Advances in substrate particle characterization using dynamic image analysis compared to sieving procedure for predicting water retention properties

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Abstract

Water/air retention and flow properties in horticultural substrates depend on pores which are created by particle arrangement and particle morphology. Manufacturers mainly select substrate components based on particle size determined through sieving processes. However, sieving methods are most suitable to characterize granular materials (with 1:1, length:width ratio). Particle size distribution of substrate components may be improperly assessed due to their much larger diversity of particle morphology (fibers, plates, etc.). Particle width and shape of numerous substrate components (white and black peats, bark, wood fiber, perlite, compost) were measured using dynamic image analysis, and compared with the mean particle size determined from the EN15428 sieving method. Dynamic image analysis showed much smaller mean particle width in comparison to sieving. It also provided additional information about particle length, confirming the non-granular shape of most of substrate components. Relationships between particle morphology and water holding capacity were explored. A strong correlation was observed between mean particle length and water holding capacity. This work reports the strong interest to deeply investigate particle morphology using dynamic image analysis for predicting physical properties.

Keywords: particle size, particle length, water retention, substrate components

INTRODUCTION

Substrate manufacturers engineer the particle size of substrate components to provide the plant root system a suitable physical environment. Particle size distribution (PSD) in part determines particle arrangement of substrate constituents, and is one of the main factors used to describe physical properties. Relationships between PSD and physical properties have already been developed, indicating the larger the particle size, the higher the air-filled porosity (AFP), and the lower the water retention properties (Bunt, 1983; Handreck, 1983; Abad et al., 2005; Caron et al., 2005; Owen and Altland, 2008; Fields et al., 2015). However, there is not a real consensus on the effect of specific particle size fractions on water and air retention properties. Caron et al. (2005) reported that increase in particle size was not correlated to gas diffusivity in substrates resulting from both increase in air filled porosity and decrease in pore connectivity and then pore effectiveness.

Sieving procedures are the most common methods for determining PSD, separating particles according to their 2nd largest dimension, i.e. their width (Igathinathane et al., 2009; Bartley, 2019). These methods are relevant for granular particles, but their accuracy largely decreases with increasing elongation of substrate particles (Gil et al., 2014; Bartley, 2019). Moreover, they do not provide information about particle length. Consequently, sieving methods are limited in describing PSD for most horticultural substrate components showing a large diversity of irregular shapes with fibers, chips, and plates, which are far from spherical (Durand et al., 2021).

In contrast, tools based on dynamic image analysis (DIA) have been recently used for characterizing substrate particle size and shape (Bartley, 2019; Durand et al., 2021; Nguyen et al., 2022). Tools differ: 1) by method of dispersing the particles (dry or wet) and 2) particle

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image resolution. Also, the principles of DIA methods also are largely different to those of sieving methods, and Bartley (2019) showed that the particle size and distributions obtained by image analysis differed from sieving.

The objectives of this study were: 1) to compare particle size of several substrate components using the EN15428 standard sieving procedure and by dynamic image analysis, 2) highlight the relevance of dynamic image analysis for both an expanded description of substrate particle and prediction of water retention properties.

MATERIALS AND METHODS

Samples

Experiments were carried out on 19 raw materials, representing the main growing media constituents in the current European market. Information about these materials are given in Table 1.

Table 1. Study materials.

No.	Materials	Supplier[a]	Origin	Extraction/process	Bulk density[b] ($g\ cm^{-3}$)	Indicated PSD[c] (mm)
1	White peat, fine, H5[d]	PTH	Ireland	Milled, screened	0.10	0-5
2	White peat, fine, H3-H6	KD	Lithuania	Milled	0.10	0-7
3	White peat, fine, H2-H5	FLO	Latvia	Milled	0.10	0-5
4	White peat, fine, H2-H5	FLO	Germany	Sod	0.08	0-7
5	White peat, fine, H2-H5	KD	Lithuania	Sod	0.11	0-7
6	White peat, medium, H3-H6	KD	Lithuania	Milled	0.11	0-25
7	White peat, medium, H2-H5	FLO	Latvia	Milled	0.10	5-20
8	Black peat, H6-H8	KD	Lithuania	Frozen, milled, sieved	0.17	0-5
9	Black peat, H5-H8	FLO	Germany	Frozen	0.18	0-7
10	Sedge peat	ETF	France	Excaved	0.24	0-10
11	Coir, fine	PTH	Sri Lanka	Ground, sieved	0.08	0-5
12	Coco fiber, medium	PTH	Ivory Coast		0.08	N/A
13	Wood fiber, fine	KD	Germany	Defibrated	0.08	0-2
14	Wood fiber, medium	KD	Germany	Defibrated	0.09	2-4
15	Wood fiber, medium	FLO	Germany		0.09	N/A
16	Fresh pine bark, fine	PTH	France	Screened	0.22	0-5
17	Composted pine bark, fine	PTH	France		0.25	0-5
18	Green waste compost	KD	Germany		0.50	0-5
19	Perlite, coarse	KD	Germany		0.10	1-7.5

[a] ETF = EVADEA Tourbières de France, FLO = Floragard Vertiebs-GmbH, KD = Klasmann-Deilmann, PTH = Premier Tech Horticulture France.

[b] Measured through EN 13041 procedure (2000).

[c] PSD indicated by the suppliers.

[d] Von Post degree of humification.

Methods

1. Dry sieving – EN 15428 standard method.

Dry sieving analysis was carried out using the EN 15428 standard method (2007). However, the numbers of sieves, with square aperture, was increased for a more detailed PSD analysis, passing from four sieves for the standard method (8, 4, 2, 1 mm aperture) to eight sieves (8, 5, 4, 2, 1, 0,5, 0,2, 0,05 mm). 125 mL of air-dried materials (<15% moisture content by mass) were shaken during 7 min with a sieve shaker AS 200 (Retsch, Haan, Germany). The materials retained on each sieve were collected and weighted; three repetitions for each raw material. Arithmetic mean particle size was assessed through Gradistat software (Blott and

Pye, 2001) version 16.0 (2020).

2. Dynamic image analysis.

Measurements were conducted with the QicPic dynamic image analyzer (Sympatec GmbH, Germany). The device can detect particle sizes in a range from 17 µm to 33.8 mm. Length and width of each particle were assessed from the $\mathrm{Feret}_{\mathrm{MAX}}$ and $\mathrm{Chord}_{\mathrm{MIN}}$ diameters, respectively (Nguyen et al., 2022). The particle length and width is shown in Figure 1. $\mathrm{Feret}_{\mathrm{MAX}}$ is the maximal distance between two parallel tangents of the particle contour. Chord width is defined by the straight distance of two points of the particle contour. The software analyzes the particle image by rotating the image 180 degrees in 20 separate steps of 9 degrees. For each rotation, the maximum horizontal chord is determined, $\mathrm{Chord}_{\mathrm{MIN}}$ is the shortest maximum chord among all chord measured.

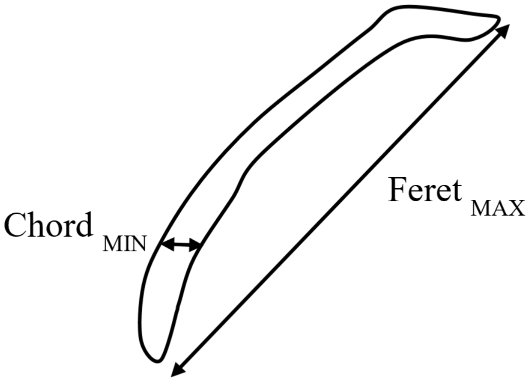

Figure 1. Particle width and length, represented by $\mathrm{Chord}_{\mathrm{MIN}}$ and $\mathrm{Feret}_{\mathrm{MAX}}$ diameters, respectively.

In contrast with the EN15428 standard procedure where sieving is carried out on air-dried materials, DIA is implemented on wet materials previously and precisely dispersed in water. Approximately 2 to 3 g of material were stirred with ~10-15 L water in a tank for 10 min, then passed through the QicPic in a constant flow controlled by a peristaltic pump, and circulated through the flow cell equipped with a camera for continuous image recording. Three repetitions were carried out, representing 10^7 particles per replicate. Results were then analyzed with the associated software, PAQXOS. The weighting of each particle is done according to the projected area of the particles.

3. Water retention properties.

Water retention curves were performed according to standard method EN13041 (2000), for which bulk density (BD), total porosity (TP), air-filled porosity (AFP), water holding capacity (WHC) and available water (AW) were calculated. The principle consists in putting substrate–filled cylinders into equilibrium at different and successive water potentials using a suction table, i.e., -1, -3.2, -5 and -10 kPa, and to determine their volumetric water content at these values of water potentials. Four replicates per material were carried out.

RESULTS

Comparison EN15428 sieving procedure vs. DIA

Mean particle size measured by dry sieving were much higher than particle width from $\mathrm{Chord}_{\mathrm{MIN}}$ diameter assessed by DIA (Table 2). Particle dispersion in water prior to DIA may have improved the separation of individual particles, whereas particle segregation is more difficult and probably less thorough during the sieving of air-dried raw materials.

Table 2. Mean particle dimensions measured from sieving and dynamic image analysis (DIA).

No.	Materials	Mean particle $Feret_{MAX}$ (DIA) (µm)	Mean particle $Chord_{MIN}$ (DIA) (µm)	Mean particle size (EN 15428 sieving) (µm)
1	IE white peat, fine H5	811	346	938
2	LT white peat, fine H3-H6	519	203	2535
3	LV white peat, fine H2-H5	1208	480	1140
4	DE white peat, fine H2-H5	821	247	1388
5	LT white peat, fine H2-H5	488	198	1588
6	LT white peat, medium H3-H6	557	225	3032
7	LV white peat, medium H2-H5	1894	679	5405
8	LT black peat H6-H8	490	230	1145
9	DE black peat H5-H8	635	328	1028
10	FR sedge peat	233	119	2460
11	Coir, fine	715	364	974
12	Coco fiber, medium	1813	281	2063
13	Wood fiber, fine	1707	475	1600
14	Wood fiber, medium	2428	712	2113
15	Wood fiber, medium	2961	823	2505
16	Fresh pine bark, fine	1573	718	1859
17	Composted pine bark, fine	700	332	1848
18	Green waste compost	787	282	1228
19	Perlite, coarse	3590	3176	2886

Moreover, the sieving procedure at best separates particles based on the 2nd largest particle dimension (equivalent to its width). However, the length:width ratio has been shown to prevent particles with more than 1:1 ratio from segregating at this smaller dimension (Bartley et al., 2019) DIA assessed particle length independently from width, reducing the influence of the L:W ratio and providing more detailed information about materials.

The differences in particle mean size was also influenced by the shapes of raw materials studied. Most of them are mostly non-spherical, as showed by large differences between mean particle width and length. Perlite was the exception, where particle dimensions measured from sieving and DIA are in the same order. Perlite was the most granular material tested with an average L:W ratio of 1.1. Except for perlite, the material L:W ratio ranged from approximately 2 to over 6. Indeed, except for perlite, the mean particle size determined by sieving was similar or exceeded the length of the particle determined by DIA. Providing both length and width for each particle indicates the usefulness of DIA for characterizing PSD of substrate components.

DIA vs. water holding capacity (WHC)

An empirical model, based on the similar mathematical expression of the van Genuchten model (1980), was applied to describe the effect on water holding capacity (WHC) and particle dimensions (Figure 2). Mean particle size measured from dry sieving procedure showed little relation the WHC (r^2=0,12) (Figure 2a). DIA showed that the greater the mean particle width and length, the lower the WHC (Figure 2b and 2c). The best fit was between WHC and mean particle length (r^2=0.87), followed by mean particle width from DIA (r^2=0.60). In contrast to the sieving procedure, particle length and to a lesser extent, particle width determined by DIA may be another facet in determining WHC in substrates.

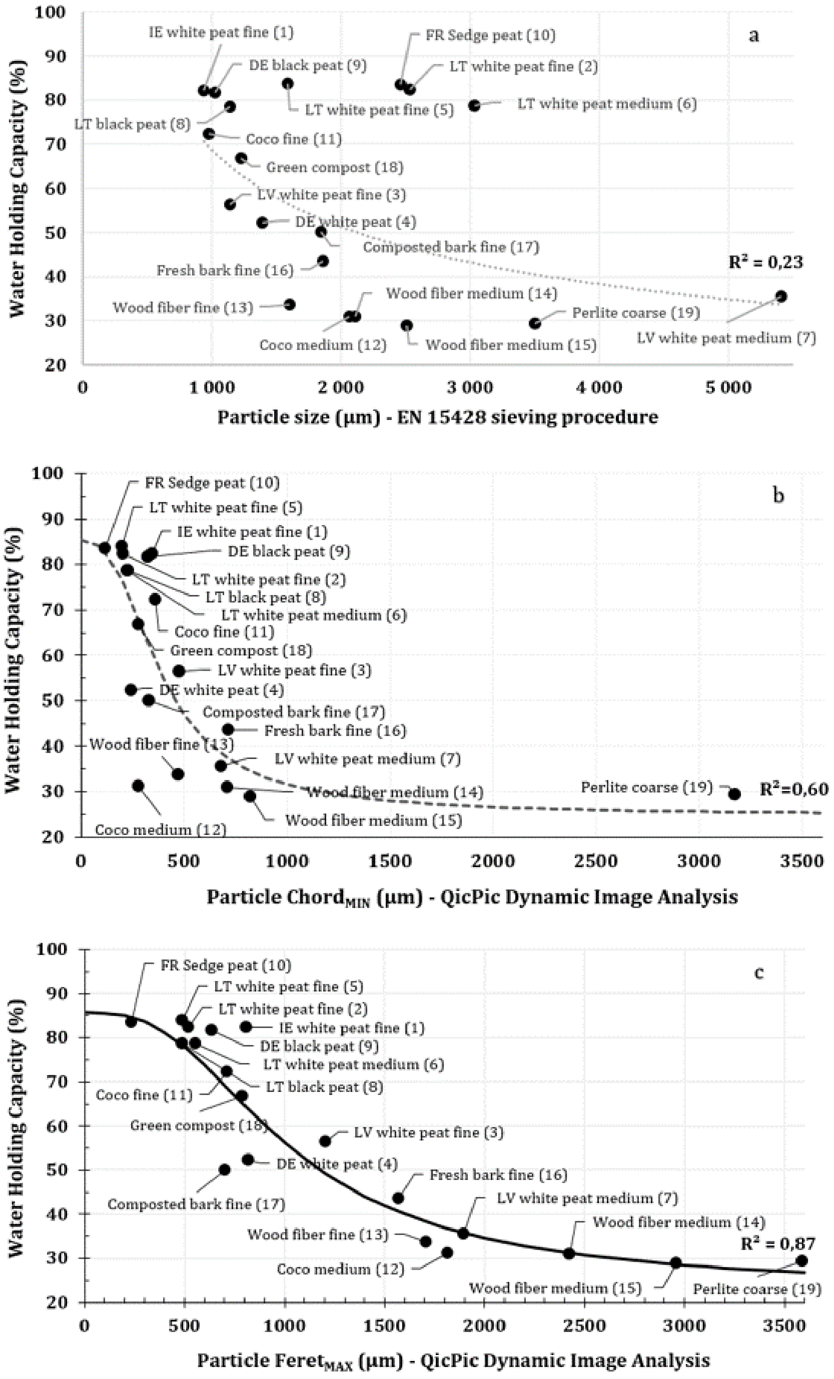

Figure 2. Water holding capacity as a function of (a) mean particle size determined by EN15428 sieving procedure, (b) mean particle width (Chord$_{MIN}$) and (c) mean particle length (Feret$_{MAX}$) measured by dynamic image analysis.

DISCUSSION AND CONCLUSIONS

In comparison with sieving, DIA provided more information by describing each particle in both width and length and then confirmed the non-granular shapes for most of raw materials tested.

A possibly strong relationship between particle length and water holding capacity has been shown for a large diversity of raw materials used as growing media constituents, confirming that PSD largely influences substrates physical properties. Those also depend on other parameters, in particular bulk density when filling of pots (Heiskanen et al., 1996). However, particle length might be considered as an indicator of water retention properties. Further investigations will be extended to mixes, and will also explore relationships between particle size (length and width) and transfer properties, i.e. gas diffusivity and hydraulic conductivity.

This work has demonstrated promising interest in DIA tools for measuring particle size, and their length in particular. Although informative and easy to implement, standard sieving procedures is more limited for non-granular materials in predicting substrate physical properties, because they do not describe particle morphology. DIA may offer an additional approach for substrate manufacturers to better engineer and select raw materials on a particle morphology basis.

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