Original Research Article

Optimization of Particle Size Distribution of Coco Pith: Implications of Soil Suitability Classes, Varietal Variation, Processing Method and Status of Ageing.

Abstract

This study was conducted to investigate the impact of the genetic nature of coconut palm varieties (TT and DT), soil suitability classes (S_1-S_4), fiber extraction method (Wet milling and Dry milling), and ageing status (aged and non-aged) on the PD (Second particle size (0.2 mm – 1 mm), fourth particle size (1 mm – 2 mm), fine particle size (< 0.2 mm) and fiber fraction (> 2 mm)) of CP (CP) obtained from the coconut husk sampled from the Coconut Triangle in Sri Lanka. The results revealed the PD of CP varies (P<0.05) based on their genetic nature, environmental factors, and the fiber extraction process. Moreover, the effect of these factors and their interaction varied depending on the particle type. The optimal fine particle content (<0.2 mm) below the preferred threshold (less than 10%) was obtained in variety DT when cultivated in S1 and S2, as well as in S4 with aging, regardless of the milling method. Similarly, variety TT exhibited lower fine particle content when grown in S1 with aging, S4, and in S2 and S3 regardless of the aging process. Ageing enhanced dry-milled coir pith by reducing short fiber content while wet milling elevated short fiber content in wet-milled coir pith. Hence, the inclusion of aging should be guided by the targeted PD and the specific milling technique employed.

Key Words: particle distribution, milling methods, ageing, coco pith

1. Introduction

Coconut, a prominent perennial plantation crop in Sri Lanka, occupies approximately 20 percent of the arable lands in the country (Pathiraja et al., 2015). The majority (around 70%), of coconut cultivations in Sri Lanka are concentrated in the three districts; Kurunegala, Puttalam, and Gampaha forming the "Coconut Triangle" (Pathmeswaran et al., 2018), spanning in 505,000 hectares with an annual harvest, totaling 3,391 million nuts (Annual report, 2022). Coconut cultivation make a substantial contribution to the economy processing the second highest agricultural land extent followed by the paddy cultivation in Sri Lanka.

Coconut palms produce a large, single seeded fruit botanically denoted as a drupe. The fruit consists of several layers; the exocarp (a thin outermost layer), the mesocarp (a thick layer of fibrous tissues also known as the husk or coir), and the endocarp (a hard lignified layer or shell). Beneath the endocarp a solid endosperm can be found inside of which liquid endosperm can be found. For the extraction of kernel, mesocarp of the coconut fruit, is typically removed through a process called de-husking and the dehusked exocarp has been traditionally being used for the extraction of coir fiber the primary raw material for the fiber industry (Abad et al., 2002; Rosairo et al., 2004).

Coco pith (CP) or coir dust, the pithy fibrous material within the husk, binding the coir fiber, was previously considered industrial waste. However, over time, these fibrous particles, spanning a range of sizes from 0.2 mm to 2.0 mm (Rose et al., 2012), have emerged as an excellent alternative growing medium or substrate for soilless agriculture due to their favorable physical and chemical properties. Referred to as "coco-peat" in the industry, CP is highly regarded as a substitute for peat, the primary horticultural growing medium.

The performance of coconut palms in the Coconut Triangle is influenced by various factors. Firstly, the distinct Agro-Climatic Zones (the Wet Zone, Wet Intermediate Zone, and Dry Intermediate Zone) present in its three districts: Within these zones, a diverse range of soil types has been categorized into different series, ranging from highly suitable S_1 class to marginally suitable S5 class for coconut growth (Somasiri et al., 2006). These soil suitability classes play a critical role in determining growth performance of coconut palm, particularly related to soil conditions.

Further, varietal differences/ genetic makeup of coconut fruits and their components exhibits variability related to growth performances. Coconut germplasm in Sri Lanka, include various varieties, characterized by morphological variations and breeding systems (Liyanage, 1958). Within each local variety, different coconut forms are available leading to yield 17 coconut forms across three varieties (Ekanayake et al., 2010). Additionally, a few improved varieties introduced by Coconut Research Institute of Sri Lanka (CRISL) have been recommended for both commercial and home garden level cultivations, either as single or mixed stands (Liyanage et al., 1988). The coconut form Typica of the local variety Typica, widely known as the 'Sri Lankan Tall' is cross bred and named as CRIC 60 or TT (Liyanage et al., 1988), dominates commercial coconut cultivations, representing over 95% of the total coconut extent in the Coconut Triangle (Perera et al., 2001). Another improved hybrid variety, CRIC 65 or DT (Dwarf x Tall), resulting from crossing the TT and Green Dwarf (GD), has gained significant commercialization value due to its high yield performance and early bearing nature along with shorter trunk height (Liyanage et al., 1988). Therefore, the varietal identity and soil suitability classes (mentioned above) could significantly influence the properties of different parts/components of the coconut tree, including the coconut husks and their composition (i.e. fiber and CP) leading to variability in the quality aspects.

The method of coconut husk milling, essential for extracting coir fiber in general, employs two mechanical techniques: 'Wet milling' and 'Dry milling'. Wet milling, traditionally used for fiber extraction from soaked coconut husks (Mishra and Basu, 2020), involves soaking the husks before processing. On the other hand, dry milling involves mechanical action on the husks without prior soaking (Niro et al., 2012). Presently, dry milling has gained popularity as the preferred method of fiber extraction due to various concerns associated with wet milling that include occupational safety, environmental pollution, and worker preferences against working in soaking pits (Onni et al., 2023). Additionally, dry milling offers advantages in terms of time and labor efficiency despite the price advantage for fiber extracted from wet milling.

Although CP is considered to be a stable raw material as a substrate for plant propagation in soilless culture, it is not ready to use as it comes out of the coir mill due to the presence of various compounds such as cellulose, hemi cellulose, and lignin at varying ratios. An ideal raw CP for value-added CP based substrate industry, must be stable (Prasad & Maher, 2004) and consistent hence the stability and consistency in a mix of CP is achieved by ‘ageing’, a process in which CP is subjected to microbial decomposition with the help of naturally occurring bacteria and fungi that lead to decompose all degradable compounds (Kumar and Ganesh, 2012) and leave the stable fibrous material that serves as an ideal substrate for plant growth.

In industrial practice, the standard is to arrange PD in the following order: fine particles (<0.2 mm) < second grade (0.2 - 1 mm) < fourth grade (1-2 mm) particles, fiber/ short fibers (> 2 mm) with incremental proportions in raw materials before segregation. Having lower fiber content enhances the quality of CP as a substrate for plant growth. This is because fibers contribute minimally to functional properties such as compressibility and expansion power, as well as essential physical properties including rehydration, air-filled porosity, and water holding capacity. Similarly, fine particles below 0.2 mm size exhibit lower functional and physical properties, reinforcing the significance of optimizing PD for optimal CP performance in agricultural applications (Kumarasinghe et al., 2015).

Coco pith with a particle size ranging between 0.2 mm and 2 mm stands out as an ideal/optimal substrate for plant growth (Rose et al., 2012). However, its composition exhibits substantial variability across different sources (Evens et al., 1996). To maintain its PD within this optimal range, it becomes necessary to remove smaller fractions (<0.2 mm) and short fiber (> 2 mm) components (Kumarasinghe et al., 2015), as they can compromise key properties such as air porosity and compressibility in the final product significantly influencing its physical and chemical properties (Evens et al., 1996; Abad et al., 2002; Noguera et al., 2011). Though the impact of heterogeneity of PD on various physical characteristics has been studied (Jayaseeli and Raj, 2010), the importance of identifying favorable ratios among different particle size groups (fine, second, and fourth particle sizes) and fiber content to achieve superior substrate quality remains poorly understood.

The primary aim of this study was to investigate the impact of soil suitability classes (S_1-S_4), genetic nature of coconut palm varieties (TT and DT), fiber extraction method (Wet milling and Dry milling), and ageing status (aged and non-aged) on the PD of CP. Specifically, we focused on characterizing the individual and interactive effects of these factors on the PD of CP. By examining how these variables interplay with one another, we can gain insights into the complex relationship between coconut palm genetics, soil characteristics, processing methods, and ageing status, all of which contribute to the PD of CP. Further, the approach allows us to comprehensively assess the factors influencing CP properties, linking our investigation to the broader context of optimizing CP as a substrate for plant growth. The coconut husk, constituting the exocarp (outermost layer) of the coconut fruit, is typically removed through de-husking to process the nut for kernel extraction. Historically, the coir fiber extracted from the husk has been the primary raw material for the fiber industry (Abad et al., 2002; Rosairo et al., 2004). CP or coir dust, the pithy fibrous material within the husk, binding the coir fiber, was previously considered industrial waste. However, over time, these fibrous particles, spanning a range of sizes from 0.2 mm to 2.0 mm (Rose et al., 2012), have emerged as an excellent alternative growing medium or substrate for soilless agriculture due to their favorable physical and chemical properties. Referred to as "coco-peat" in the industry, CP is highly regarded as a substitute for peat, the primary horticultural growing medium. Nevertheless, there are certain limitations associated with CP concerning its use as an ideal substrate due to the governing factors of CP value chain. Key determinants of CP properties include soil suitability class (reflecting soil conditions), varietal diversity, processing methods, and the status of biological degradation or ageing (Theradimani, et al., 2018).

The performance of coconut palms in the Coconut Triangle is influenced by various factors. Firstly, the distinct Agro-Climatic Zones (the Wet Zone, Wet Intermediate Zone, and Dry Intermediate Zone) present in its three districts: Within these zones, a diverse range of soil types has been categorized into different series, ranging from highly suitable S_1 class to marginally suitable S_5 class for coconut growth (Somasiri et al., 2006). These soil suitability classes play a critical role in determining growth performance of coconut palm, particularly related to soil conditions.

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CP with a particle size ranging between 0.2 mm and 2 mm stands out as an ideal substrate for plant growth (Rose et al., 2012). However, its composition exhibits variability across different sources (Evens et al., 1996). To maintain its PD within this optimal range, it becomes necessary to remove smaller fractions (<0.2 mm) and short fiber components (Kumarasinghe et al., 2015), as they can compromise key properties such as air porosity and compressibility in the final product. The particle size composition of CP significantly influences its physical and chemical properties (Abad et al., 2002; Evens et al., 1996; Noguera et al., 2011). Moreover, the heterogeneity of PD has been studied for its impact on various physical characteristics (Jayaseeli and Raj, 2010), highlighting the importance of identifying favorable ratios among different particle size groups (fine, second, and fourth particle sizes) and fiber content to achieve superior substrate quality.

In industrial practice, the standard is to arrange PD in the following order: fiber (short fibers) < fine particles (<0.2 mm) < second grade (0.2 - 1 mm) < fourth grade (1-2 mm) particles, with incremental proportions in raw materials before segregation. Consequently, lower fiber content enhances the quality of CP as a substrate for plant growth. This is because fibers contribute minimally to functional properties such as compressibility and expansion power, as well as essential physical properties including rehydration, air-filled porosity, and water holding capacity. Similarly, fine particles below 0.2 mm size exhibit lower functional and physical properties, reinforcing the significance of optimizing PD for optimal CP performance in agricultural applications (Kumarasinghe, et al., 2015).

The primary aim of this study was to investigate the impact of key factors on the PD of CP, including the genetic nature of coconut palm varieties (TT and DT), soil suitability classes (S_1-S_4), fiber extraction method (Wet milling and Dry milling), and ageing status (aged and non-aged). Specifically, we sought to characterize the individual and interactive effects of these factors on the particle size components of CP. By examining how these variables interplay with one another, we can gain insights into the complex relationship between coconut palm genetics, soil characteristics, processing methods, and ageing status, all of which contribute to the PD of CP. This approach allows us to comprehensively assess the factors influencing CP properties, linking our investigation to the broader context of optimizing CP as a substrate for plant growth.

2. Materials and Methods

2.1 Selection of sample plots and collection of husk samples

Coconut estates containing over 100 coconut palms were selected from Kurunegala, Gampaha, and Puttalam Districts representing the Coconut Triangle, a specific coconut growing area in Sri Lanka. This area spans over three distinct agro–climatic regions: the Low Country Intermediate Zone (LCIMZ), the Low Country Wet Zone (LCWZ), and the Low Country Dry Zone (LCDZ), a classification based on the mean annual rainfall and the elevation (0 – 300 m from mean sea level). The selected estates were such that some consisted of $Tall \times Tall$ (TT) variety while the others consisted of $Dwarf \times Tall$ (DT) variety of coconut. Altogether, there were 30 estates selected for variety TT and 18 estates selected for variety DT. Nut samples (each consisted of 150 – 200 mature nuts) were collected from the harvest obtained during August 2020 and December 2021, for each of those estates separately. The nut samples were then labeled with their respective estate numbers (A1–A48), securely packed in polypropylene bags, and transported via canopy–covered trucks under ambient temperature conditions to the factory premises of Jiffy (Pvt.) Ltd. at Kobeigane, in Kurunegala District. However, out of 48 samples selected, 5 samples with estate numbers A10,A13, A18, A20 and A24 were found to be belonged to estates that do not satisfy the CRISL guidelines for land suitability classes (Somasiri, et al., 2006). Accordingly, the five sites with those numbers were removed and did not consider for the analysis. Eventually, there were 30 estates selected for variety TT and 18 estates selected for variety DT.

2.2 Milling and ageing

Each sample of nuts underwent a dehusking procedure, by dividing the husk into four approximately equal portions. These samples were then subjected to milling, by two alternative milling methods practiced by the coir processing industry namely, ‘Dry’ milling and “Wet” milling. Dry milling and wet milling employ distinct fiber extraction techniques, with differences in the nature of the husk subjected to extraction between the two methods. Dry milling applies higher mechanical impact, utilizing a rotating hammer milling mechanism (Niro et al., 2012; Perdana et al., 2022) (decortication) on relatively dry or mildly wet husks typically obtained just after dehusking (with a green or brown color peel). The wet milling method often involves brown husks sourced from the nuts used for "*copra*" or desiccated coconut industry. These husks are soaked in a soaking pit for 3-4 months (for retting), and fiber extraction is carried out using a machine, featuring a combing action with thin metal spikes on a rotating drum, known as '*petti kuttama*' (Ariyawansa et al., 2005; Onni et al., 2023)

Two of the husk portions of each nut samples were randomly selected for wet milling, carefully packed into Nylon sacks, labeled with corresponding estate numbers, and submerged in a retting pit at Kobeigane for 16 weeks before being used for wet milling. Other two portions designated for dry milling were milled using a decorticator (Niro et al., 2012), and CP was collected directly. CP from one portion of the dry milled husks underwent ageing for 16 weeks while maintaining a moisture content of around 70% and with periodical turning for aeration. This process involves decomposition initiated by microbial activity, facilitated by naturally occurring bacteria and fungi, as observed during storage (Theradimani et al., 2018). The other portion was sun dried and subjected to testing for PD after the follow-up process. After 16 weeks the aged CP sample from dry milling was also sun dried and stored for subsequent particle distribution test after the follow-up process.

Similarly, the soaked husks designated for wet milling were removed from the retting pit, drained, and milled in the mill to collect CP. One of the sub-samples from wet milled CP was subjected to a follow-up process, then sun dried and stored for subsequent particle distribution testing. The other portion of the wet milled sub-sample was piled for ageing for 16 weeks, and sun dried after the follow-up process and stored.

The follow up process for all four portions involved soaking of CP in a calcium nitrate solution for buffering, at a rate of 4 kg m^{-3} of CP (industry standard), followed by washing twice with fresh water (having electrical conductivity ranging from 0.2 to 0.5 mS cm^{-2} and pH ranging from 5.8 to 7.2).

2.3 Experimental design

The study was structured such that each pairing of soil suitability class and variety was represented across multiple estates. Then for each estate the husk sample selected was divided into four and randomly allocated into four combinations of milling method and aging status. Thus, each estate was considered as an experimental block and each block is nested within each combination of soil suitability class and variety. Accordingly, the study consisted of four factors, namely, (i) soil suitability class with four levels, S_1, S_2, S_3, and S_4 (Somasiri et al., 2006), (ii) variety with two levels, TT and DT (Liyanage et al., 1988), (iii) milling method with two levels, dry milling and wet milling, and (iv) ageing status with two levels, with aging and without aging. Note that there were no equal number of blocks for each combination of soil suitability class and variety. In fact, number of blocks per combination varied between 2 to 10, resulting an unbalanced block design.

2.4 Analysis of particle size distribution

Analysis of PD was conducted utilizing the sieve analysis method (Schweyer and Work, 1941) with an electric sieve shaker (Endocotts sieve shaker, model EFL 2000, made in UK) to separate the particles into various size categories.

Initially, from the resulted CP of each combination of milling and aging status, representative one liter volume of CP was measured using a standard measuring cylinder and weighed before placing on the particle distributor. The sieve shaker was then operated for 3 minutes, during which four types of particles, namely, (i) fiber, (ii) fourth, second, and fine were identified and collected separately, and their respective weights were measured. Basis of this classification is the particle size. "Fiber" means the short fiber fraction that remains on the 2 mm sieve plate and is considered as the fiber in CP which has an adverse effect on the physical properties of CP based substrates due to impoverished physical characteristics of these particles. The "fourth" particle refers to particle sizes within the range of 1 mm to 2 mm, while the "second" particle represents sizes ranging from 0.2 mm to 1.0 mm. Any particles smaller than 0.2 mm, which pass through a 0.2 mm sieve plate, are classified as "fine" particles.

2.5 Data analysis

The measurements considered in the study were second particle size (0.2 mm – 1 mm) (SEC), fourth particle size (1 mm – 2 mm) (FOUR), fine particle size (< 0.2 mm) (FINE) and fiber fraction (> 2 mm) (FIB). All measurements were in ratio scale and all were found to follow the normal distribution. Hence the effects of factors and their interactions were studied by performing unbalanced analysis of variance (ANOVA). SAS (SAS On Demand for Academics) software (SAS, 2013) package was used for data analysis. Because the design used was an unbalanced design, PROC GLM of SAS was used fit the ANOVA model. The relevant mean separation was performed using least square means (LSMEANS) procedure.

3. Results

In general, the PD of CP was found to vary based on their genetic nature, environmental factors, and the fiber extraction process. Moreover, effect of these factors and their interaction varied depending on the particle type. The effect of factors and their interactions on each particle type is discussed below.

3.1 Effect of milling method and aging on the composition of fiber particles in coco pith

The type III analysis of the ANOVA on the effect of four factors and their interaction effects are presented in Table 1. According to Table 1, only the interaction effect between milling method and aging status was significant (P=0.0035) on fiber particle type. However, main effects of soil suitability class and variety, or their interaction effects were not significant with respect to fiber content. The two-way interaction between milling method and ageing status was of the form that both dry and wet milling methods result in different fiber contents in aged and non-aged CP.

During dry milling, the low moisture content of the husk results mixed fibers of varying lengths. Consequently, the sieving system effectively separates most fiber particles at the end of milling, leading to lower short fiber content in the resulting CP. Conversely, husks exposed to wet milling are fully saturated, causing some short fibers to pass through the mesh during sieving and thereby increasing the fiber content in wet milled CP.

Aging facilitates the separation of CP particles from fibers and breaks down coarse CP particles into finer ones, potentially leading to the decomposition of lignocellulosic material and altering the original composition (Meenatchisunderam, 1979). As the material ages further, the original fiber content is subjected to significant changes. In wet milling methods, the short fiber content notably increases from 9.93% to 12.14% with aging. Conversely, in dry milling method, aging leads to a significant decrease in fiber content from 10.89% to 9.67%. However, this decrease in fiber content in aged dry milled material may be influenced by other unidentified factors (Figure 1).

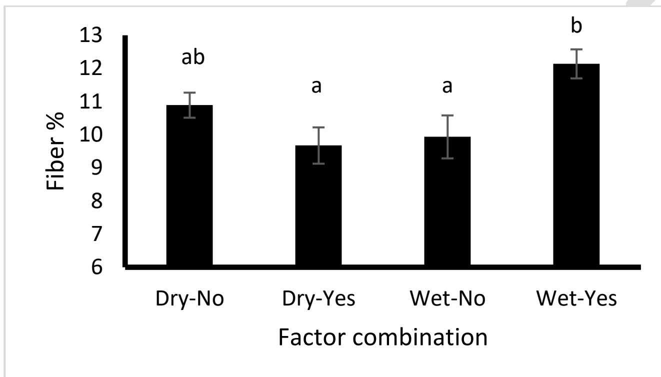

Figure 1: Interaction effect of milling method and ageing status on fiber content of CP. [Error bars indicate SE of means]. [The same column label indicates non-significant mean differences at *P*=0.05]

The aged CP from dry milling and non–aged CP from wet milling exhibited the lowest percentage of fiber content (Figure 1). However, their difference from non-aged CP from dry milling was minimal. From a commercial standpoint, achieving the lowest fiber content is desirable, regardless of soil type and variety (as it is operationally challenging to sort material based on these factors). The optimal combinations for minimizing fiber content include: (i) aged CP from dry milling and (ii) non-aged CP from wet milling.

3.2 Effect of variety, soil suitability class and aging on the composition of fine particles in coco pith

Similar to fiber, fine particles (<0.2 mm) are undesirable for maintaining the expected physical properties of CP when used as a substrate for plant growth. Fine particles exhibit higher water holding capacity and lower air-filled porosity (Kumarasinghe, et al., 2015), making them unsuitable for compressing into blocks for manufacturing products. Fine particles also lack sufficient expansion properties, and they demonstrate poor rehydration after drying. Therefore, minimizing the fine particle content is crucial for ensuring the quality of the raw material.

The main effects of variety (P = 0.0713), soil suitability class (SS) (P = 0.6458), and aging status (P = 0.4224) per se did not yield significant effects on the fine particle content of CP samples.

However, their three–way interaction affected the fine particle content significantly (P = 0.0468). Specifically, variety DT in soil suitability classes S_2 and S_3 when aged, and S_4 when not aged, exhibited the highest significant fine particle content (11.47±0.14%) in CP. The industry norm for good quality CP is less than 10% fine content. Regardless of soil suitability class and aging status, variety DT showed a higher average fine particle content (10.22±1.53%) than TT (9.21±0.95%). In variety DT, only S_4 (7.19%) and S_2 (8.92%) met the <10% fine particle condition when aged (Figure 2).

CP from variety TT achieved the norm of less than 10% fine particles in soil suitability class S_1 with aging (9.37), in S_2 and S_3 regardless of the aging status (8.66±0.78) and in S_4 without aging (8.75). The variety TT in all combinations exhibited less than 10% fine particle content except for a very marginal increase in S_1 (10.47%) and S_4 when aged (10.43%). These findings indicate that CP from variety TT is the preferable option for sourcing CP due to its lower fine particle content, regardless of soil suitability class or aging status. However, in case the CP requirement cannot be met from TT material, as alternatives, non–aged DT material from S_2, or DT from S_4 after aging can be used.

Regarding the main effects milling method significantly (P<0.0001) impacts the fine particle content of CP. Dry milling results in a significantly lower (8.09%) fine particle percentage compared to wet milling, which exhibits the highest fine particle content (11.27%). During wet milling, soaking of husks promotes microbial activity, leading to the breakdown of pith particles into smaller particles due to the degradation of the lignin structure of fiber (Rajan et al., 2005); (Nazareth and Mavinkurve, 1987).

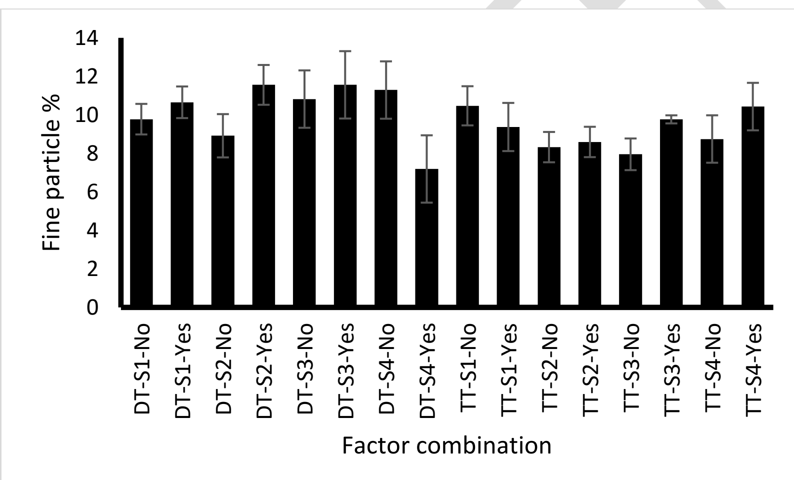

Figure 2: Interaction effect of variety, soil suitability class and ageing on fine particle percentage of CP [Error bars indicate SE of means]

3.3 Effect of milling method and ageing status on the composition of second particles in coco pith

"Second particles" content (0.2 mm – 1 mm) is a crucial category of CP, particularly important for producing value-added CP products like pellets and blocks for seedling nurseries. These particles serve as a foundation for formulating CP blends for various products, working in conjunction with the fourth particles. Among the effects of four factors with respect to composition of second particles, one of the highest order effects found was the interaction between milling method and aging status (*p*=0.0100) (Figure 3).

According to Figure 3, the interaction between the milling method and aging status is of the form that similarly high second particle content were found in aged (48.14%) and non-aged (47.81%) CP when dry milled. Wet milling gave a similarly high second particle content in CP when process without ageing (47.95%) where aging significantly reduced the second particle content (43%). However, that was also well above the industry norm for second particles (40%). The notable reduction in second particle percentage (43%) with wet–milled CP that underwent aging (Wet–Yes), could be attributed to possible microbial degradation of binding materials within the tissue, as observed in previous studies (Theradimani et al., 2018; Meenatchisunderam, 1979). Significantly high fine particle content reported in wet milled and aged samples (Figure 1) supports possible breaking down of part of the second particle fraction of the wet milled samples into fine particles due to enhanced microbial degradation during aging. Meanwhile, the significant main effects of aging status (*P*=0.0015) and milling method (*P*=0.0160) per se were also observed on the second particle content of CP, supporting the above results.

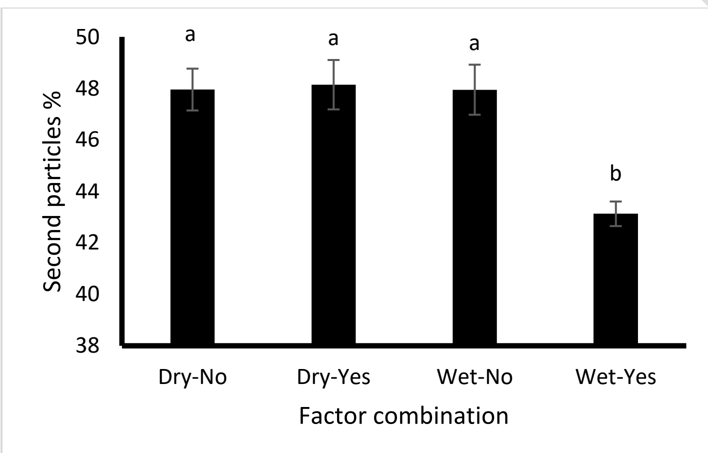

Figure 3: Combined effect of milling method and ageing status on second particle content of CP. (Dry=dry milled, Wet=wet milled, No=without ageing, Yes=with aging). [Error bars indicate SE of means]. [The same column label indicates non-significant mean differences at *P*=0.05]

3.4 Effect of milling method and variety on the composition of second particles in coco pith

The other higher order effect on second particle content was the interaction effect of milling method×variety (*P*=0.0077). Moreover, milling method showed a significant main effect (*P*=0.0160) on second particle content, but the main effect of variety was not significant (*P*=0.6796). The interaction between milling method and variety is presented in Figure 4.

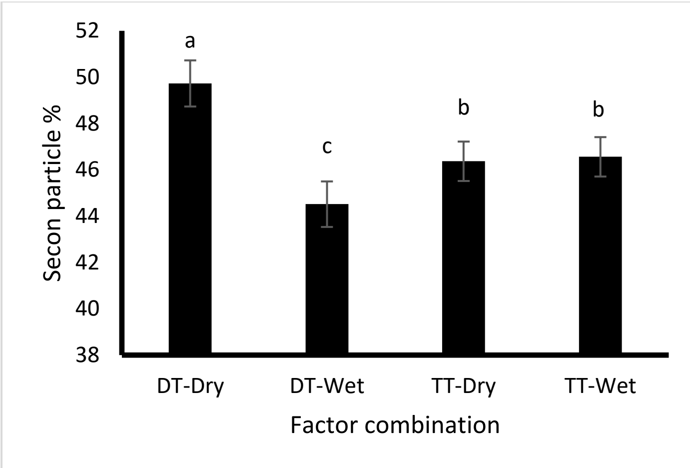

Figure 4: Combined effect of variety and milling method on the second particle content of CP. (Dry=dry milling, Wet=wet milling) [Error bars indicate SE of means]. [The same column label indicates non-significant mean differences at *P*=0.05]

Meanwhile, both varieties under both milling methods exhibited more than 40% second particle content, abiding with the industrial norm. The significant interaction between variety and milling method (*p*=0.0077) revealed the highest second particle content (49.59%) when variety DT was processed using dry milling. As discussed earlier, the dry milling technique promotes the breakdown of pith particles during processing, resulting in a high percentage of second particles in the DT and dry milling method combination.

Variety DT significantly influenced milling method for the second particle content of CP, suggesting that switching from wet to dry milling can increase the level of second particle content. Wet milling had a negative influence on the second particle content of VAR DT, with the lowest second particle content observed (44.52%). Meanwhile, variety TT showed no influence on the milling method, regarding the percentage of second particles in CP.

3.5 Effect of variety, soil suitability class, milling method and aging on the composition of fourth particles in coco pith

The particle size range of 1.0 - 2.0 mm, termed "fourth” particle, is crucial for maintaining the quality of value-added CP based products. The industry norm for high-quality coco peat production emphasizes a high percentage of fourth particles, typically around 35% in raw CP materials.

Significant four-way interaction among all factors (*P*=0.0332) was observed on the fourth particle content of CP. Graphical representation of the four-way interaction is displayed in Figure 5.

S_1

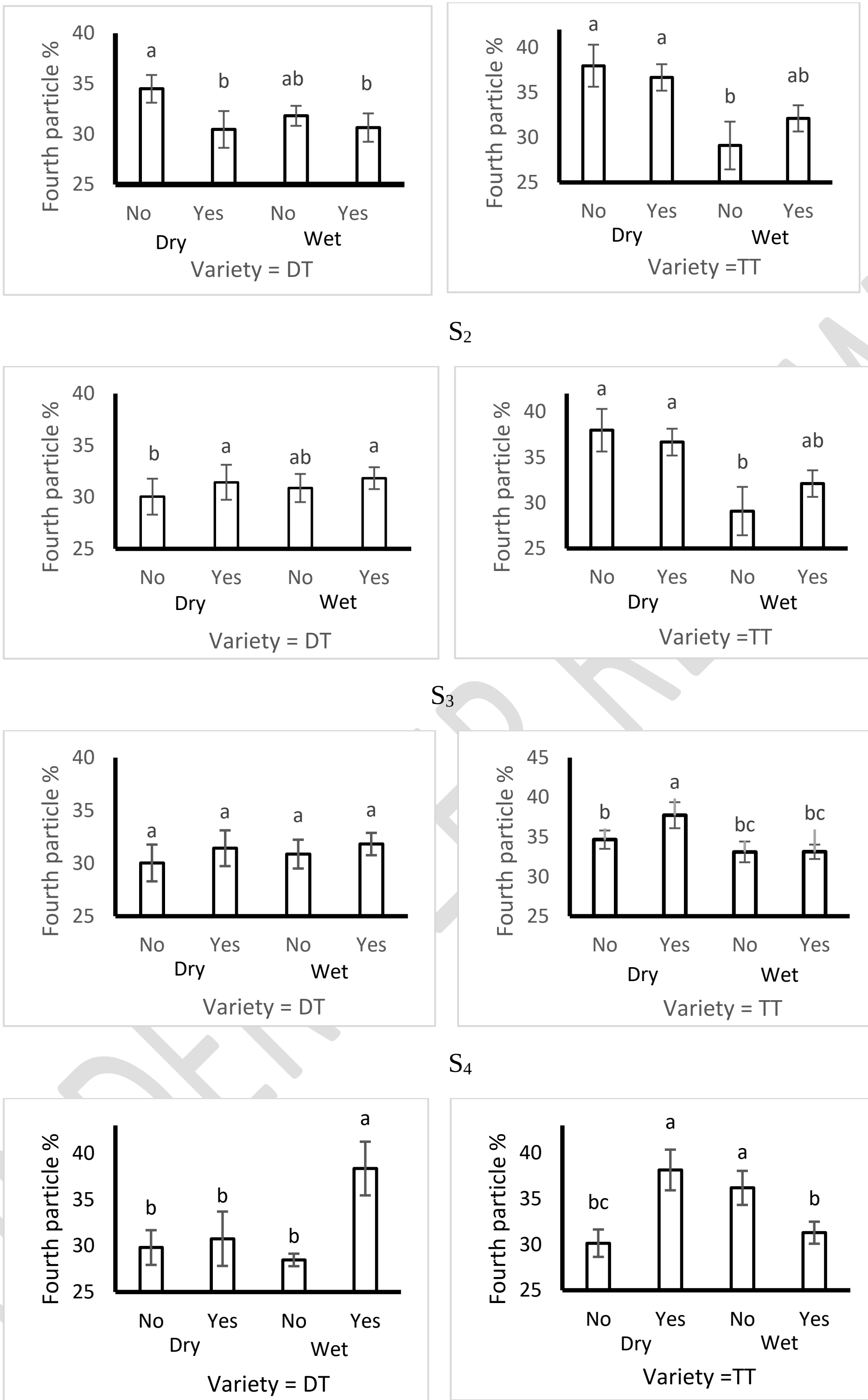

Figure 5: Combined effect of soil suitability class, variety, milling method and aging status on fourth particle content of CP. [Error bars indicate SE of means.] TT=Tall variety, S_1-S_4= Soil suitability classes, Dry=Dry milled CP, Wet=Wet milled CP, No=Without ageing, Yes=With aging. [The same column label indicates non-significant mean differences at *P*=0.05]

As per the four-way interaction (Figure 5), variety DT cultivated in S_4 and processed by wet milling followed by aging exhibited the highest fourth particle content (38.34%). Conversely, the same combination without aging (instead of aging) resulted in the lowest fourth particle content (28.47%). The variety DT cultivated in all other soil suitability classes, regardless of the milling method and ageing status, displayed different levels of fourth particle content, all resulting in less than 35% particle content (29.81 - 34.49%). Meanwhile, variety TT cultivated in S_4, followed by dry milling and ageing, showed a higher content of fourth particles (38.17%). The same variety, when subjected to wet milling without ageing, exhibited a content of 36.18% fourth particles. Variety TT cultivated in S_2 and S_3, displayed fourth particle contents of 37.74% and 35.31%, respectively under dry milling and aging.

Since the milling method and aging are within the control of operational management, manipulating these factors can lead to desired outcomes in fourth particle content. The results suggest that achieving a fourth particle content above 35% in CP can be accomplished by processing variety TT in soil suitability classes S_1, S_2, S_3, and S_4 through dry milling followed by aging, and also in S_4 through wet milling without ageing. For variety DT cultivated in S_2 and S_4, the optimal combination is wet milling followed by aging to increase the fourth particle size category, while dry milling followed by aging produced optimal fourth particle size content for variety DT grown in S_1 and S_3. Switching from wet milling to dry milling for variety TT in S_1, S_2, and S_3, the average output of fourth particle content can be raised from 32.46% to 36.57%. Similarly, wet milled CP from variety TT in S_1, S_2, and S_3, which showed lower averages of fourth particle content, can be increased to 36.57% on average by changing the milling method to dry milling followed by aging.

A significant two-way interaction (p=0.0077) was also observed between variety and milling method on the fourth particle content of CP. Dry milling of variety TT yielded the highest fourth particle content (35.6%), while wet milling resulted in significantly lower particle content (32.0%). This indicates that dry milling of TT generates a higher percentage of fourth particles compared to wet milling, provided other two factors are fixed. On the other hand, dry-milled DT had the lowest fourth particle level at 31.6%.

Variety (p=0.0041) and milling method (p=0.0475) demonstrated significant main effects on the fourth particle size category, while soil suitability class (SS) and aging did not exhibit significant main effects.

Table 1: Means of main effects and interactions for different particle sizes
[*P*=<0.05]

Particle Fraction	**Effect**	**LSMeans**	***p***
Fiber	MM×Ageing	9.52	0.0035
Fine	MM	17.52	<0.0001
	VAR×Ageing×SS	4.98	0.0468
Second	MM	13.75	0.0142
	Ageing	12.65	0.0242
	MM×Ageing	14.51	0.0133
	MM×VAR	14.84	0.0077
Fourth	MM	8.03	0.0454
	Ageing	7.88	0.0499
	VAR	11.86	0.0035

MM×VAR	11.00	0.0066
MM×Ageing×VAR×SS	6.97	0.0332

According to Table 1, milling method was the key factor influencing fine, second, and fourth particle contents, while aging mainly affected second and fourth particles. Additionally, the main effect variety influenced fourth particle content. The interaction between milling method and aging status influenced fiber and second particle contents, while the interaction between milling method and variety affected the content of second and fourth particles. Furthermore, the factor soil suitability class contributed to a three-way interaction with variety and aging status for fine particle content, and a fourth-order interaction was observed with milling method, aging status, and variety for the fourth particle content.

4. Discussion

An efficient manufacturing system in the CP based propagation media industry needs lower levels of fiber and fine particles, while optimizing the second and fourth particles. Considering the optimal combinations for minimizing fiber content includes aged CP from dry milling and non-aged CP from wet milling. When selecting between these options, the one with the lower cost should be chosen, as the primary aim is to obtain CP with minimal fiber content. In a situation where the required volume of target material cannot be sourced solely from the optimal milling and aging combinations (i.e. options (ii) or (i) as mentioned above), additional raw material may be procured from other combinations (such as dry-non-aged) with slightly higher fiber contents. This approach is sensible as it allows managing the production costs by categorizing incoming raw materials based on milling method and aging status. Adequate research evidence was not found on the influence of any external factors, such as growing environment, varietal variation, or any other factor that could affect the fiber content existing in sourced CP and its influence on the quality of CP.

Similarly, fine particles (<0.2 mm) are also undesirable for maintaining the expected physical properties of CP when used as a substrate for growing plants. This fact is well documented, in regard to the use of CP for coco pellets (Kumarasinghe et al., 2015). Fine particles exhibit higher water holding capacity and lower air filled porosity (Kumarasinghe et al., 2015), making them unsuitable for compressing into blocks for manufacturing products. Fine particles also lack sufficient expansion properties, and they demonstrate poor rehydration after drying. Therefore, minimizing the fine particle content is crucial for ensuring the quality of the raw material as these accounts as a waste.

The results of this study demonstrated that the percentage of fine particles in CP exhibited a three-way interaction among soil suitability class, variety, and aging status. Soil suitability class plays a crucial role in determining the land's suitability for coconut cultivation within specific climate and hydrological regions (Somasiri et al., 2006). Soil suitability class 1 (S_1) soil offers the best conditions for coconut trees to thrive, resulting in optimal nut characteristics. Conversely, class S_5 soil presents limitations in soil structure, topography, and irrigation requirements, requiring grower intervention with recommended agronomic practices even though some limitations in the soil structure such as excessive clay content may not be rectified easily. Therefore, soil suitability class can significantly affect the quality of coconut husk. Meanwhile, Tall variety (CRIC 60) is the most prevalent coconut variety distributed across the Coconut Triangle. Even though variety DT (CRIC

65) is recommended for cultivation in wet regions due to its preference for adequate soil moisture, there are instances of DT cultivation in drier areas with substantial irrigation, particularly in the Kurunegala district. Influence of the genetic nature of the coconut on the composition of particle sizes in CP is a new study area. The influence of aging or microbial decomposition was substantially studied by many authors specifically in coir fiber studies which is readily applicable in CP as well (Meenatchisunderam, 1979; Rajan et al., 2005; Kumar and Ganesh, 2012; Theradimani et al., 2018).

The second particle size within the 0.2 – 1 mm particle range is useful in the production of value-added CP products. In general, CP contains around 40% second particles at the end of the process. We found a much higher (49.59%) second particle level in dry milled CP from variety DT in *MM x VAR* interaction (p=0.0085). The significant (p=0.0100) interaction between MM and aging status demonstrated around 48% second particle content except wet milled CP after aging. This situation emphasizes wet milling of CP in the presence of aging to break down particles to smaller sizes (Meenatchisunderam, 1979; Theradimani et al., 2018). It indicates that there should be proper process control to limit retting of husks before wet milling and finish aging at the correct aging period.

The "fourth" particle size, ranging between 1.0 - 2.0 mm, is the next important grade in value-added CP-based products. Approximately 35% of fourth particles present in good quality CP, adhering to industry standards. A significant four-way interaction among all four factors was evident for this particle category (P=0.0332). This situation is notably complex, as particle size is influenced by soil, genetic, processing, and aging conditions. The analysis emphasizes that the combined influence on particle size is more noticeable from variety TT. Overall, the literature evidence on the influence of factors on the distribution of particles of CP from previous studies is limited, indicating a potential research area for future studies aimed at optimizing beneficial particle fractions for more productive CP based mixes or products.

5. Conclusion

Minimizing fiber content in raw CP is essential in industry perspectives, and wet milling has been found to be superior to dry milling for achieving this reduction. Additionally, aging enhances the reduction of short fiber content in dry milled CP but increases the short fiber content in wet milled CP.

Achieving minimum levels of fine particles (less than 10%) is also crucial for the selection of raw materials. These levels were met in variety DT when grown in S_1 and S_2, and in S_4 with aging, regardless of the milling method. Variety TT exhibited lower fine particle content when grown in S_1 with aging, in S_2 and S_3 regardless of aging status, and in S_4 without aging.

The second particle content was influenced by dry milling, regardless of aging status, and wet milling without aging. Variety TT consistently had over 40% second particles, which is beneficial, regardless of the milling method, while variety DT showed this level only with dry milling.

The variety TT generally exhibited higher fourth particle content compared to DT, with dry milling proving superior to wet milling. Variety TT under dry milling and DT under wet milling consistently yielded the highest fourth particle size, regardless of soil class and aging status.

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DISCLAIMER (ARTIFICIAL INTELLIGENCE): Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during writing or editing of manuscripts

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