Particle size distribution effects on physical characteristics of coconut and pine bark substrates

Efeitos da granulometria nas características físicas dos substratos de coco e de pinus

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ABSTRACT

Efficient plant production in recipients requires appropriate knowledge of the substrate characteristics that have important role in supporting plant root systems and offering suitable moisture for their growth. The primary source of the substrate defines different characteristics to the growth media, limiting its successful employment in crop water management. In order to indicate suitable physical substrate attributes for capillarity irrigation, the objective of this study was to evaluate the effects of two particle size distribution (fine and coarse) of coconut and pine bark substrates on physical attributes related to water retention. For both of analyzed substrates, pore meter and particle size distribution analysis methods were employed, adding gravitational particle separation for the coconut material. The results have indicated that the coconut substrate with coarse particles distribution presented deficiency for watering processes by capillary rise due to a higher porosity caused by the fiber constitution. Fine substrates, with smaller average particle size and lower percentage of particle fibers, showed more suitability for water storage processes and, consequently, capillary rise processes. The fine coconut substrate presented higher aeration with high water retention capacity.

KEYWORDS: Container production, water retention, greenhouse, aeration.

RESUMO

O desempenho da produção vegetal em recipientes requer o conhecimento adequado das características dos substratos que possuem função importante de suporte ao sistema radicular das plantas e de propiciar umidade adequada ao seu crescimento. A fonte primária do substrato define diferentes características físicas ao meio de crescimento. Com o objetivo de indicar um substrato com atributos físicos adequados para utilização na irrigação por capilaridade, avaliaram-se os efeitos de duas granulometrias (fina e grossa) de substratos de fibra de coco e de pinus nas características físicas relacionadas à retenção de água. Para ambos os substratos, empregaram-se os métodos de porômetro e de análise granulométrica, sendo que, no caso dos substratos de coco, adicionou-se também a separação gravitacional de partículas. Os resultados indicaram que o substrato de coco com maior granulometria mostrou-se deficiente para processos de molhamento por ascensão capilar, devido à maior porosidade gerada pela constituição fibrosa. Os substratos com menor tamanho médio de partículas e menor percentual de fibras favoreceram os processos de armazenamento de água e, consequentemente, os processos de ascensão capilar. O substrato fino de coco apresentou maior aeração com alta capacidade de retenção de água.

PALAVRAS-CHAVE: Produção em tubetes,

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retenção de água, ambiente protegido, aeração.

INTRODUCTION

Containerized plant production requires technical information about substrates, due to its direct influence on the vigor, development and health of the crop, especially during the seedling segment. Since those materials showed high heterogeneity, their physical properties may vary strongly, requiring some characterization to properly adapt them to different use conditions.

Physical properties of the substrates such as total porosity, density, organic matter composition and particle size distribution are important parameters for their descriptions and quality determination (FONTENO, 1993). Verdonk and Gabriëls (1988) and considered essential for the determination of substrate physical characterization density, total porosity, air bulk percentage, water retention capacity and particle size distribution. Yeager (1995) recommended that substrates used in container production must present total porosity of between 50 and 85%, aeration space between 10% and 30% and container capacity of between 45 and 65%.

The substrate particle size distribution is one of the parameters that significantly affects its substrate physical performance. Milks et al. (1989) discovered that substrates with fine particles showed smaller aeration porosity and greater available water stored quantity after water liberation processes. The particle size distribution of substrates also interferes with gas diffusion at the root growth environment (CARON et al., 2001). However, when an excessive amount of fine particles is presented in the substrate composition, problems may occur with the plant aeration, causing reduction in vegetative growth (ZANETTI et al., 2003), indicating the necessity to keep a minimum aeration level in the substrates, especially in small containers (MILKS et al., 1989).

A balanced substrate particle distribution would result in a plant growth environment that allows a better water liberation buffering effect, with a greater quantity of stored water in the process, demonstrating that particle size has a predominant role in watering processes (FERNANDES and CORÁ, 2004). Laboratory practices revealed that particle size distribution analysis combined with physical-hydric determinations are important in describing capillary rise process. In addition to particle size distribution, the particle shapes also influences water movement (WEERTS et al., 2000).

Substrate physical properties, such as density and water retention capacity, are easy to measure, but they must be carefully determined, especially in laboratories that employ non-compression techniques that can cause non-uniform samples with high variability results among them (VERDONK et al., 1978; de KREIJ et al., 2001). In these parameter determinations, the porometer method has shown to be the most appropriate and faster technique for repetitions (FONTENO, 1993). The convenience of such a method, in conjunction with its reliability, motivated its development by Dilger (1998) and application by Pire and Pereira (2003).

This work had the objective of evaluating the effects of two particle distribution sizes (fine and coarse) of pine bark and coconut substrates on physical attributes related to water retention to determine the one that was better suited to capillary irrigation in containers.

MATERIAL AND METHODS

The experiments were conducted at the Hydraulic and Irrigation Laboratory of Agricultural Engineering College at State University of Campinas, Brazil. Two commercial substrates were evaluated: pine bark (P) and coconut fiber (C) with two particle pattern sizes: coarse (C) and fine (F), to analyze the effects of the particle size on density, retention and porosity variation. Therefore, the following treatments were tested: fine pine bark (FP), coarse pine bark (CP), fine coconut (FC) and coarse coconut (CC). The treatments particle distribution sizes were determined using three 200-gram air dried samples, sifted by a set of sieves with six different meshes: 6.3, 4.76; 2, 1, 0.5 and 0.25 mm. The 6.3 mm and 4.76 mm sieves retain non-decomposed substrate particles, which are responsible for allowing larger internal air structure formation at the substrate. Sieves with 0.5 mm and 0.25 mm retain thin particles, which are mostly responsible for surface contact and root capillarity effect.

A morphological analysis of the particle samples was conducted for coconut fiber substrate retained in each sieve to separate the amount of granular and fiber particle. This particle separation was accomplished by placing a recipient filled with coconut substrate into a vibrating sieve machine, at a 15º to 30º angle related to the counter surface. This condition generated a descending movement of granular particles, while the fiber particles concentrated at surface level. This procedure created a fiber matted arrangement which had to be removed manually. The vibration process was repeated three times to improve granular and fiber component separation quality. After the separation process, the diameters and lengths of ten randomly selected fibers were measured, employing micrometers and caliper rule, respectively.

To evaluate the physical parameters related to water retention of the treatments, 10 PVC porometers, with 25 mm diameter and 590 cm³ capacity were built. The following parameters were determined for all substrates: density, water retention, aeration pores, total porosity, particle density and air retained in total saturation. Each parameter value was determined by an average of 10 repetitions with the estimation of standard deviation and variation coefficient and applying T-test.

The density was estimated using a ratio of the substrate dried-mass to the porometer volume. The water retention was calculated by the quotient of the difference of the wet and dry weight and the porometer volume. The aeration spaces were determined through the water volume drained from the porometer after being unblocked. The sum of the values of retention capacity and aeration space provides the substrate total porosity. Particle density was obtained through the volumetric relation defined by the following equation:

Equation 1.

$$PV = \left(\frac{DS}{PD}\right) + A + WH$$

where:

PV = Porometer volume (L^3);
DS = Dry substrate density (M);
PD = Particle density (M L^{-3});
A = Air space (L^3);
WH = Retained water ((L^3);

In order to reduce error sources and variability, a few differentiated laboratory practices proposed by Pire and Pereira (2003) were adopted. The porometers were filled with a long opening funnel to reduce particle segregation during this procedure. A piece of cloth was placed at the porometer opening to avoid material loss at the compression impact. To achieve the porometer saturation, filled with coconut substrate, the porometers were emptied into a plastic box filled with water. Proceeding saturation was slow, lasting about 48 hours to promote adequate saturation level, preventing porometers from falling over, what actually occurred when this recommendation was not observed, especially for the fine coconut substrate. This occurrence was observed due to the high substrate aeration under dried-air conditions and their hydrophobic properties.

RESULTS AND DISCUSSION

Particle size distribution analysis

Pine bark substrate: Figure 1 presents the particle size distribution of pine bark substrate for both particles types (coarse and fine).

Figure 1 shows that the coarse pine bark substrate (CP) was composed of 31.76% of 2 mm diameter particle, while 0.5 and 1 mm particles constituted 22.44% and 19.54% of the total weight, respectively. The smallest particles, characterized by the 0.25 mm and <0.25 mm

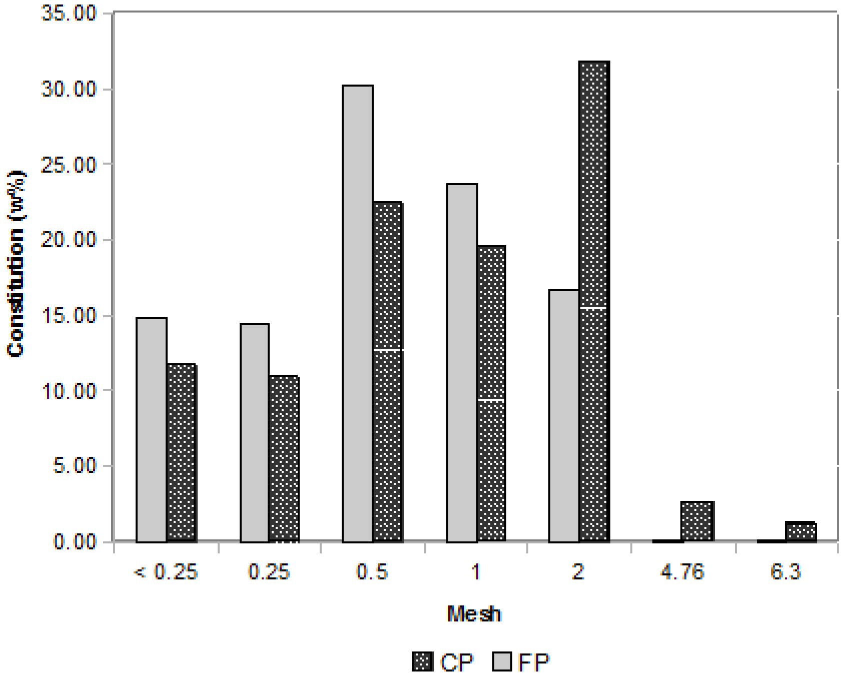

Figure 1 - Particle size distribution of fine pine bark substrate (FP) and coarse pine bark substrate (CP) in total weight percentage.

sieves represented 10.86 and 11.68%, adding up to 22.54%. At this substrate, particles with diameters above 1 mm made up 50% of the particles. Figure 1 also illustrated that fine pine bark substrate (FP) presented 30.2% of its total weight with 0.5 mm diameter particles, though 1.0 and 2.0 mm sieves showed retained percentages of 23.7 and 16.68%, respectively. The finer particles, separated by 0.25 and <0.25 mm sieves, represented respectively, 14.40 and 14.79%, making up 29.19%. The fine pine bark substrate presented 59.39% of particles classified at the three smallest sieves meshes. The quantities of particles retained in the 6.3 mm and 4.7 mm sieves were not significant for both pine bark substrates

Coconut substrate: Since the coconut substrate is characterized by having particles with different composition, not only for its size but also for particle type, the analysis of this topic was separated by the particle size class. Particle distribution size for the fine coconut substrate is presented in Figure 2, where granular and fiber particles are evidenced.

Fine coconut (FC) substrate presented 0.7 and 0.6% of the total weight retained in the 6.3 and 4.7 mm sieves. Not a single granular particle was observed in those sieves sizes, but only matted fiber. The main granular components of FC were 0.5 mm particles, representing 37.9% of the substrate weight, while particles with 0.25 mm and <0.25 mm represented together 30.5%. The fine coconut substrate concentrated 68.4% of its particle distribution at the three smallest sieves classifications.

Fine coconut substrate particle distribution is similar to the fine pine bark substrate, where 0.5 mm particles prevailed. The pine substrate particles classified with the 0.5 mm sieve represented 31.2%, though the coconut substrate reached 37.9%. The coconut substrate results were in agreement with the values found by Caron et al. (2005a), who reported on the constitution being formed by approximately 40% of particles until 0.8 mm.

Particle size distribution for the coarse coconut fiber substrate (CC) is presented in Figure 3, where granular or fiber particles are found.

Coarse coconut substrate presented a larger fiber particle proportion, represented by highly coarse and non-decomposed coconut

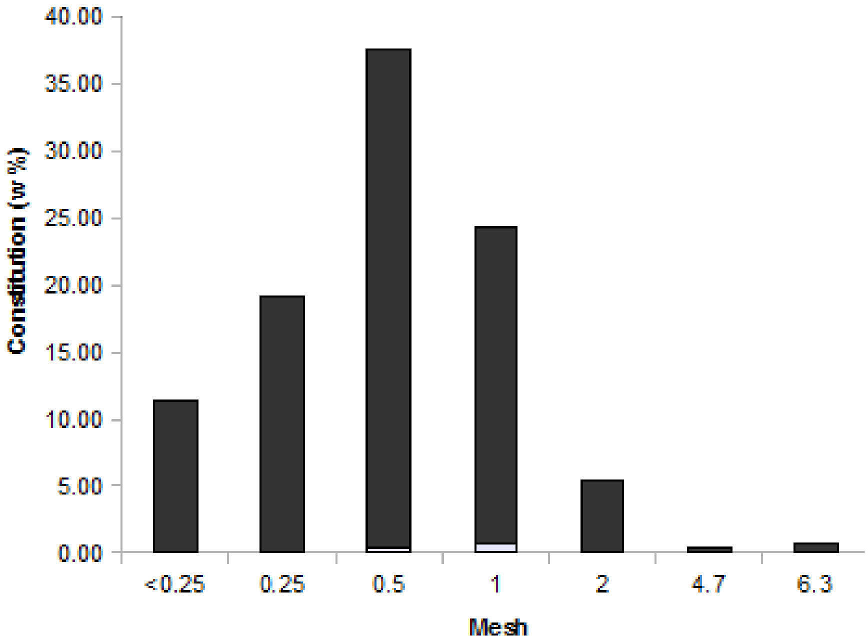

Figure 2 - Particle distribution of fine coconut substrate (FC) including granular and fiber particles.

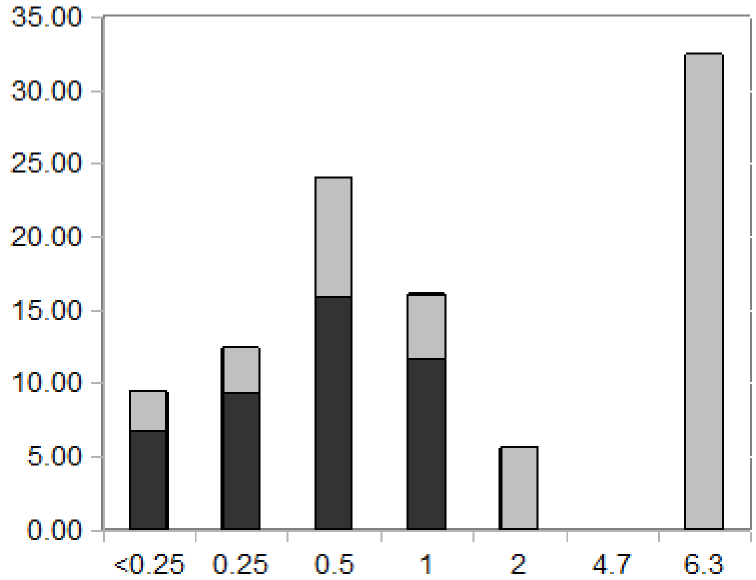

Figure 3 - Coarse coconut substrate particle distribution (CC), including granular and fiber particles.

shell at the first mesh of 6.3 mm, with a total retained substrate of 32.46% of the total weight. The 4.7 mm sieve did not hold any amount of this substrate, due to the matted fiber formed in the sieve above. At the 2 mm sieve, the retained sample represented 5.6% of the total substrate weight and no granular particles were detected. The fine substrate particles, collected by the 0.25 and <0.25 mm sieves, showed the smallest weights retained, with 12.4% and 9.4%, respectively, making up 21.8% of the substrate weight. Sieves of 0.5 mm, 1.0 mm, and 2 mm presented substrate constitution of 24.1%, 16.0%, and 5.6%, respectively. Analyzing the presence of fiber particles in the samples collected into the sieves of 0.25 mm and <0.25 mm, the fiber percentage were, respectively, 3.1 and 2.7% of the substrate weight. For the sieves of 1 and 0.5 mm, the fiber percentage represented respectively, 4.4 and 8.2%. The prevalence of coarse particles in this substrate type may be expressed through the fact that 54.1% of retained substrate concentrated at the 6.3 mm, 2 mm, and 1mm sieves.

The coarse coconut substrate sample at the 6.3 mm sieve represented the main component of the non-decomposed coconut shell particles and very coarse fibers. This sample was constituted only of fiber particles, presenting no granular components, which will produce an aeration volume at this growth environment due to available space without substrate. The predominant composition of fiber particles will limit the use of this substrate in sub irrigation systems that use capillary action, due to the lack of contact particles for water rising. This behavior is confirmed since the percentage of total fibers reached 56.52% of the coarse coconut substrate weight.

In each sample of coconut retained in the sieves, there is a fiber percentage held in the granular particles, as may be seen at Figures 2 and 3. Comparatively, the fine coconut substrate presented a reduced amount of fiber in its constitution, with less than 1.0% of substrate at 0.25 mm, 0.5 mm, and 1.0 mm sieves

Table 1 showed the average values of length and diameter (in mm) of the fibers retained at each sieve mesh for the two particle size of coconut substrate.

As expected, the fiber diameters for the fine coconut substrate are smaller than the coarse substrate, which showed greater difference among the fiber lengths than diameters. This characteristic may indicate that, using sieves for physical substrate classification, the length of the fibers carries a more accurate correlation with the sieve mesh diameter than the fiber diameter. Considering fiber length as a significant factor for air volume formation in the coconut substrate, its determination by sieves is recommended to infer root growth environment continuity.

Physical parameters

The mean values of bulk density, particle density, water retention capacity, aeration porosity and total porosity for both evaluated substrate are presented at Table 2.

Bulk density: The bulk density for the pine bark substrate did not show significant difference between the evaluated particle sizes ($p<0.05$), with values of 266.8 kg m^{-3} for the fine particles and 268.9 kg m^{-3} for coarse. However, for the coconut substrate there was a significant difference ($p<0.05$) between the particles sizes, with the fine coconut substrate presenting a higher density, 199.9 kg m^{-3}, when compared to the coarse substrate with 77.4 kg m^{-3}. The results demonstrated that the coarse coconut substrate is less dense than the fine pine bark substrate, due to the size and arrangement of particles in the evaluated volume. The difference between fine and coarse coconut substrate bulk density can be attributed mainly to substrate composition. The primary source and the size of the particles originated in the manufacturing process created the differences between the substrates, determining that the density of coconut substrate varied with particle sizes, while the pine bark substrate did not show this behavior.

Particle density: The average particle density of fine pine bark substrate was 938.0 kg m^{-3}, being significantly different from coarse substrate, with 644.1 kg m^{-3} ($p<0.05$). The fine substrate showed a particle density 45.8% higher than the coarse pine bark substrate. This difference between particle densities of pine bark

Table 1 - Dimension average of coconut fiber retained particles into different sieve meshes.

Sieve	Coarse Coconut		Fine Coconut
Mesh (mm)	Diameter (mm)	Length (mm)	Diameter (mm)
1	0.22	19.0	0.13
0.5	0.15	11.0	0.11
0.25	0.14	9.70	0.10
<0.25	0.08	5.50	-

Table 2 - Average values and statistical parameters for pine and coconut substrates with two particle sizes for: bulk density (BD), particle density (PD), water-retention capacity (WR), aeration porosity (AP), total porosity (TP).

Substrates	BD ($kg\ m^{-3}$)	PD ($kg\ m^{-3}$)	WR ($L\ m^{-3}$)	AP ($L\ m^{-3}$)	TP ($L\ m^{-3}$)
FP	266.8 a	938.9 a	657.4 a	58.2 a	715.6 b
cv (%)	4.4	4.0	3.3	28.4	1.5
CP	268.8 a	644.1 bc	494.1 b	88.4 a	582.5 c
cv (%)	2.6	2.4	4.6	26.9	0.9
FC	199.9 b	684.9 b	637.2 a	70.9 a	708.0 b
cv (%)	1.4	2.8	2.4	18.1	1.1
CC	77.4 c	600.6 c	376.1 b	495.0 b	871.0 a
cv (%)	11.2	1.5	17.5	16.3	1.8

Obs.: FP = fine pine substrate; CP = coarse pine substrate; FC = fine coconut substrate; CC = coarse coconut substrate. In columns, values followed by the same letter does not differ significantly at p = 0.05.

substrates revealed that the particle size may be related to the variations of substrate material induced by decomposition processes, since bigger particles are subject to less decomposition processes when compared to the finer ones. For coconut substrates, a significant difference was observed ($p<0.05$) between different particles sizes, with the fine presenting an average value of 684.9 kg m^{-3} and the coarse 600.6 kg m^{-3}, with a difference of 14.0%. The difference between particle densities of the coconut fiber types were smaller than the pine bark substrate, due to the fact that coarse substrate composition has more fiber particles than granular ones.

Water retention capacity: There were significant differences ($p<0.05$) in water retention values between particle sizes of the same substrate, while no significant differences ($p<0.05$) were found for identical particle sizes between the evaluated substrates. Fine pine bark substrate presented 657.4 L m^{-3} of water retention, while the same substrate with coarse texture showed an average value of 494.1 L m^{-3}, means an increase of 33.0%. The retention capacity of 637.2 L m^{-3} for the fine coconut substrate was 69.4% bigger than the coarse substrate with an average value of 376.1 L m^{-3}. The homogenous particle size distribution and the smallest size of particles of the fine substrates defined a better retention characteristic when compared to the coarse texture substrate (FERNANDES and CORÁ, 2004). Greater water retention was observed for fine pine or coconut substrates presenting planting advantages in commercial nurseries. According to Martins et al., (2009), observing growth of initial palm heart plants using vermiculita substrate at high water holding content (90 mL of water per 100 grams of substrate) gave greater speed of germination and quality of plants. According to those authors, the speed of germination and quality of plants (length, diameter and weight) indicated that water availability influences plant growth. At 86.7% of the water holding of the vermiculita substrate the values of plant growth were bigger.

Aeration porosity: Aeration porosity represents the pores which provide aeration to the substrate without retaining water. Among the evaluated physical attributes, this parameter showed the greater variation coefficient, which may explained by the air structure formation randomly generated by particles settlement. As a consequence, only the coarse coconut substrate, with a mean aeration porosity of 495.0 L m^{-3}, presents significant difference ($p<0.05$) from the others analyzed conditions. The fine pine bark substrate with 58.2 L m^{-3}, the coarse pine with

88.4 L m^{-3} and the fine coconut substrate with 70.9 L m^{-3}, did not showed significant differences ($p<0.05$) in aeration porosity. The highest aeration porosity value of the coarse coconut substrate, agreed with the smallest observed water retention capacity (MILKS et al., 1989), attributed to the presence of fibers particles that create large aeration spaces. The results of aeration porosity, demonstrate that the FP, CP and FC substrates showed air volumes representing 5 to 7% of root growth media volume with high variability levels. These results agree with Caron et al. (2005B), who also found high variability in the values of aeration porosity, attributing it to the substrate manufacturing process.

The consequences of porosity in commercial nurseries were described by Seguino et al., 2011 for the Grumixameira (*E. brasiliensis* La.). According to the authors low aeration pine substrate retards the development of Grumixameira, while higher airings (90% v/v) provide increased seedling development.

Total Porosity: The total porosity value measured the fine pine bark substrate of 715.6 L m^{-3} had significant difference ($p<0.05$) from the coarse pine bark substrate with 582.5 L m^{-3}, and showed no significant difference from the fine coconut substrate with 708.0 L m^{-3}. The statistical similarity between fine substrates resulted from large contact surfaces given by the high particle breakdown. Otherwise, the coarse coconut substrate presented the highest total porosity with 871.0 L m^{-3}, value with significant difference from the other substrates. The result for coarse coconut substrate may be explained by the air structures formed by partially-decomposed fibers as well as the fine particles present in the samples.

Consideration among substrates

Grain size distribution: During the substrate manufacturing process, the pine bark crust decomposition creates particles with colloidal shapes, while the coconut fibers generate both long and colloidal fiber shapes. The results obtained with regards to particle size distribution showed differences between the coarse and the fine coconut substrates. Particle constitution was less variable in the coarse pine bark than observed in the coarse coconut substrate, that showed evident variation in quantity and quality of the two types of particles (granular and fiber). Although the inner particle porosity turned out to be an important attribute for watering processes, the presence of small particles in the pine bark substrates can also contribute to create favorable conditions.

Water retention: It was observed that the particle sizes affected the substrate water retention process, with the fine pine bark and coconut substrates having a mean retention value of 65.7% and 63.7% in volume, respectively. The higher water retention of the fine substrates permits characterizing them as more active substrates in capillarity processes. Water retention values found in those substrates and in the coarse pine bark substrate (49.4%) are inside the recommended range of 45% and 65% (YEAGER, 1995). On the contrary, the coarse coconut substrates showed water retention of 37.6%, below the recommended interval. The highest variation coefficient of water retention capacity found at this substrate (17.5%), may be caused by the irregular particle size pattern and the large presence of fiber particles, which restricted the uniformity of the particle arrangement inside the recipient.

Microporosity: By subtracting the aeration porosity value from the total porosity, it is possible to estimate the microporosity, responsible for water retention at the substrate. For the fine pine bark substrate, microporosity value was 657.4 L m^{-3}, the highest value observed among the substrates, meaning 91.9% of the total pore volume of the substrate. Otherwise, coarse pine bark substrate microporosity resulted in 84.8%, smaller than the fine texture. The presence of micropores affects the water retention processes due to the capillarity occurrence. Therefore, the smallest microporosity measured at the coarse pine bark substrate is coherent with the smallest water retention capacity. The fine coconut substrate provided a microporosity of 90.0% of the total pore volume, though the coarse coconut substrate had only 43.2%. In the coconut substrate, the effects of capillary forces due the microporosity and the small amount of fiber particles resulted in a high value of water retention for the fine substrate, the opposite effect was found in the coarse one due to the significant presence of fiber particles.

Final considerations: When comparing fine pine bark and coconut substrates, it was observed equal values of water retention in volume-base and total porosity. However, the coconut substrate showed a bigger aeration porosity, as well as lower bulk and particle density, required characteristics for a growth medium. The fine coconut substrate condition resulted in lower substrate weight with the same water retention capacity as the fine pine bark substrate. Additionally, the highest aeration porosity of fine coconut substrate with the same total porosity as the fine pine bark substrate revealed a better aeration. Thus, this substrate presented a better physical characteristic for water relations when wet, but when it is dry showed wetting restriction, a negative characteristic originated from coconut products.

CONCLUSIONS

Comparing the effects of particle size distribution of pine bark and coconut substrates on their physical parameters, allows us to conclude that finer substrates showed the best water retention capacity, and consequently more adequate for capillary processes, than coarse substrates. The coconut substrate revealed better aeration properties with high water retention capacity, considered positive features when compared with the pine bark substrate.

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