities (0.45 – 0.65 cm^3 cm^3; Bilderback et al., 2013). However, overs were far below recommendations (< 0.40 cm^3 cm^3). This trend continued for AS, where recommended values range within 0.10 – 0.30 cm^3 cm^3 and all overs and the 65% unders exceeded suggested air-filled porosity values (Bilderback et al., 2013).

There were slight differences examined in unders TP values ($p = 0.0079$) and no differences in overs (**Table 1**; $p = 0.2375$;). However, a t-test of summarized overs against unders showed no differences between total porosity values (**Table 1**; $p = 0.3947$). Screening bark substrates can have strong impacts on air-filled porosity ($p < 0.0001$) and water holding characteristics ($p < 0.0001$; Table 1) simply by shifting the AS:CC ratio due to alterations in particle arrangement and surface area proportions, while typically having negligible effect on TP (Altland et al., 2011). This follows the fundamental geometric principle that a group of uniform spherical objects will always occupy 66.7% (vol.) of a cylindrical container (Jury and Horton, 2004), regardless of sphere volume. Though bark particles are relatively platy, this principle more-or-less follows the results herein, where similar findings were also observed by Fields et al. (2021). The 70% unders had the greatest D_b values ($p = 0.0003$), and after 60% MC in overs, D_b began to increase with increasing moisture (**Table 1**; $p = 0.0162$).

In this study, moisture content had relatively little influence on resultant bark physical properties (Table 1). However, it has been demonstrated that increasing proportions of fine particles can increase CC and decrease AS (Altland et al., 2018).

Among the PSD analysis, unders had no differences ($p = 0.0646$); however, in overs, as moisture content increased, extra-large particle percentages decreased (**Table 1**; $p = 0.0007$). These results were inverted for unders large ($p < 0.0001$) particles, and overs medium ($p < 0.0001$) and fine ($p < 0.0001$) particle diameter proportions, where, as moisture content increased, particle proportions also increased (**Table 1**). This is likely due to fine particles adhesively attaching to the bark particles at time of screening (Jackson et al., 2010). In bark fines, MC played key roles in both overs and unders as MC increased, where less fine particles were present in unders and more fine particles were present in overs (**Table 1**; $p < 0.0001$).

Table 1. Static physical properties and particle size distribution of screened pine bark substrates under different moisture contents.

Static Physical Properties [a]

Substrate	Partitioned Particles	Container capacity cm^3 cm^{-3}	Air space cm^3 cm^{-3}	Total porosity cm^3 cm^{-3}	Bulk density g cm^{-3}
Unscreened	-	0.32	0.35	0.66	0.17
50%	Overs	0.29 a [c]	0.43 a	0.73 a	0.15 ab
55%	Overs	0.32 a	0.47 a	0.79 a	0.16 ab
60%	Overs	0.34 a	0.49 a	0.82 a	0.15 b
65%	Overs	0.28 a	0.44 a	0.72 a	0.16 a
70%	Overs	0.40 a	0.44 a	0.84 a	0.16 a
P-value overs [d]	-	0.4820	0.1211	0.2375	0.0162
50%	Unders	0.55 ab	0.17 b	0.72 b	0.19 a
55%	Unders	0.57 a	0.15 b	0.72 b	0.19 a
60%	Unders	0.55 ab	0.22 b	0.77 ab	0.19 a
65%	Unders	0.47 b	0.35 a	0.82 a	0.17 b
70%	Unders	0.54 ab	0.22 b	0.76 ab	0.20 a
P-value unders	-	0.0239	<0.0001	0.0079	0.0003
P-value overs vs unders [e]		<0.0001	<0.0001	0.3947	<0.0001

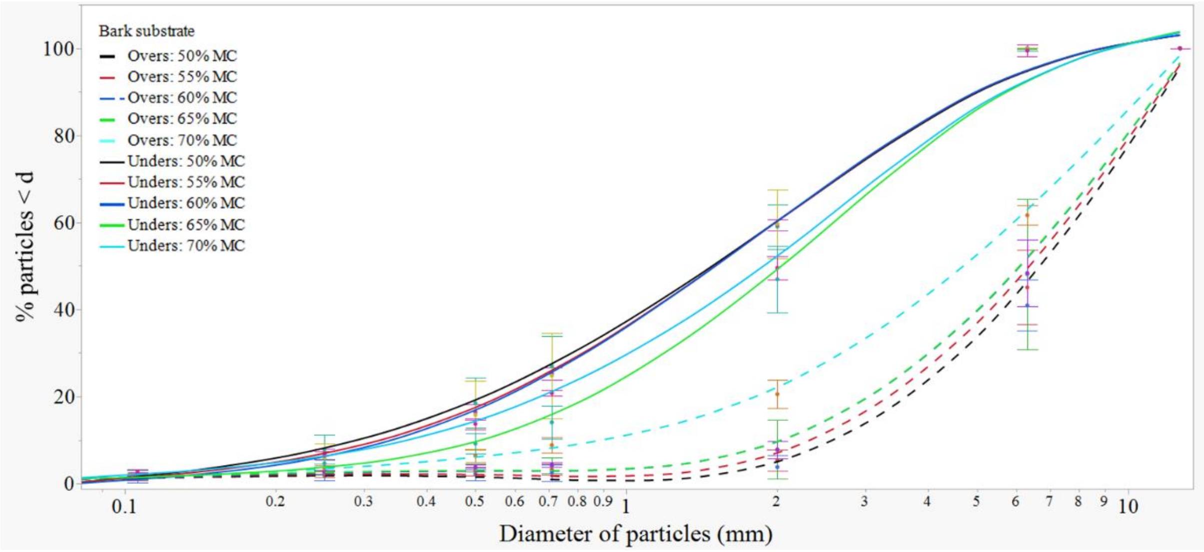
Particle Size Distribution [b]

Substrate	Partitioned Particles	Extra Large (>6.3 mm) %	Large (6.3–2.00 mm) %	Medium (2.00-0.71 mm) %	Fines (<0.71 mm) %
Unscreened	-	38.2	43.2	12.7	7.0
50%	Overs	59.3 a	37.3 a	1.3 b	2.5 c
55%	Overs	55.4 a	40.1 a	2.1 b	3.2 bc
60%	Overs	51.9 a	40.2 a	3.7 b	4.2 bc
65%	Overs	52.1 a	40.9 a	3.5 b	4.4 b
70%	Overs	38.9 b	41.7 a	11.9 a	9.0 a
P-value overs		0.0007	0.3908	<0.0001	<0.0001
50%	Unders	0.0 a	40.7 b	31.8 bc	27.0 a
55%	Unders	0.0 a	40.4 b	34.1 ab	25.2 a
60%	Unders	0.0 a	40.7 b	35.1 a	25.0 a
65%	Unders	0.4 a	53.3 a	33.2 ab	14.2 b
70%	Unders	0.6 a	50.4 a	29.1 c	21.0 a
P-value unders		0.0646	<0.0001	0.0007	0.0004
P-value overs vs unders [e]		<0.0001	0.0068	<0.0001	<0.0001

[a] Measured via porometer analysis. Total porosity = air space (minimum air-filled porosity after free drainage) + container capacity (maximum water holding capacity after free drainage). [b] Percent of total sample dry mass within the particle size range.[c] Letters denote detected differences amongst means separately (overs within overs; unders within unders) utilizing Tukey's HSD (α = 0.05). [d] Measures of overall treatment effects utilizing ANOVA analysis with a significance value of (α = 0.05) separately (overs within overs; unders within unders) utilizing Tukey's HSD (α = 0.05). [e] Measures of overall treatment effects utilizing ANOVA analysis with a significance value of (α = 0.05) separately (overs against unders) utilizing Tukey's HSD (α = 0.05).

The particle size distribution curve demonstrates that overs bark contains significantly fewer fine bark particles (> 0.71 mm) than unders bark proportions (**Fig. 1**). Moreover, a large gap exists between the two screened barks as % of bark particles below a particular diameter increases (**Fig. 1**).

Figure 1. Particle size distribution curve of screened bark at different initial moisture contents. Each error bar is constructed using a 95% confidence interval of the mean.



Uniquely, there was a concave down arrangement observed in the PSD bark fines unders, where particle proportions decreased with increasing moisture content, and then inverted at 65% MC (**Table 1**). A comparison of summarized unders against summarized overs values show significant differences, regardless of moisture content, of all particle diameter classifications (**Table 1**).

Screening. There was a strong correlation ($r = 0.7624$) between moisture content and the time it took to clear the screen after the final feed. Screening bark at 55% MC resulted among the fastest time to clear the aperture, while screening bark at 70% MC took the longest ($p < 0.0001$; Table 2). This is likely due to the increased proportions of medium and fine over particles blocking screen apertures (**Table 1**; Jackson et al., 2010).

Moisture content prior to screening played significant roles in processed bark output (**Table 2**). Generally, as moisture content increased, bark volume ($p < 0.0001$) and mass ($p < 0.0001$) decreased for unders (**Table 2**). These results were inverted for overs (**Table 2**; $p = 0.0049$). Furthermore, there were strong negative correlations between MC and volume ($r = -0.9171$) and mass ($r = -0.9386$) in under particles. Conversely, there were strong positive correlations between MC and volume ($r = 0.7941$) and mass ($r = 0.9383$) in over particles.

The more balanced bark separation on a volume or mass basis decreased as moisture content increased (**Table 2**), alluding that the drier the bark prior to screening will result in more particle separation.

Table 2. Screening parameters

Moisture Content	Partitioned Particles	Time to clear screen after final feed (sec)[a]	Volume (cm^3)	Mass (g)	Particle separation ratio (%; volume basis)[c]	Particle separation ratio (%; mass basis)[b]	Particle mass remaining on screen (g)
50%	Overs	15 bc	60.1 bc	2886.3 c	55 c	55 c	NA
55%	Overs	13 c	56.0 c	3106.0 c	57 c	59 bc	NA
60%	Overs	15 bc	65.6 abc	3805.0 c	64 bc	67 b	NA
65%	Overs	18 b	76.5 ab	5061.7 b	76 b	80 a	88.3 b
70%	Overs	43 a	79.2 a	6278.0 a	92 a	87 a	759.3 a
P-value	-	<0.0001	0.0049	<0.0001	<0.0001	<0.0001	<0.0001
50%	Unders	15 bc [d]	49.2 a	2339.0 a	45 a	45 a	-
55%	Unders	13 c	43.7 a	2182.5 a	43 a	41 ab	-
60%	Unders	15 bc	38.2 ab	1913.3 a	36 ab	34 b	-
65%	Unders	18 b	24.6 b	1240.0 b	24 b	20 c	-
70%	Unders	43 a	6.8 c	1043.7 b	8 c	13 c	-
P-value [e]	-	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	-
P-value overs vs unders [f]	-	-	<0.0001	<0.0001	<0.0001	<0.0001	-

The particle separation ratio (% of partitioned particles relative to the total mass or volume) based off both volume (*p* < 0.0001) and mass (*p* < 0.0001) was lowest in 70% MC unders and conversely greatest in 70% MC overs (**Table 2**). Jackson et al. (2010) reported that the greater the moisture content results in decreased screened bark proportions, which is parallel to the results herein (**Table 2**). In opposition to the results evidenced in this study, Fields et al. (2017) screened bark with a 4-mm aperture at 66.4% MC and received practically an equal (~50%) partition by volume. This is further validation that there are several variations in bark that can affect processing (Kaderabek et al., 2016; Stewart et al., 2019).

After the bark processing was completed, the remaining particles on the screen were collected and weighed. No particles remained on the screen in overs ≤ 60% MC treatments (**Table 2**). However, in both the 65% and 70% MC treatments, 2% ± 0 SD and 10% ± 0 SD of the total bark mass screened remained on the aperture, respectively (Table 2). This is likely due to more fine particles are adhered to larger coarse bark (Table 1), which creates a bark particle obstruction, blocking other bark particles from being partitioned. This phenomenon was demonstrated to be more pronounced as the bark had greater MC (**Table 2**).

CONCLUSION

It is evident that bark moisture content prior to screening is a key factor in bark processing output, affecting the final product on both a volume or mass basis. While initial moisture content had minimal impacts on the physical properties of the growing substrates; there were significant effects on particle separation ratios. The greatest partition of particles occurred when the bark was processed as lower moisture contents (i.e., 50%). Future research should identify an optimal MC range for bark particle processing with minimal hydrophobicity concerns.

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