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Research Article

Comparative Evaluation of the Bioactive Potential of a Powder and the Particle Size Fractions of Plant Organs From *Dacryodes edulis*, *Solanum torvum*, and *Curcuma longa*

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The bioactive potential of plant organ powders depends on their bioactive compound content and is influenced by the properties of particle size fractions (PSFs). This study evaluated the effects of PSFs on total polyphenols, flavonoids, and condensed tannins in plant organ powders and compared them with those of unsieved powders (UnPs). Young (YLDE) and mature (MLDE) leaves, bark (BDE) of *Dacryodes edulis*, *Solanum torvum* leaves (LST), and *Curcuma longa* rhizome (RCL) were collected and processed into powders ($Ø \leq 1000\,\mu$m sieve, AFNOR brand). These powders were then divided into two batches, one of which was separated into fractions of different sizes. The total polyphenols, flavonoids, and condensed tannin contents were determined. UnP and seven PSFs were obtained, with the 250–400 μm fraction being the most abundant. The UnP of RCL, YLDE, and LST had the highest contents of total polyphenols (303.70 ± 1.66 mg GAE/100 g DM), flavonoids (218.19 ± 1.93 mg QE/100 g DM), and condensed tannins (19.16 ± 0.29 mg CE/100 g DM), respectively. The contents of these bioactive compounds were higher in the $< 125\,\mu$m fraction. The extraction of total polyphenols and flavonoids from UnP exceeded the sum of PSFs, whereas the condensed tannins were higher in the sum of PSFs for YLDE, MLDE, and BDE. For LST and RCL, the extracts of the three compounds from UnP and the sum of the PSFs were equal. The powder fractioning method was advantageous for the extraction of condensed tannins from the YLDE, MLDE, and BDE.

Keywords: bioactive compound contents; particle size fraction; plant organs; unsieved powder

1. Introduction

Plant organs are rich sources of bioactive compounds (BCs) such as polyphenols, flavonoids, and tannins, which are known for their diverse biological activities [1, 2]. These compounds are prioritized in research for managing metabolic and chronic diseases [3] and are integral to many cosmetic product formulations. However, accessing these compounds in plant matrices poses a significant challenge, particularly during extraction processes. The form in which these matrices are present during extraction significantly influences the accessibility of BCs [2, 4, 5]. To this end, many authors have chosen to increase the specific surface area of these matrices by transforming them into powders [6].

Food powders are characterized by their particle size (< 1 mm), shape, specific surface area, and chemical composition [7, 8]. These characteristics are influenced by various factors, including the type of plant organ (leaf, bark, fruit, or root), postharvest techniques (sorting, washing, cleaning, or storage), thermal treatments (blanching, drying, or cooking), and mechanical treatments (grinding or sieving) [6, 7, 9].

Among these properties, particle size and specific surface area significantly affect the extraction efficiency of chemical compounds [7]. Therefore, grinding powder into smaller particles could increase the extraction of chemical compounds. However, multiple fractions have been observed in the particle size distributions of food powders, with some fractions, especially finer particle size fractions (PSFs), characterized by higher chemical compound contents [10, 11]. Thus, extracting the BCs of food powder from each PSF could prove more advantageous. This approach could reveal limitations or losses in BC contents compared with extractions performed solely on unsieved food powders. Both extraction approaches are crucial when evaluating the bioactive potential of plant organ powders.

The plant organs investigated included the leaves and bark of *Dacryodes edulis*, the leaves of *Solanum torvum*, and the rhizome of *Curcuma longa*. These organs are utilized in the form of powders in herbal medicine, cosmetics, and the food industry, primarily because of their bioactive potential (high content of BCs) and the biological activities of these compounds [12–15]. Before use, these powders can take two main forms: unsieved powder (the most commonly used form) and one or more PSFs (the least commonly used form) [6, 13, 16]. Either form of powder could be more favorable for obtaining the maximum contents of BCs. Given that the effects of PSFs of the aforementioned plant organs on their BC contents have been understudied compared with those of their unsieved powders, this study is aimed at comparing the effects of unsieved powders with those of PSFs on the contents of total polyphenols, flavonoids, and condensed tannins in the organs of *D. edulis* (leaves and bark), *S. torvum* (leaves), and *C. longa* (rhizomes).

2. Material and Methods

2.1. Sampling of Plant Organs. The plants from which the organs were harvested showed no signs of deficiency or disease contamination. The young leaves (YLDE) (characterized by a bright green color and located at the branch apex), mature leaves (MLDE) (distinguished by a dark green color and positioned away from the branch apex), and bark (BDE) (located at the tree trunk level) of *D. edulis*, along with the leaves of *S. torvum* (LST) and the rhizome of *C. longa* (RCL), were collected from farms via simple random sampling in the Nkolbisson (Yaoundé), Espoir (Douala), and Dakar (Douala) districts of Cameroon, respectively. These matrices were identified at the Cameroon Herbarium according to the following characteristics:

- *D. edulis*: samples identified by comparison with Dang D. 372 material from specimen collection Herbarium No. 25650 SRFCam.
- *S. torvum*: sample identified by comparison with Surville No. 476 material from specimen collection Herbarium No. 14615 SRFCam.
- *C. longa*: sample identified by comparison with Westphal 9974 material from specimen collection Herbarium No. 43153 SRFCam.

The samples from each collection site were then mixed to represent each organ.

2.2. Powder Production. Following the harvest, the leaves, bark, and rhizome were rinsed with clean water and subsequently dried at 25°C (for leaves) and 40°C (for bark and rhizome) using an electric dryer (Stockii, Dorrex, Paris, France) over a period of 5 h. The dried materials were then ground using a Moulinex grinder (4500 W, 220–240 V, France) and sieved through a mesh with a 1000 μm aperture (AFNOR brand) to produce a powder (Figure 1). The resulting powders were stored in airtight containers at 4°C until further analysis.

2.3. Determination of the PSF of the Powders. The particle size of the food powder was determined postsieving. A column of sieves from AFNOR (Association Française de Normalisation), arranged in descending order of size (1000, 800, 710, 500, 400, 250, 125, 100, 50, and 40 μm) up to the collector, was utilized for this purpose [17]. A mass (M_1) of powder, placed at the top of a stack of sieves, was subjected to a 50 Hz vibration for 15 min using a Merck-type vibrator. Particles smaller than the sieve mesh passed through (M_i), whereas those larger than the sieve mesh remained (M_j). Each mass was weighed to determine the particle size distribution (R_p) according to the formula below. The PSFs were inferred on the basis of the mass of the sieved particles.

$$R_p = \frac{M_i}{M_1} \times 100$$

2.4. Details on the Masses of Powders Prior to BC Extraction. A BC in an unsieved powder ($\varnothing < 1000\,\mu$m) possesses a mass denoted as $(M_{BC})_1$. This mass is distributed proportionally (denoted as m_{BC}) across each PSF that constitutes this powder. The sum of the masses of the BCs contained in all the PSFs can be evaluated and expressed as $(M_{BC})_2$. To this effect, $(M_{BC})_2 = \sum_{i=1}^{n}(x_i)(m_{BC})_i$, where n is the number of PSFs and x_i is the mass percentage of the PSF i. By comparing the values of both $(M_{BC})_1$ and $(M_{BC})_2$, it is possible to determine whether particle size fractioning of a powder before extracting its BCs is beneficial for efficiency. Thus, if

- $(M_{BC})_1 > (M_{BC})_2$: Extraction of a BC from a powder, on the basis of the sum of its mass in each PSF, is not advantageous.
- $(M_{BC})_1 < (M_{BC})_2$: Extraction of a BC from a powder, on the basis of the sum of its mass in each PSF, is advantageous.
- $(M_{BC})_1 = (M_{BC})_2$: Extraction of a BC solely from an unsieved powder is deemed satisfactory.

2.5. Chemicals for BC Analysis. The following reagents were utilized for the analysis of BCs: Folin–Ciocalteu's reagent (Sigma-Aldrich, F9252), ethanol, methanol (Sigma-Aldrich,

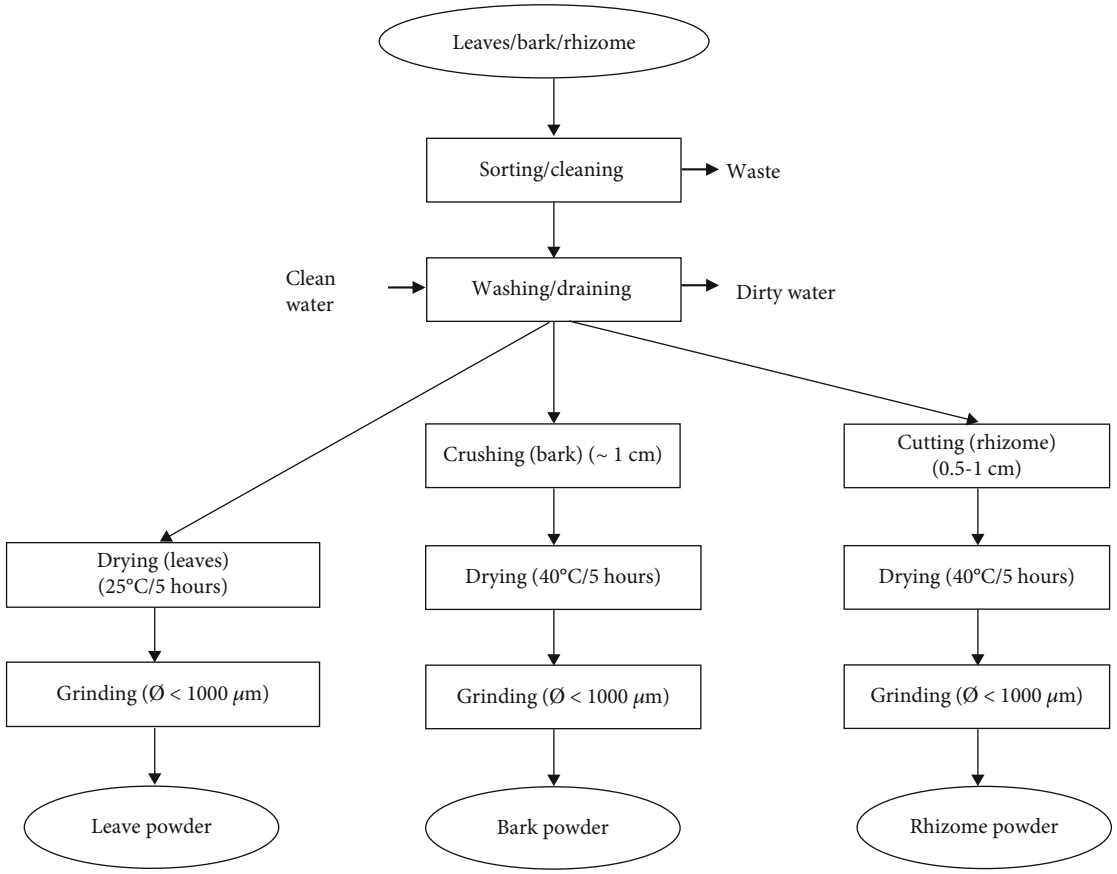


Figure 1: Production of different powders from plant organs (leaves and bark of *D. edulis*, leaves of *S. torvum*, and rhizomes of *C. longa*).

CAS67-56-1), sodium carbonate (Na_2CO_3) (Sigma-Aldrich, S7795), aluminum trichloride ($AlCl_3$) (Sigma-Aldrich, CAS7446-70-0), vanillin, gallic acid (Sigma-Aldrich, CAS149-91-7), catechin, quercetin (Sigma-Aldrich, CAS849061-97-8), and hydrochloric acid (HCl).

2.6. Extraction of BCs From Plant Organ Powders. The extraction of BCs was performed using the method of Senizza et al. [14] with some modifications. Approximatively 2.5 mL of 80% methanol was added to 0.5 g of powder in a test tube. Methanol was selected as the extraction solvent because it yields better results for phytochemicals, as reported by Ramamurthy et al. [18]. This mixture was left to macerate for 24 h to extract total polyphenols. The resulting mixture was then centrifuged using a DL 6000 model centrifuge (rotor 15 cm, Japan) at 3000 × g. The supernatant was collected and stored at +4°C prior to analysis.

2.7. Determination of Moisture and BC Contents

2.7.1. Moisture Content. The moisture content of the plant organ powders was determined using the AOAC [19] method with slight modifications. Approximately 3 g of powder (M_1) was placed in a preweighed capsule after being dried at 105°C for 3 h and cooled in a desiccator. The whole (capsule and powder) was then dried in an oven (Model Memmert, D 91107 Schwabach, Germany) at 105 ± 2°C for 18–24 h, followed by cooling to ambient temperature in a desiccator until it reached a constant weight (M_2). The moisture content (M_C) is calculated according to the following formula:

$$M_C = \left[\frac{(M_1 - M_2)}{M_1}\right] \times 100$$

2.7.2. Total Polyphenols. The total polyphenol content was determined according to the method described by Makkar, Siddhuraju, and Becker [20], with some modifications. An extract (100 μL) was combined with 200 μL of tenfold diluted Folin–Ciocalteu reagent and 200 μL of 7.5% (*w*/*v*) sodium carbonate. The mixture was vortexed and incubated in the dark at room temperature for 10 min. Approximately 1000 μL of distilled water was then added, and the mixture was vortexed again. The absorbance was measured at 760 nm using a BK-UV1600 PC visible spectrometer (China). The total polyphenol content was calculated against a calibration curve established with gallic acid and expressed as milligrams of gallic acid equivalent per 100 g of dry matter (DM) (mg GAE/100 g DM).

2.7.3. Total Flavonoids. The total flavonoid content was determined according to the method described by Chang et al. [21], with slight modifications. An extract (500 μL) was mixed with 500 μL of a freshly prepared 2% (*w*/*v*)

aluminum chloride solution. The mixture was incubated in the dark at room temperature for 15 min. The absorbance was measured at 430 nm using a BK-UV1600 PC visible spectrometer (China). The total flavonoid content was calculated against a calibration curve and expressed as milligrams of quercetin equivalent per 100 g of DM (mg QE/100 g DM).

2.7.4. Condensed Tannins. The condensed tannin content of the plant powders was evaluated using concentrated sulfuric acid to depolymerize the tannins, enabling them to react with vanillin and produce red anthocyanidins that were detected at 510 nm using UV/visible spectrophotometry [22]. To 50 μL of extract, 3 mL of 4% (w/v) vanillin in 80% methanol was added, followed by 750 μL of concentrated hydrochloric acid, and the mixture was vortexed. The mixture was incubated at 30°C for 20 min. The absorbance was read at 550 nm using UV/visible spectrophotometry (BK-UV1600 PC visible spectrometer, China) against a hydromethanolic solvent (70/30) as a blank. The tannin content was calculated from a standard curve prepared from a standard solution of catechin (0.2 g/L). The results were expressed as milligrams of catechin equivalents per 100 g of DM (mg CE/100 g DM).

2.8. Statistical Analysis. Analyses were performed in triplicate. Microsoft Excel 2013 software was used to calculate the means, standard deviations, and plotting curves. Statgraphic Centurion 15.2 software (StatPoint Technologies Inc., Warrenton, Virginia, United States) was used for variance analysis and mean separation using the Duncan multiple range test at $p \leq 0.05$.

3. Results and Discussion

3.1. Moisture Content of the Plant Powders. The moisture content of the matrices studied ranged significantly from 5.90 ± 0.01 to 7.15 ± 0.03 g/100 g DM (Table 1). These values, which are lower than the permissible limit of 15 g/100 g DM for optimal dry food storage [23], indicate an effective dehydration process, ensuring that the powders remain dry for extended periods. Given that water serves as a solvent, it promotes the growth of food spoilage microorganisms. A high water content in the powder increases its water activity and perishability. The observed reduction in water content thus ensures the long-term storage of these powders. Additionally, the moisture contents obtained in this study were used to calculate the contents of other compounds in the powders on a dry basis. Comparable moisture contents below the threshold of 15 g/100 g DM ranging from 7.00 to 13.5 g/100 g DM have been reported by several authors for leafy vegetables, rhizomes, and bark of plants [6, 24, 25].

3.2. Bioactive Potential of Unsieved Powders of Plant Organs. Powders derived from food plants, which are rich in BCs, are known to possess high bioactive potential. They have been extensively researched in traditional medicine, cosmetics, and the food industry [26]. The selection of these powders to address specific issues depends on the BC content of each matrix. Table 1 presents the variations in total polyphenols, total flavonoids, and condensed tannins obtained from the unsieved powders of the studied plant organs.

3.2.1. Total Polyphenol Content. The total polyphenol content of the five powders studied significantly varied from 47.17 ± 0.17 to 303.70 ± 1.66 mg GAE/100 g DM (Table 1). The highest content was yielded by RCL, whereas the lowest content was yielded by LST. These compounds, also known as secondary metabolites, are synthesized in response to external threats to the plant [20]. Therefore, RCL likely faces more environmental stressors (temperature, rainfall, herbivory, and infections) than other plants do, particularly LST. Several authors have reported polyphenol content values such as 528 mg GAE/100 g DM in the LST [14] and 24,010 mg GAE/100 g DM in the RCL [24] and their correlations with biological activities (antioxidant, antimicrobial, antidiabetic, anticancer, etc.). It is observed that these values are all higher than those obtained in this study for both LST and RCL. This discrepancy is primarily due to the type of solvent used. The chemical characteristics of solvents (polar and nonpolar) can influence the development of interactions (covalent bonding, hydrogen bonding, van der Waal forces, etc.) with polyphenols, leading to significant variability in their content in extracts [27]. This significantly impacts the assessment of the bioactive potential of unsieved powders from the studied plant organs.

3.2.2. Total Flavonoid Content. The total flavonoid content was lowest in LST and highest in YLDEs, with values of 11.86 ± 0.82 and 218.19 ± 1.98 mg QE/100 g DM, respectively (Table 1). Different values of total flavonoid contents have been obtained by different authors from LSTs (75 mg QE/100 g DM) [14] and from leaves of *D. edulis* (630.00 mg QE/100 g DM) [28]. Like total polyphenols, this secondary metabolite, a phenolic compound, is present in plant organs in response to environmental threats. This may explain the observed differences in these results. Flavonoids are an important group of BCs characterized by their multiple properties such as antimicrobial, antioxidant, anticancer, and antidiabetic properties [20, 29]. These activities are related to the different contents of these compounds in plant matrices as reported by various authors [30–32].

3.2.3. Condensed Tannin Content. Among the five plant powders studied, condensed tannins presented the lowest content of phenolic compounds, ranging from 8.02 ± 0.84 to 19.16 ± 0.29 mg CE/100 g DM (Table 1). The lowest content was yielded by the BDE, while the LST had the highest content. These results were lower than those reported (1.81 mg/100 g) by Ogboru, Okolie, and Agboje [31] on BDEs and higher than those reported (13.00 mg CE/100 g DM) by Senizza et al. [14] on LSTs. These discrepancies can be attributed to external factors (rain, herbivores, rodents, environment, etc.) that stimulate their synthesis in plants [20] and to the solvents used for their extraction [27]. Despite the observed variability, this group of BCs plays a crucial metabolic role. Condensed tannins, or proanthocyanidins, are oligomers of two or more flavan-3-ols, such as catechin and epicatechin. They exhibit a high

Table 1: Contents of bioactive compounds in the unsieved powders of plant organs.

Plant organs (unsieved powders)	Plant organs $((M_{BC})_1)$				
	YLDE	MLDE	BDE	LST	RCL
Moisture content*	7.10 ± 0.02^{c}	5.90 ± 0.01^{a}	6.70 ± 0.01^{b}	7.15 ± 0.03^{c}	7.10 ± 0.03^{c}
Total polyphenols (mg GAE/100 g DM)	271.10 ± 2.27^{b}	296.20 ± 2.71^{c}	297.10 ± 1.13^{c}	47.17 ± 0.17^{a}	303.70 ± 1.66^{d}
Total flavonoids (mg QE/100 g DM)	218.19 ± 1.93^{e}	176.47 ± 1.99^{c}	189.25 ± 0.96^{d}	11.86 ± 0.82^{a}	30.83 ± 1.41^{b}
Condensed tannins (mg CE/100 g DM)	16.52 ± 0.20^{c}	14.55 ± 0.19^{b}	8.02 ± 0.84^{a}	19.16 ± 0.29^{d}	13.94 ± 0.45^{b}

Note: Means in the same row with different superscript letters are significantly different from each other ($p \leq 0.05$).
Abbreviations: BDE, bark of *Dacryodes edulis*; LST, leaves of *Solanum torvum*; MLDE, mature leaves of *Dacryodes edulis*; Mn ± SD, means ± standard deviations; RCL, rhizome of *Curcuma longa*; YLDE, young leaves of *Dacryodes edulis*.
*g/100 g DM.

affinity for proteins, forming protein–tannin complexes. The consumption of a plant containing condensed tannins results in decreased nutrient utilization, with protein being the most affected, and reduced food intake. However, this phenolic compound plays a significant role in glycemic control [1] and in the treatment of various ailments such as leucorrhea, rhinorrhea, and diarrhea [31].

3.3. PSF of Plant Organ Powders. The obtained PSFs were < 125, 125–200, 200–250, 250–400, 400–500, 500–800, and ≥ 800 μm. Their respective masses, expressed as percentages, are presented in Table 2, with significant differences observed among them. For all powders, the fraction with the highest mass was 250–400 μm, with the exception of the RCL powder, which presented the highest mass in the fraction ≥ 800 μm. The YLDE, MLDE, and BDE powders did not contain any PSF ≥ 800 μm. However, for the YLDE powder, the mass of the fraction 500–800 μm (29.18 ± 0.63 %) was similar in importance to that of the 250–400 μm fraction (29.24 ± 0.50%). Several factors can account for the observed differences between the masses of PSFs across all powders, such as the type of plant, the plant organ, drying and grinding conditions, and sieving [7, 33]. These PSFs contain varying quantities of BCs, which can be evaluated and compared with those obtained from unsieved powder (Table 1). This evaluation allows for an accurate assessment of the BC content within the matrix. Previous studies have highlighted the importance of a powder's particle size distribution in enhancing its therapeutic, nutritional, and functional potential [7, 10, 11, 25, 34]. Some have identified specific PSFs as being more beneficial for certain uses [7, 10, 11], as the accessibility of BCs within these PSFs can vary significantly.

3.4. Bioactive Potential of the PSFs of Plant Organ Powders

3.4.1. Total Polyphenol Content. The characteristics of a plant organ powder, including its mass, structure, size, and shape, influence the chemical contents of the powder and its potential uses [8]. With respect to the bioactive potential, Table 3 shows that the total polyphenol content significantly increased from the coarse to the fine fractions. The values ranged from 184.07 ± 0.88 to 217.43 ± 1.15, 208.49 ± 2.30 to 228.49 ± 1.23, and 149.62 ± 2.23 to 202.79 ± 1.67 mg GAE/100 g DM in the YLDE, MLDE, and BDE powders, respectively. The fraction < 125 μm presented the highest total polyphenol content for all these powders. The LST and RCL powders had the highest contents, 48.24 ± 0.22 and 304.54 ± 1.43 mg GAE/100 g DM, in the 250–400 and ≥ 800 μm fractions, respectively. *D. edulis* organs (leaves and bark) exhibit similar total polyphenol behavior, in contrast to the leaves of *S. torvum* and the rhizome of *C. longa*, each of which presents a unique behavior.

The observed increase in total polyphenol contents from coarse to fine fractions is likely due to the increase in the specific surface area of the powder during grinding, which improves the contact between the solvent and extractives during the extraction process (maceration). Consequently, finer particles tend to release higher total polyphenol contents. Similar observations were reported by Deli et al. [10, 11] for different PSFs of three plant organ powders in Cameroon. Thus, it would be advantageous to finely grind plant organs to improve the accessibility of their BCs. However, it should also be noted in this study that the behavior of the LST and RCL powders contrasts with that previously described for the YLDE, MLDE, and BDE powders. This finding indicates that increasing the specific surface area of a powder does not automatically increase the accessibility of its polyphenol content.

The contradiction observed in these results also suggests that the nature of the plant organ studied (leaf, bark, and rhizome) is an important factor in the variability of the accessibility of polyphenols contained in powders with a high specific surface area. This may be due not only to the polysaccharide content of unsieved powders, which are relatively distributed in each of their PSFs, but also to interactions between polyphenols and polysaccharides [35]. Several authors have reported differences in structure [36], particle size, and aggregates [37], which are formed by interactions between polyphenols (procyanidins) and polysaccharides (hyaluronans and Rhamnogalacturonan II). These factors can affect their accessibility. Indeed, the accessibility of polyphenols remains an important factor that significantly influences the recognized bioactive potential of the plant organ powders studied.

3.4.2. Total Flavonoid Contents. Flavonoids, a large group of phenolic compounds, are highly valued for the bioactive potential of their diverse molecules [20]. They play a significant role in managing metabolic and chronic diseases [21].

Table 2: Mass of the particle size fraction constituting the unsieved plant organ powders.

Particle size fraction (μm)	Plant organs (%)				
	YLDE	MLDE	BDE	LST	RCL
< 125	11.46 ± 0.66^{d}	13.90 ± 0.60^{e}	2.16 ± 0.03^{b}	17.73 ± 0.70^{f}	11.88 ± 0.20^{d}
125–200	10.03 ± 0.10^{bc}	9.14 ± 0.50^{c}	13.53 ± 0.30^{d}	16.23 ± 0.27^{e}	11.06 ± 0.15^{c}
200–250	9.33 ± 0.66^{b}	6.56 ± 0.23^{b}	13.91 ± 0.35^{d}	12.50 ± 0.43^{d}	8.53 ± 0.28^{b}
250–400	29.24 ± 0.50^{e}	31.22 ± 0.43^{g}	48.33 ± 0.78^{e}	34.42 ± 0.68^{g}	7.09 ± 0.18^{a}
400–500	10.76 ± 0.23^{cd}	13.05 ± 0.16^{d}	8.42 ± 0.16^{c}	6.61 ± 0.13^{b}	7.56 ± 0.31^{a}
500–800	29.18 ± 0.63^{e}	26.13 ± 0.44^{f}	13.65 ± 0.18^{d}	9.16 ± 0.13^{c}	20.56 ± 0.40^{e}
≥ 800	0.00^{a}	0.00^{a}	0.00^{a}	3.35 ± 0.11^{a}	33.32 ± 0.99^{f}

Note: Means in the same column with different superscript letters are significantly different from each other ($p \leq 0.05$).
Abbreviations: BDE, bark of *Dacryodes edulis*; LST, leaves of *Solanum torvum*; MLDE, mature leaves of *Dacryodes edulis*; Mn ± SD, means ± standard deviations; RCL, rhizome of *Curcuma longa*; YLDE, young leaves of *Dacryodes edulis*.

Table 3: Total polyphenol content of PSFs from plant organ powders (mg GAE/100 g DM).

Particle size fraction (μm)	Plant organs $(m_{BC})_i$				
	YLDE	MLDE	BDE	LST	RCL
< 125	217.43 ± 1.15^{e}	228.49 ± 1.23^{e}	202.79 ± 1.67^{e}	45.47 ± 0.16^{b}	296.88 ± 1.37^{cd}
125–200	214.07 ± 0.97^{d}	227.87 ± 1.85^{e}	190.67 ± 2.23^{d}	44.45 ± 0.20^{a}	299.92 ± 1.65^{d}
200–250	212.47 ± 1.15^{d}	224.42 ± 1.59^{d}	172.57 ± 2.42^{bc}	46.57 ± 0.20^{c}	281.63 ± 3.14^{a}
250–400	206.90 ± 1.23^{c}	217.69 ± 1.23^{c}	175.74 ± 1.49^{c}	48.24 ± 0.22^{d}	291.57 ± 1.35^{b}
400–500	199.73 ± 1.68^{b}	212.74 ± 1.23^{b}	171.26 ± 2.98^{b}	46.24 ± 0.25^{c}	304.14 ± 1.38^{e}
500–800	184.07 ± 0.88^{a}	208.49 ± 2.30^{a}	149.62 ± 2.23^{a}	46.44 ± 0.30^{c}	293.63 ± 2.42^{bc}
≥ 800	/	/	/	44.39 ± 0.26^{a}	304.54 ± 1.43^{e}

Note: Means in the same column with different superscript letters are significantly different from each other ($p \leq 0.05$).
Abbreviations: BDE, bark of *Dacryodes edulis*; LST, leaves of *Solanum torvum*; MLDE, mature leaves of *Dacryodes edulis*; Mn ± SD, means ± standard deviations; RCL, rhizome of *Curcuma longa*; YLDE, young leaves of *Dacryodes edulis*.

This potential can be enhanced by increasing the specific surface area of plant organ powders. As shown in Table 4, the total flavonoid content significantly increased from the coarse to fine powders of the PSFs. The values range from 132.83 ± 0.74 to 194.21 ± 0.56, 153.54 ± 1.30 to 179.10 ± 1.86, 78.76 ± 1.41 to 130.79 ± 1.41, and 32.27 ± 0.81 to 43.61 ± 1.82 mg QE/100 g DM in the YLDE, MLDE, BDE, and RCL powders, respectively. The < 125 μm fraction has the highest content of all these powders. However, the total flavonoid content of the LST powders, which varied widely, was highest in the 400–500 μm fraction at 15.25 ± 0.39 mg QE/100 g DM. As previously noted, the increase in the specific surface area of these powders can account for these results. Deli et al. [10, 11] reported lower total flavonoid contents (21.26 mg RE/g DM) with a smaller particle size (0–180 μm) (increasing the specific surface area) of a plant organ powder (*Hibiscus sabdariffa* calyces). This discrepancy could be attributed to the type of plant and plant organ. However, according to these results, the bioactive potential of these plant organs, which is correlated with the total flavonoid content, can be increased by reducing the particle size of the powder. However, this can vary with the plant organs studied.

3.4.3. Condensed Tannin Contents. Table 5 presents the condensed tannin contents of the PSFs derived from various plant food organ powders. A significant increase in the condensed tannin content was observed from coarse to fine powders. The values range from 27.11 ± 1.69 to 113.55 ± 1.69, 42.37 ± 1.69 to 92.37 ± 2.54, 14.03 ± 0.62 to 23.89 ± 0.13, and 14.45 ± 0.95 to 18.20 ± 0.58 mg CE/100 g DM in the YLDE, MLDE, LST, and RCL powders, respectively. The < 125 μm fraction has the highest content for all these powders, whereas the BDE powders have the highest content in the 500–800 and 250–400 μm fractions at 22.03 ± 1.69 mg CE/100 g DM. Apart from the observed variations in the BDE powders, the significant increases in condensed tannin contents can be attributed to the reasons previously mentioned for the total polyphenol and total flavonoid contents. However, for *D. edulis*, the distribution of condensed tannin contents across PSFs differed between the leaves and bark. The characteristics of the particles, such as their structure, shape, and hardness, can limit the increase in their specific surface area, which may explain these differences. Similar observations were reported by Ho, Truong, and Bhandari [8], who noted that the characteristics of powders influence their functionality and stability. However, fine particles are crucial for obtaining the highest condensed tannin contents from plant organs.

3.5. Comparison of the Bioactive Potential of the Unsieved Powders and the Sum of the PSFs. The results indicate that fine particles of plant organ powders present high contents of total polyphenols, flavonoids, and condensed tannins,

Table 4: Total flavonoid content of PSFs from plant organ powders (mg QE/100 g DM).

Particle size fraction (μm)	Plant organs $(m_{BC})_i$				
	YLDE	MLDE	BDE	LST	RCL
< 125	194.21 ± 0.56^{f}	179.10 ± 1.86^{e}	130.79 ± 1.41^{e}	13.39 ± 0.63^{bc}	43.61 ± 1.82^{d}
125–200	168.47 ± 0.93^{e}	170.70 ± 1.67^{d}	112.56 ± 2.30^{d}	12.56 ± 0.21^{b}	41.76 ± 1.84^{d}
200–250	159.70 ± 0.37^{d}	156.15 ± 2.42^{c}	105.22 ± 2.56^{c}	10.82 ± 0.35^{a}	38.35 ± 0.92^{c}
250–400	151.86 ± 1.49^{c}	149.62 ± 1.11^{b}	103.09 ± 1.15^{bc}	13.80 ± 0.95^{c}	38.70 ± 1.90^{c}
400–500	146.08 ± 0.93^{b}	141.41 ± 1.11^{a}	101.41 ± 1.23^{b}	15.25 ± 0.39^{d}	36.37 ± 1.90^{bc}
500–800	132.83 ± 0.74^{a}	153.54 ± 1.30^{c}	78.76 ± 1.41^{a}	12.56 ± 0.38^{b}	34.25 ± 0.77^{ab}
≥ 800	/	/	/	10.56 ± 0.25^{a}	32.27 ± 0.81^{a}

Note: Means in the same column with different superscript letters are significantly different from each other ($p \leq 0.05$).
Abbreviations: BDE, bark of *Dacryodes edulis*; LST, leaves of *Solanum torvum*; MLDE, mature leaves of *Dacryodes edulis*; Mn ± SD, means ± standard deviations; RCL, rhizome of *Curcuma longa*; YLDE, young leaves of *Dacryodes edulis*.

Table 5: Condensed tannin content of PSFs from plant food organ powders (mg CE/100 g DM).

Particle size fraction (μm)	Plant organs $(m_{BC})_i$				
	YLDE	MLDE	BDE	LST	RCL
< 125	113.55 ± 1.69^{e}	92.37 ± 2.54^{d}	9.32 ± 0.84^{a}	23.89 ± 0.13^{d}	18.20 ± 0.58^{c}
125–200	73.72 ± 2.54^{d}	83.05 ± 3.38^{c}	12.28 ± 1.27^{b}	15.97 ± 0.24^{b}	18.57 ± 0.69^{c}
200–250	59.32 ± 1.69^{c}	62.71 ± 1.69^{b}	8.38 ± 1.10^{a}	17.29 ± 0.62^{c}	15.48 ± 0.36^{b}
250–400	40.67 ± 1.69^{b}	58.47 ± 2.54^{b}	22.03 ± 1.69^{c}	15.53 ± 0.66^{b}	9.34 ± 0.33^{a}
400–500	26.27 ± 0.84^{a}	44.91 ± 2.54^{a}	14.40 ± 0.84^{b}	13.62 ± 0.90^{a}	9.33 ± 0.61^{a}
500–800	27.11 ± 1.69^{a}	42.37 ± 1.69^{a}	22.03 ± 1.69^{c}	14.39 ± 0.54^{a}	15.32 ± 1.22^{b}
≥ 800	/	/	/	14.03 ± 0.62^{a}	14.45 ± 0.95^{b}

Note: Means in the same column with different superscript letters are significantly different from each other ($p \leq 0.05$).
Abbreviations: BDE, bark of *Dacryodes edulis*; LST, leaves of *Solanum torvum*; MLDE, mature leaves of *Dacryodes edulis*; Mn ± SD, means ± standard deviations; RCL, rhizome of *Curcuma longa*; YLDE, young leaves of *Dacryodes edulis*.

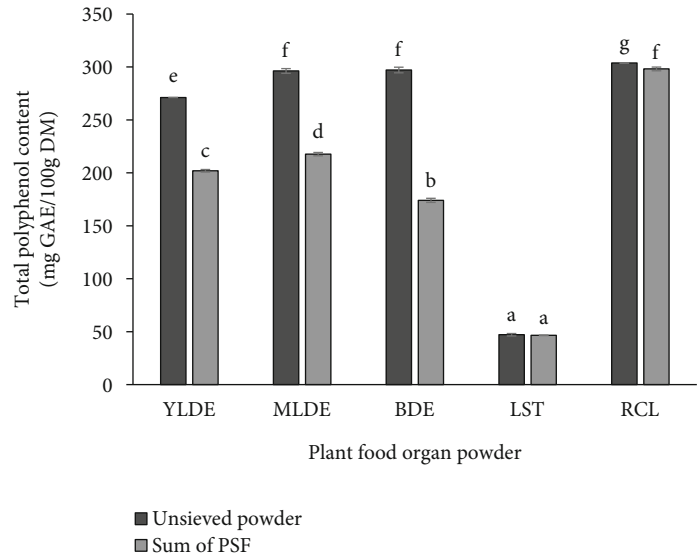


Figure 2: Comparison between total polyphenol contents of unsieved powders ($(M_{BC})_1$) and the sum of PSFs ($(M_{BC})_2$) of plant organs. YLDE, young leaves of *Dacryodes edulis*; MLDE, mature leaves of *Dacryodes edulis*; BDE, bark of *Dacryodes edulis*; LST, leaves of *Solanum torvum*; RCL, rhizome of *Curcuma longa*. Lowercase letters differing from one another assigned above each bar indicate a significant difference at the probability threshold of $p \leq 0.05$.

suggesting that the bioactive potential of these powders is higher than that of unsieved powders. However, each PSF contains a nonnegligible content of BCs, the sum of which should equate to that in the unsieved powders. Any discrepancy between the two could suggest a need to review the extraction methods currently used for determining the

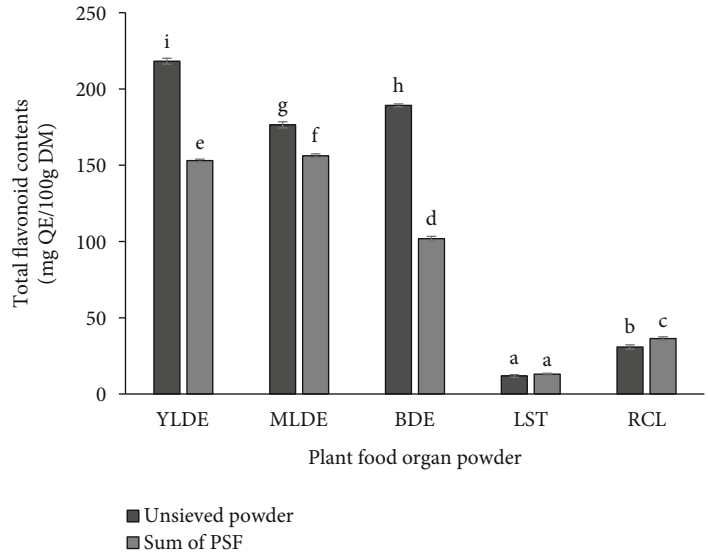


Figure 3: Comparison between total flavonoid contents of unsieved powders ($(M_{BC})_1$) and the sum of PSFs ($(M_{BC})_2$) of plant organs. YLDE, young leaves of *Dacryodes edulis*; MLDE, mature leaves of *Dacryodes edulis*; BDE, bark of *Dacryodes edulis*; LST, leaves of *Solanum torvum*; RCL, rhizome of *Curcuma longa*. Lowercase letters differing from one another assigned above each bar indicate a significant difference at the probability threshold of $p \leq 0.05$.

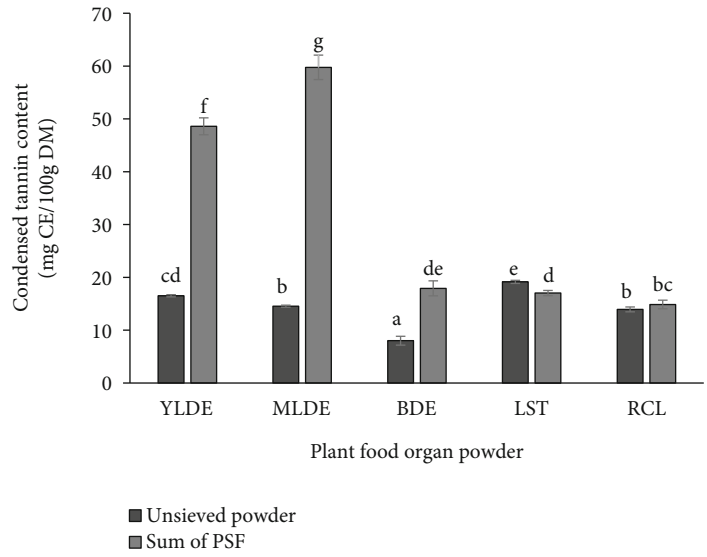


Figure 4: Comparison between condensed tannin contents of unsieved powders ($(M_{BC})_1$) and the sum of PSFs ($(M_{BC})_2$) of plant organs. YLDE, young leaves of *Dacryodes edulis*; MLDE, mature leaves of *Dacryodes edulis*; BDE, bark of *Dacryodes edulis*; LST, leaves of *Solanum torvum*; RCL, rhizome of *Curcuma longa*. Lowercase letters differing from one another assigned above each bar indicate a significant difference at the probability threshold of $p \leq 0.05$.

components of a powder. Figures 2, 3, and 4 present a comparison of the contents of total polyphenols, total flavonoids, and condensed tannins between the unsieved powders and the sum of the PSFs. The question arises as to which of these methods would be most advantageous for extracting (accessing) BCs to assess the bioactive potential of the studied organ powders.

The results show that for the leaves or bark of *D. edulis* and the rhizome of *C. longa*, fractionating the powders is not advantageous for extracting total polyphenols. Compared with the sum of the PSFs, the unsieved powder had significantly higher total polyphenol contents (Figure 2). However, the total polyphenol contents of the leaves of *S. torvum* were similar to those of the unsieved powders, indicating satisfactory extraction from the unsieved powders in these cases. The plant organs do not appear to be the only factor responsible for the observed variations. The hardness of the particles, which was not studied in this work, could also influence these results.

The total flavonoid content (Figure 3) was similar to the total polyphenol content. The fractionating method for

extracting total flavonoid contents is not advantageous for *D. edulis* organs (leaves and bark). The extraction of this compound from unsieved powders of *S. torvum* leaves and *C. longa* rhizomes is satisfactory. The condensed tannin contents of the unsieved powders and the sum of the PSFs are similar for the RCL. This is not the case for LST, which has a significantly higher condensed tannin content in the unsieved powders (Figure 4). However, for the YLDE, MLDE, and BDE, the condensed tannin contents in the sum of the PSFs were significantly higher than those in the unsieved powders. Therefore, the fractionation method is advantageous for *D. edulis* organs.

4. Conclusion

The substantial contents of total polyphenols, flavonoids, and condensed tannins in the YLDE, MLDE, BDE, LST, and RCL powders affirm their significant bioactive potential. Certain PSFs of these powders are more abundant in mass compared to others. This influences their BC content and consequently their potential. The 250–400 μm fraction predominantly constitutes these powders. These three BCs (total polyphenols, flavonoids, and condensed tannins) are more abundant in the fine PSFs, particularly the $< 125\,\mu$m fraction. The fractionation method of plant organ powders is not advantageous for extracting total polyphenols and flavonoids. This method is, however, beneficial for extracting smaller molecules such as condensed tannins. Nonetheless, this also depends on the specific plant organ studied. This result is of interest in the development of active ingredients in cosmetics and the management of chronic and/or metabolic diseases in public health. It would indeed be highly beneficial in enhancing the biological activities associated with the assimilation of these BCs obtained from the sum of these different PSFs. However, the results of this study will be extended to several other food matrices for further consolidation.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

Author Contributions

Assiéné Agamou Julien Armel: conceptualization, investigation, methodology, data analysis, writing—original draft, writing—review and editing; Djeukeu Asongni William: methodology; data analysis, review the original draft; Tizé Zra: methodology, data analysis; Fongnzossié Fedoung Evariste: supervision, methodology, review the original draft.

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