***Original Research Article***

**Some nutritional and bioactive characteristics of powders from *Corchorus olitorius* L. and *Abelmoschus esculentus* L. Moench highly sought for chronic disease management**

**ABSTRACT**

**Aims:** To determine the powders from the leaves and fruits of ***Corchorus olitorius*** and ***Abelmoschus esculentus***, which simultaneously exhibit high antioxidant activity, high nutrient density, and reduced energy density

**Study design:** Samples are collected from the farms and then processed into powders prior to analysis. The obtained results are analyzed, interpreted, and discussed in accordance with the study's objectives.

**Place and duration of study:** Department of Home Economics, Advanced Teacher’s Training College for Technical Education, between April 2024 and November 2024.

**Methodology:** Fresh leaves and fruits of these plants (*C. olitorius* and *A. esculentus)* were harvested and processed into powders. The macronutrient content, mineral composition, bioactive compounds, antioxidant activity were analyzed.

**Results:** Four main powders emerged, each suitable for specific applications. Powders from *C. olitorius* leaves and *A. esculentus* fruit exhibited high antioxidant activity (close to the standard, vitamin C). Only *A. esculentus* fruit powders showed high nutrient density and reduced energy density (average). It is characterized by high contents of iron (1.29 ± 0.01 mg/100g DM), zinc (2.70 ± 0.02 mg/100g DM), magnesium (257.58 ± 2.34 mg/100g DM), potassium (2684.62 ± 2.43 mg/100g DM), sodium (153.63 ± 2.78 mg/100g DM), and total flavonoids (15.03 ± 0.97 mg QE/g DM),

**Conclusion:** Only the powder from *A. esculentus* fruits exhibited high antioxidant activity, high nutrient density and reduced energy density (average). It is more advisable than other powders for meeting the needs of patients with chronic diseases specifically overweight and obesity.

**Keywords:** Plant organ powders; Antioxidant activity; Nutrient density; Energy density

1. **INTRODUCTION**

Patients suffering from chronic diseases, specifically overweight or obesity, are at high risk of mineral deficiencies (such as calcium, iron, zinc, copper, etc.), low intake of antioxidants, and various other essential nutrients (Xanthakos, 2009). Dietary management for these patients, based on calorie reduction, does not always address these mineral deficiencies (low nutrient density) or even antioxidants (Astrup & Bügel, 2018). Given this problem, the selection of foods and dietary supplements should be informed by precise knowledge of the content of food matrices and their derivatives. Among these foods, plant-based food powders are particularly relevant.

Food powders are extensively utilized in their galenic forms for fighting malnutrition (as food supplements) (Jung et al., 2019) and chronic diseases (as food supplements, infusions, decoctions) (Assiéné, Djeukeu, Assiéné, Mbida-Mbida, et al., 2024). They are also used as the main ingredient in traditional dishes. The plant organs used for these purposes include leaves, fruits, bark, and roots. These organs are rich in primary metabolites (proteins, carbohydrates, lipids, minerals, and vitamins) and secondary metabolites (polyphenols, tannins, flavonoids, phytates, oxalates, etc.). Their content is subject to variation based on several factors, such as species, soil, climate, herbivore attacks, and human activities (Makkar et al., 2007). One key factor often overlooked by many therapists during powder production is the influence of particle size (granulometry) on nutritional and bioactive potential. Numerous scientific studies have highlighted the significant effect of granulometry on nutrient contents and bioactive compounds (Assiéné, Djeukeu, Assiéné, Tize, et al., 2024). It is evident that food powders obtained from any plant organ, without considering granulometry, cannot be effectively harnessed. Surprisingly, despite this, many therapists recommend plant-based powders for patients suffering from malnutrition and chronic diseases without a prior understanding of how granulometry affects nutrient and bioactive content. The most informed therapists advocate for specific particle sizes (< 1000 µm or < 500 µm) during the production process. Their motivation stems from ancestral knowledge of the health benefits (antidiabetic, anticancer, antiobesity, etc.) associated with plant organs. In this regard, the leaves and fruits of Corchorus olitorius and Abelmoschus esculentus are among the most common organs utilized by many therapists.

*Corchorus olitorius* (Malvaceae), which is native to tropical and subtropical regions worldwide, is found in several African countries, including Egypt, the Ivory Coast, Benin, Nigeria, and Cameroon. Its leaves, which are commonly consumed as leafy vegetables because of their viscosity, are used to treat a broad spectrum of pathologies (dysentery, malaria, fever, gonorrhea, etc.) (Abdel-Razek et al., 2022). The fruits are capsules containing multiple seeds used for plant reproduction (Loumerem & Alercia, 2016). *Abelmoschus esculentus*, or okra, is a vegetable plant from the Malvaceae family; that is commonly used for its edible immature fruit (Bawa & Badrie, 2016). Like *Corchorus olitorius*, it thrives in tropical and subtropical regions worldwide (Gemede et al., 2015) and is found in East and Central Africa. All its organs (leaves, flowers, stems, seeds) are edible. The leaves and fruits of ***Corchorus olitorius*** and ***Abelmoschus esculentus*** are rich in minerals, proteins, sugars, fibers, and numerous bioactive compounds (Sha’a et al., 2019). However, the content of these compounds varies when they are transformed into powders, which significantly affects their nutritional and bioactive characteristics.

In view of the above, it is clear that, the use of food powders as supplementary foods in the fight against chronic diseases, without prior consideration of granulometric effects and the multiple molecular interactions that might occur in mixtures, poses the risk of yielding powders with uncontrolled nutritional and bioactive characteristics. The direct consequence of this oversight, which many therapists encounter (met in our markets and various dietetic cabinet), is uncontrolled and inadequate dietary management that fails to meet the precise needs of patients. The objective of this study was to determine the powders derived from the leaves and fruits of ***Corchorus olitorius*** and ***Abelmoschus esculentus***, which simultaneously exhibit high antioxidant activity, high nutrient density, and reduced energy density.

1. **MATERIAL AND METHODS**

**2.1. Organ sampling**

The organs of *Corchorus olitorius* and *Abelmoschus esculentus* (leaf and fruit), which are commonly consumed, were harvested early in the morning in the Mboppi district, Douala 1er. Both plant matrices were identified by the Cameroon herbarium:

* *Corchorus olitorius*: The specimen was identified by comparison with the herbarium material of Westphal collector 10077 from herbarium collection specimen number 44871 SRFCam.
* *Abelmoschus esculentus*: The specimen was identified in comparison with the herbarium material of Westphal collector 9069 from Herbarium collection specimen number 42868 SRFCam.

**2.2. Powder production**

Fresh, dark-green leaves and fresh, tender fruits (with seeds) were cleaned, washed, and cut into pieces smaller than 5 mm. The samples were dried at 30 and 35 °C for 5 and 10 hours, respectively, in a Stockli dehydrator, Dorrex, France. The dehydrated materials were ground to a particle size smaller than 500 µm (the particle size of the powders most commonly used by therapists), and the resulting powders were stored in opaque, airtight boxes at room temperature.

**2.3. Determination of powder moisture content**

The moisture content of the plant powders was determined according to the Association of Official Analytical Chemists method (AOAC, 2011).

**2.4. Determination of the nutrient content of powders**

**2.4.1. Mineral contents**

The mineral contents (Cu, Zn, Mn, Fe, Ca, Mg, K, and Na) of the plant powders were determined according to the Harborne (1998) method.

**2.4.2. Available carbohydrates**

The available carbohydrates were determined according to the Fischer & Stein (1961) method.

**2.4.3. Total lipids**

The total lipid content was determined using the hot extraction method in a Soxhlet apparatus, as described by Bourely (1982). The dried powders, obtained by drying at 105 °C, were placed on numbered filter papers, dried, and weighed. Oil extraction was carried out using hexane in the Soxhlet apparatus for 12 h. The oil content was calculated relative to the dry matter by the weight difference of the sachet before and after complete lipid extraction. The oil content (TL) per 100 g of dry powder is given by the following formula:

TL = [(M1 − M) / (M1 − M2)] ∗ 100

**2.4.4. Total protein and ash**

The total protein content was determined by the Kjeldahl method (AOAC, 1999). The total ash content was determined after incineration of the powders according to the protocol described by the AOAC (1999).

**2.5. Crude fibers**

The crude fiber content of the powders was evaluated using the Weende (Wolff, 1968) method.

**2.6. Determination of the bioactive compounds of powders**

**2.6.1. Phytochemical screening**

This analysis was carried out to identify the presence of classes of bioactive compounds contained in the powders. These include alkaloids, polyphenols, flavonoids, tannins, sterols, triterpenes, saponins, quinones, and anthraquinones. Qualitative analysis was carried out according to standard procedures (Harborne, 1998; Senizza et al., 2021).

**2.6.2. Preparation of extracts**

The method used for extraction followed that of Senizza et al. (2021). Maceration was employed as the extraction technique. The powders were extracted using methanol (at a ratio of 1:2, mass to volume) for 48 hours at room temperature. Methanol was chosen as the extraction solvent due to its reported effectiveness in extracting phytochemicals and antioxidants as noted by Ramamurthy et al. (2012). After extraction, the samples were filtered through Whatman No. 1 filter paper. The filtered extracts were then dried at 40 °C using a rotary evaporator for 30 minutes. All extracts were stored in amber glass bottles at room temperature to prevent light-induced effects.

**2.6.3. Bioactive compounds**

**2.6.3.1. Total polyphenols**

The total polyphenol content was determined according to the method of Makkar et al. (2007) with some modifications. An extract (100 μl) was mixed with 200 μl of Folin-Ciocalteu reagent (diluted ten times) and 200 μl of 7.5% sodium carbonate (w/v). The mixture was vortexed and incubated in the dark at room temperature for ten minutes. Approximately 1000 μl of distilled water was added and the mixture was then vortexed. The absorbance was measured at 760 nm using a spectrophotometer (BK-UV1600 PC visible spectrometer, China). Total polyphenol contents were calculated against a calibration curve established using gallic acid as a standard and expressed in milligram gallic acid equivalent per gram of dry matter (mg GAE/g DM).

* + - 1. **Total flavonoids**

Total flavonoid contents were determined according to Chang et al. (2002) with slight modifications. An extract (500 μl) was mixed with 500 μl of freshly prepared aluminum chloride solution (2% w/v). The mixture was incubated in the dark at room temperature for fifteen minutes. The absorbance was measured at 430 nm using a spectrophotometer (BK-UV1600 PC visible spectrometer, China). Total flavonoid contents were calculated against a calibration curve and expressed in milligrams quercetin equivalent per gram of dry matter (mg QE/g DM).

* + - 1. **Condensed tannins**

Condensed tannin contents were evaluated using the modified method of Ogboru et al. (2015). To 50 μl of extract, 3 ml of 4% (w/v) vanillin in methanol (80%) was added. This was followed by the addition of 750 μl of concentrated hydrochloric acid and vortexing. The mixture was incubated at 30 ˚C for 20 min. The absorbance was read at 550 nm by UV/visible spectrophotometry (BK-UV1600 PC visible spectrometer, China) against the hydromethanolic solvent (70/30) as a blank. Tannin contents were calculated from a standard curve prepared using a standard solution of catechin (0.2 g/l). The results were expressed as milligrams catechin equivalent per gram of dry matter (mg CE/g DM).

**2.7. Determination of antioxidant activities**

**2.7.1. 2,2-Diphenyl-1-picrylhydrazyl (DPPH) Radical Scavenging Activity Assay**

The radical-scavenging activity was determined according to the method of Ramamurthy et al. (2012). The extract (0.3 ml) was mixed with 2.7 ml of 0.5 mM methanolic 1,1-diphenyl-2-picrylhydrazyl (DPPH). The reaction mixture was incubated at 37 °C for 30 min, and the absorbance was measured spectrophotometrically at 517 nm. The radical-scavenging activity (IC50) of the extract, expressed in µg/ml, required to reduce the total free DPPH radical by 50% was determined based on the percentage inhibition of DPPH (discoloration). This assessment was performed using the following equation:

$$ \% Inhibition DPPH=[(A\_{DPPH}-A\_{S})/A\_{DPPH}] x 100$$

where AS is the absorbance of the DPPH solution with sample extract and ADPPH is the absorbance of the DPPH solution without extract. Ascorbic acid was used as a standard.

**2.7.2. 2,2′-Azinobis-(3-ethylbenzothiazoline-6-sulphonic acid) (ABTS) Radical Scavenging Activity Assay**

The procedure followed the method reported by Galla et al. (2017) with some modifications. The ABTS+ radical was generated by reacting 7 mM ABTS+ and 2.45 mM potassium persulphate (K2S2O8). After incubation at room temperature in the dark for 16 h, the solution was diluted to obtain an absorbance of 0.70 ± 0.02 at 734 nm. The ABTS+ solution (1 ml) was added to the extract (10 µl), mixed thoroughly, and incubated for 30 min. The absorbance of the reactive mixture was measured at 734 nm. Ascorbic acid (vitamin C) was used as the standard. The **radical scavenging activity (IC50)** of the extract, expressed in µg/ml, required to reduce the total free ABTS radical by 50% was determined based on the percentage inhibition of ABTS using the following equation:

$$\% Inhibition ABTS=[(A\_{ABTS}-A\_{S})/A\_{ABTS}] x 100$$

where AS is the absorbance of the ABTS solution with sample extract and AABTS is the absorbance of the ABTS solution without extract.

**2.7.3. Ferric reducing antioxidant power (FRAP) assay**

The reducing power of the iron (Fe3+) extracts was determined according to the method described by Padmaja et al. (2011) with some modifications. Approximately 25 µl of each diluted extract (2 mg/ml in methanol) was introduced into a new microplate, and 25 µl of 1.2 mg/ml Fe3+ solution was added. The plates were preincubated for 15 minutes at room temperature. Subsequently, 50 µl of 0.2% ortho-phenanthroline was added to obtain final extract concentrations of 250, 125, 62.5, 31.25, 15.625, 7.8125, 3.90625, and 1.95325 µg/ml. The reaction mixtures were further incubated for 15 min at room temperature, after which the absorbance was measured at 505 nm under a UV/visible light spectrophotometer (Infinite M200 TECAN, Swiss) against a blank (made of 25 µl of methanol + 25 µl of Fe3+ + 50 µl of ortho-phenanthroline). Ascorbic acid (vitamin C) was used as the positive control. From the obtained optical density, reducing percentages were calculated for each concentration and used to determine the RC50 (expressed in µg/ml) from dose-response curves.

**2.9. Statistical analysis**

Analyses were carried out in triplicate. Microsoft Excel 2016 software was used for the calculation of means and standard deviations. Statgraphic Centurion 15.2 software (StatPoint Technologies, Inc., Warrenton, Virginia, USA) was used for analysis of variance (one-way ANOVA and multiple way ANOVA) and the means were separated using the Duncan multiple range test at P < .05.

1. **RESULTS AND DISCUSSION**

**3.1. Moisture content of leaf and fruit powders**

Table 2 presents the moisture contents of the leaves and fruit powders of *Corchorus olitorius* and *Abelmoschus esculentus*. The moisture content varied significantly, ranging from 5.36 ± 0.01 to 12.45 ± 0.18 g/100 g DM. These values indicate that the dehydration process effectively reduced the free water content in the leaves and fruits to levels below the permissible limit (15 g /100 g DM) (Rodríguez-Miranda et al., 2011). Water serves as a solvent that promotes the growth of food spoilage microorganisms. A high-water content in fruits and vegetables increases their water activity, thereby enhancing their perishability. The observed reduction in water content thus ensures that the powders can be stored for extended periods. Additionally, the moisture contents obtained in this study were also utilized to calculate the contents of other compounds in the powders on a dry basis. Comparable results (8.00 to 13.5 g/100 g DM) were reported by Assiéné et al. (2015) for leafy vegetables from various localities in Cameroon.

Table 2: Nutrient contents of the leaves and fruit powders of *Corchorus olitorius* and *Abelmoschus esculentus*

|  |  |  |
| --- | --- | --- |
| **Nutrients** |  *Corchorus olitorius*  |  *Abelmoschus esculentus* |
| Leave | Fruit | Leave | Fruit |
| **Proximate composition (g/100 g DM) and Energy (Kcal/100 g DM)** |
| Moisture content  | 5.36 ± 0.01a | 8.53 ± 0.04b | 9.08 ± 0.03c | 12.45 ± 0.18d |
| Total protein  | 20.63 ± 0.10d | 10.42 ± 0.20a | 18.87 ± 0.10c | 15.52 ± 0.30b |
| Available carbohydrate  | 31.11 ± 0.16a | 56.71 ± 0.40c | 43.75 ± 0.30b | 57.35 ± 0.80c |
| Total lipid | 5.29 ± 0.01c | 1.81 ± 0.01a | 7.64 ± 0.03d | 2.70 ± 0.01b |
| Total ash  | 9.38 ± 0.20b | 12.95 ± 0.10c | 15.22 ± 0.10d | 7.61 ± 0.10a |
| Crude fiber  | 9.52 ± 0.20b | 13.04 ± 0.30d | 10.34 ± 0.20c | 7.26 ± 0.20a |
| Energy  | 254.57 ± 1.13a | 284.81 ± 2.49b | 319.24 ± 1.87c | 315.78 ± 4.49c |
| **Mineral content (mg/100 g DM)** |
| Iron (Fe) | 0.96 ± 0.01a | 0.96 ± 0.01a | 0.96 ± 0.01a | 1.29 ± 0.01b |
| Zinc (Zn) | 0.93 ± 0.01a | 0.93 ± 0.01a | 0.93 ± 0.01a | 2.70 ± 0.02b |
| Copper (Cu) | 19.45 ± 0.20d  | 5.80 ± 0.02b | 3.08 ± 0.01a | 11.24 ± 0.20c |
| Calcium (Ca) | 1760.00 ± 3.20c | 1280.00 ± 2.30b | 1120.00 ± 2.03a | 1760.00 ± 3.03c |
| Magnesium (Mg) | 165.24 ± 1.30c | 9.72 ± 0.15a | 58.32 ± 1.19b | 257.58 ± 2.34d |
| Phosphorus (P) | 300.31 ± 3.98c | 6.30 ± 0.20a | 36.16 ± 1.34b | 302.57 ± 1.28c |
| Potassium (K) | 2466.43 ± 3.23c | 1866.53 ± 3.40b | 1139.32 ± 1.23a | 2684.62 ± 2.43d |
| Sodium (Na) | 142.20 ± 1.23c | 110.39 ± 2.01b | 73.92 ± 1.08a | 153.63 ± 2.78d |
| Mn ± Sd: Mean ± Standard deviation; Means affected to the different superscript letters for each line indicate a significant difference at P < .05 |

**3.1. Nutritional potential of leaf and fruit powders**

**3.1.1. Proximate composition and energy intake**

The macronutrient contents, as shown in Table 2, varied significantly among the different organs. *C. olitorius* had the highest protein content in its leaves (20.63 ± 0.10 g/100 g DM) and highest fiber content in its fruits (13.04 ± 0.30 g/100 g DM). *A. esculentus* had the highest total lipid content (7.64 ± 0.03 g/100 g DM) and total ash content (15.22 ± 0.10 g/100 g DM) in the leaves. The fruits of both plants had the highest available sugar content, at 56.71 ± 0.40 g/100 g DM for *C. olitorius* and 57.35 ± 0.80 g/100 g DM for *A. esculentus*. These results indicate that the leaves and fruits of *C. olitorius* and *A. esculentus* are significant sources of sugars, followed by protein and fiber. Their energy intake ranged from 254.57 ± 1.13 to 319.24 ± 1.87 kcal. Similar results have been reported by several authors for the leaves and fruits of these two plants (Islam, 2013; Gemede et al., 2015). However, slight differences in the order of importance of these different compounds (sugars, fibers, and proteins) have been observed by other authors (Bawa & Badrie, 2016; Sha’a et al., 2019). This can be attributed to various factors, such as the soil and climate conditions specific to each plant, and the methods used to analyze the plant organs studied. As shown in Table 2, fruits may be more recommended for their high energy potential, as shown by Stadlmayr et al. (2013) and Vincente et al. (2014), compared with leaves, which may be recommended for their high protein potential, as shown by Tchiégang & Aissatou (2004). On the other hand, the significant differences observed in crude fiber content should not prevent leaves and fruits from being appreciated by consumers, given their health benefits (ballast food, satietogenic power, lipase and sucrase trapping) (Wang et al., 2016).

Given that the leaves and fruits of *C. olitorius* *and A. esculentus* are recommended for the fight against chronic diseases and numerous other pathologies (type 2 diabetes, obesity, cancer, colic, dysentery etc.) (Islam, 2013; Gemede et al., 2015; Bawa & Badrie, 2016) the total lipid content of the leaves (5.29 ± 0.01 and 7.64 ± 0.03 g/100 g DM), which is higher than that of the fruit (1.81 ± 0.01 and 2.70 ± 0.01 g/100 g DM, respectively), cannot be overlooked. This can significantly increase the energy value of the two organs studied. Similar contents (1.38 to 7.01 g.100 g DM) were reported by Tchiégang & Aissatou (2004) for several leafy vegetables grown and commonly consumed in Cameroon. The same observation applies to total ash content. In fact, ash indicates the mineral content of leaves and fruit (Table 2). The values obtained in this study were high (7.61 ± 0.10 to 15.22 ± 0.10 g/100 g DM), particularly in *C. olitorius* fruits (12.95 ± 0.10 g/100 g DM) and *A. esculentus* leaves (15.22 ± 0.10 g.100 g DM). Therefore, they should not be neglected when assessing the nutrient density of the organs of these two plants. These results are lower than those reported by Hussain et al. (2020) for *C. olitorius* fruits (2.45 ± 0.09 g/100 g DM) and similar to those reported by Sha’a et al. (2019) for *A. esculentus* leaves (15.00 ± 0.11g/100 g DM). The observed differences between these ash contents could be due to the nature of the soil, the relief of the area where the two plants are grown, the climate, and the post-harvest treatments applied to the leaves and fruit.

* + 1. **Mineral content**
			1. **Trace elements**

The contents of trace elements (iron, zinc, and copper) in the leaves and fruits of *C. olitorius* and *A. esculentus* are presented in Table 2. The iron contents ranged from 0.96 ± 0.01 to 1.29 ± 0.01 mg/100 g DM, zinc from 0.93 ± 0.01 to 2.70 ± 0.02 mg/100 g DM, and copper from 3.08 ± 0.01 to 19.45 ± 0.20 mg/100 g DM. These results demonstrate that, regardless of the organ studied, copper is the most abundant trace element. The copper content was highest in *C. olitorius* leaves (19.45 ± 0.20 mg/100 g DM) and *A. esculentus* fruits (11.24 ± 0.20 mg/100 g DM). These contents significantly exceeded those reported by Adesina et al. (2022) (0.006 mg/100 g DM) and Romdhane et al. (2020) (0.56 g/100 g DM), respectively. The observed differences between the copper contents obtained in this study and those of these different authors may be attributed to the variety of plants, the nature of the soil, and the methods of analysis. Copper is an essential trace element for humans and animals (Klevay, 2022). The human body contains approximately 100 mg, which is only required in trace amounts. In addition to its role in iron metabolism, the need for copper also stems from its involvement in a myriad of biological processes, including antioxidant defense, neuropeptide synthesis, and immune function (Bost et al., 2016).

Like those of copper, the iron and zinc contents obtained in this study should not be overlooked. The contents were highest in *A. esculentus* fruits, at 1.29 ± 0.01 and 2.70 ± 0.02 mg/100 g DM, respectively. Similar values for iron (1.95 mg/100 g DM) and zinc (2.44 mg/100 g DM) were reported by Romdhane et al. (2020) for *A. esculentus* fruits. These two trace elements are essential minerals in many of the body’s biochemical mechanisms. For instance, the body requires iron for the synthesis of oxygen transport proteins, particularly hemoglobin and myoglobin, and for the formation of heme enzymes and other iron-containing enzymes involved in electron transfer and redox reactions (Abbaspour et al., 2014). Zinc is used to treat and prevent diarrhea in infants and children. It is an important activator of more than 300 enzymes and is involved in protein synthesis (Prasad, 2014). Although the bioaccessibility of these trace elements is generally limited, as reported by several authors (Assiéné et al., 2020), their intake in milligrams (approximately 5%) remains significant in covering the recommended daily intake.

* + - 1. **Macro elements**

The macroelements (Ca, Mg, P, K, and Na) in the organs of the two plants studied were most abundant in *A. esculentus* fruits (Table 2). The values are 1760.00 ± 3.03 mg/100 g DM for calcium, 257.58 ± 2.34 mg/100 g DM for magnesium, 302.57 ± 1.28 mg/100 g DM for phosphorus, 2684.62 ± 2.43 mg/100g DM for potassium, and 153.63 ± 2.78 mg/100 g DM for sodium. Calcium and potassium are the two most abundant elements. There values significantly exceeded the 324.78 and 411.47 mg/100 g DM reported by Romdhane et al. (2020) for *A. esculentus* fruits, respectively. The same authors also reported lower contents of magnesium (124 mg/100g DM) and similar contents of sodium (155.06 mg/100g DM). Gemede et al. (2015) reported a lower phosphorus content of 101.58 mg/100 g DM. The observed differences between the macroelement values obtained in this study and those of other authors can be attributed to the effects of growing conditions on plant development (chemical and natural fertilizers, soil type, etc.), the relief of the area where the two plants are grown, season, post-harvest treatments, and the precision of the analytical methods.

These results also demonstrate that the leaves and fruits of *C. olitorius* and *A. esculentus* are significant sources of macroelements. This observation is supported by the ranges of values obtained, notably, 1120.00 ± 2.00 to 1760.00 ± 3.03 mg/100 g DM for calcium; 9.72 ± 0.15 to 257.58 ± 2.34 mg/100 g DM for magnesium; 6.30 ± 0.20 to 302.57 ± 1.28 mg/100g DM for phosphorus; 1139.32 ± 1.23 to 2684.62 ± 2.43 g/100 g DM for potassium; and 73.92 ± 1.08 to 153.63 ± 2.78 g/100 g DM for sodium. These factors contribute significantly to meeting consumers’ daily intake. In fact, regular consumption of these leaves and fruits, as reported by several authors (Gemede et al., 2015; Romdhane et al., 2020), is a major asset in the fight against micronutrient deficiencies. Indeed, these various elements play important roles in the body. Calcium is essential for muscle contraction, oocyte activation, the formation of strong bones and teeth, blood coagulation, etc. (Pravina et al., 2013). Magnesium is an essential cofactor for various metabolic reactions involving more than 300 enzymes in the human body (Alawi et al., 2018). Phosphorus plays an important role in energy metabolism (ATP, GTP, ADP, and GDP), acid base balance, and intracellular cell signaling (A. R. Chang & Anderson, 2017). Potassium is the most abundant cation in intracellular fluid, where it plays a key role in maintaining cellular functions (Stone et al., 2016). Sodium is essential for cellular homeostasis and physiological function (Farquhar et al., 2015).

In light of the above, it is clear that the leaves and fruits of *C. olitorius* and *A. esculentus* have significant nutritional potential. They should certainly make a significant contribution to meeting the nutrient requirements of the populations in which they occupy a prominent place in the diet. According to several authors (Abdel-Razek et al., 2022; Islam, 2013), the potential benefits observed in the consumption of these two organs are not limited to nutritional levels.

* 1. **Bioactive potential of leaf and fruit powders**
		1. **Identification of the bioactive compound groups**

Phytochemical screening of *C. olitorius* and *A. esculentus* leaves and fruit powders revealed a range of bioactive compound groups (Table 3). These include alkaloids, polyphenols, flavonoids, tannins, sterols, triterpenes, saponins, quinones and anthraquinones. These bioactive compounds are secondary metabolites. They are a group of compounds synthesized by plants in response to external aggression (Guerriero et al., 2018). The extent of stress or aggression certainly affects the intensity of each group of compounds, and may explain the great variability of their presence in the leaves and fruit studied. Quinones and anthraquinones are absent in *C. olitorius* fruits and *A. esculentus* leaves and fruits and are moderately present in *C. olitorius* leaves. Other compounds such as alkaloids, sterols, triterpenes and saponins are moderately abundant in the leaves and fruits of both plants. Polyphenols are present at high and moderate levels in the fruits of both plants and the leaves of *A. esculentus*, respectively. However, in *C. olitorius* leaves, this group of compounds was more abundant. Flavonoids are present in the organs of both plants. However, they are highly abundant in *A. esculentus* fruits. The same observation was made for tannins. However, they are highly abundant in *C. olitorius* leaves. Many authors reported similar results on the presence of different bioactive compounds in the leaves and fruits of the two plants (Borokini et al., 2022). Another study reported that each group of compounds possesses important bioactive activities with beneficial health effects (Bawa & Badrie, 2016).

Alkaloids are a group of compounds known for their antimalarial, antimicrobial, antiviral and anti-inflammatory properties (Debnath et al., 2018). Polyphenols have antioxidant properties. These compounds can combat oxidative stress. Oxidative stress is a risk factor for the development of a number of diseases, including cardiovascular disease and hypertension (Ozcan et al., 2014). Flavonoids are polyphenols. Some of these compounds are known for their anticancer, antiviral and antimicrobial properties (Prithvira, 2019). Tannins are a subclass of polyphenols and therefore possess the same biological activities as polyphenols. Sterols (phytosterols) are known for their cholesterol-lowering properties. Some sterols (beta-sitosterol) are used to treat benign prostatic hypertrophy (He et al., 2018). Triterpenes stand out for their anti-inflammatory and antimicrobial properties (Fang et al., 2020). Saponins have an expectorant effect and are also active against respiratory diseases such as coughs and bronchitis. Some saponins have antibacterial and antifungal properties with a broad spectrum of action (Fang et al., 2020). Quinones are used as antibiotics. Anthraquinones are laxatives and purgatives. They are also distinguished by their anticancer, anti-inflammatory, diuretic, antiarthritic, antifungal, antibacterial, and antimalarial properties (Diaz-Muñoz et al., 2018).

Table 3: Identification of some bioactive compounds in the leaves and fruit powders of *Corchorus olitorius* and *Abelmoschus esculentus*

|  |  |  |
| --- | --- | --- |
| **Bioactive compounds**  | *Corchorus olitorius* |  *Abelmoschus esculentus* |
| Leave | Fruit | Leave | Fruit |
| Alcaloïds | ++ | ++ | ++ | ++ |
| Polyphenols | **++++** | **+++** | **++** | **+++** |
| Flavonoïds | + | + | + | +++ |
| Tannins | +++ | + | + | + |
| Stérols | ++ | ++ | ++ | ++ |
| Triterpèns | ++ | ++ | ++ | ++ |
| Saponins | ++ | ++ | ++ | ++ |
| Quinones | ++ | - | - | - |
| Anthraquinones | ++ | - | - | - |
| - : Absence ; + : Presence ; ++ : Mean presence ; +++ : High presence; ++++ : Higher presence |

* + 1. **Quantification of polyphenols, flavonoids, and condensed tannins**

The bioactive compounds identified in the leaves and fruits of Corchorus olitorius and Abelmoschus esculentus, as presented in Table 3, allowed for qualitative identification of the most abundant compounds, including polyphenols, flavonoids, and tannins. The contents of these three compounds were determined and are presented in Table 4. Regardless of the studied organ, the total polyphenol content ranged from 4.28 ± 0.10 to 240.10 ± 1.99 mg GAE/g DM; the total flavonoid content ranged from 0.22 ± 0.01 to 15.03 ± 0.97 mg QE/g DM; and the condensed tannin content ranged from 0.15 ± 0.02 to 25.10 ± 1.05 mg CE/g DM.

Notably, the leaf powders of C. olitorius exhibited the highest contents of total polyphenols (240.10 ± 1.99 mg GAE/g DM) and condensed tannins (25.10 ± 1.05 mg CE/g DM). These values were nearly similar (total polyphenols: 244.18 mg GAE/g DM) and lower (condensed tannins: 95.08 mg CE/g DM) than those reported by Yan et al. (2013) for C. olitorius leaves. Compared to other leafy vegetables such as Solanum torvum, these results were significantly higher (polyphenols: 43.63 mg GAE/g DM; condensed tannins: 17.73 mg CE/g DM) than those reported by Assiéné, Djeukeu, Assiéné, Tize, et al. (2024). Additionally, the fruit powders of A. esculentus exhibited the highest total flavonoids content (15.03 ± 0.97 mg QE/g DM), surpassing the value reported by Olawuyi & Lee (2021) for A. esculentus fruits (4.10 mg RE/g DM). Compared with those of other leafy vegetables, such as Manihot esculentus (4.71 mg QE/g DM) and Ceiba pentandra (4.51 mg QE/g DM), these values were significantly higher (Raimi et al., 2014). The observed differences among these results can be attributed not only to the solvent used and the extraction method but also to various other factors, including biotic stress (fungi, insects, bacteria, weeds, etc.) and specific pedoclimatic conditions for each plant (Guerriero et al., 2018). These values indicate that the leaves and fruits of the studied plants are rich in bioactive compounds.

**Table 4: Polyphenol contents of leaf and fruit powders of *Corchorus olitorius* and *Abelmoschus esculentus***

|  |  |  |
| --- | --- | --- |
| Bioactive compounds | *Corchorus olitorius* |  *Abelmoschus esculentus* |
| Leave | Fruit | Leave | Fruit |
| Total polyphenols (mg GAE/g DM) | 240.10 ± 1.99d | 50.10 ± 1.02b | 4.28 ± 0.10a | 95.10 ± 1.04c |
| Total flavonoids (mg QE/g DM) | 0.50 ± 0.05b | 0.45 ± 0.01b | 0.22 ± 0.01a | 15.03 ± 0.97c |
| Condensed tannins (mg CE/g DM) | 25.10 ± 1.05c | 0.15 ± 0.02a | 0.17 ± 0.01a | 0.30 ± 0.01b |
| Mn ± Sd: Mean ± Standard deviation; Means affected to the different superscript letters for each line indicate a significant difference at P < .05 |

* + 1. **Antioxidant activity**

**Antioxidants** are molecules capable of inhibiting the oxidation of other molecules. In the context of food, an antioxidant is defined as any substance that, when present at a low concentration relative to that of an oxidizable substrate, significantly delays or inhibits the oxidation of that substrate. Antioxidant compounds can neutralize free radicals, including reactive oxygen species ($ROS$), superoxide ($O\_{2}^{. -}$), hydroxyl ($HO^{.}$), peroxyl ($ROO^{.}$), alkoxyl ($RO^{.}$), and nitric oxide ($NO^{.}$). By slowing the process of lipid peroxidation, which is a major cause of deterioration in food and pharmaceutical products during processing and storage (Gülçin, 2012), these antioxidant compounds can extend shelf life. Additionally, incorporating these antioxidants into the diet may help combat various chronic diseases, such as obesity, diabetes, and cardiovascular conditions. Given their central role in the diet of populations, the leaves and fruits of the two studied plants (*C. olitorius* and *A. esculentus*) are likely to be rich sources of antioxidant compounds.

**Fig. 1** illustrates that the powders derived from the leaves and fruits of C. olitorius exhibit **antioxidant activities** that significantly vary depending on the studied organ**.** The **inhibitory concentrations (IC50)** were as follows: **18.06 ± 1.04 µg/ml** for DPPH, **16.17 ± 1.35 µg/ml** for ABTS, and **22.52 ± 1.15 µg/ml** for FRAP. Notably, the leaves of C. olitorius displayed the most substantial antioxidant activities for DPPH (18.06 ± 1.04 µg/ml), ABTS (16.17 ± 1.35 µg/ml), and FRAP (22.52 ± 1.15 µg/ml), closely approaching those of the standard, which is vitamin C (8.92 ± 0.66 µg/ml for DPPH, 2.72 ± 0.80 µg/ml for ABTS, and 13.94 ± 0.70 µg/ml for FRAP). However, the inhibitory concentrations of the leaf extract responsible for the highest DPPH and ABTS antioxidant activities did not exhibit significant differences. These IC50 values are higher than those reported by Sadat et al. 2017) (75.41 µg/ml for DPPH) and Ben Yakoub et al. (2018) (500 µg/ml for FRAP) for ethanol extracts of C. olitorius leaves. Furthermore, these values are lower than those of the methanolic leaf extracts of M. sericea (13.26 ± 0.39 μg/ml for ABTS) reported by Khyade & Waman (2017). These observed differences may be attributed to the effects of the solvent type used during the extraction process from the studied organs (Mishra et al., 2012).

Similar to those of C. olitorius, the leaves and fruits of A. esculentus also exhibit **antioxidant activities** that significantly vary across different organs. The **inhibitory concentrations (IC50)** were as follows: **19.38 ± 1.52 µg/ml** for DPPH**, 47.04 ± 1.19 µg/ml** for ABTS, and **30.38 ± 2.07 µg/ml** for FRAP (**Fig. 1**). Interestingly, unlike those in C. olitorius leaves, the most substantial DPPH, ABTS, and FRAP antioxidant activities (11.07 ± 1.64, 18.04 ± 1.94, and 23.17 ± 1.35 µg/ml, respectively) were detected in the fruits of A. esculentus. These values closely resemble those of the standard molecule, vitamin C (8.92 ± 0.66 µg/ml for DPPH, 2.72 ± 0.80 µg/ml for ABTS, and 13.94 ± 0.70 µg/ml for FRAP). Notably, various authors reported lower IC50 values for methanolic extracts (1000 µg/ml for DPPH) (Ahmed & Kumar, 2016) and hydroethanolic extracts (890 µg/ml for FRAP) (Romdhane et al., 2020) from A. esculentus fruits. Although the solvent type should indeed be considered during the evaluation of these activities, it is not the sole factor responsible for the observed variations.

From the preceding analysis, it is evident that neither the solvent type used during extraction nor the specific plant organs studied serve as the primary determinants of the obtained antioxidant activities and the observed variations. Instead, the substantial diversity of bioactive compounds both in terms of quality and quantity (including nutrients and secondary metabolites), plays a pivotal role. Notably, the leaves of C. olitorius exhibited high contents of polyphenols and condensed tannins (Tables 3 and 4); and a high zinc content (Table 1). Conversely, the fruits of A. esculentus exhibited elevated values of polyphenols and flavonoids (Tables 3 and 4), along with notable zinc content (Table 1). The antioxidant properties of these bioactive molecules have been extensively investigated by numerous researchers (Prasad, 2014; Apak et al., 2016).

Phenols serve as effective electron donors due to their highly reactive hydroxyl group, which has the capacity to absorb free radicals $(ROS$, $O\_{2}^{. -}$, $HO^{.}$, $ROO^{.}$, $RO^{.}$, $NO^{.}$) (Apak et al., 2016). They can inhibit auto-oxidation and radical chain reactions by releasing hydrogen atoms. On the other hand, the resonance and non-localization properties of phenols lead to stable radical intermediates that lack suitable sites when attacked by dioxygen, resulting in new radical reactions or chains that can be rapidly oxidized (Ramamurthy et al., 2012). Notably, tannins specifically inhibit lipid peroxidation. Polyphenols possess electron-donating properties. This reducing property of tannins helps neutralize free radicals by forming stable products, effectively terminating radical chain reactions that can be detrimental to the organism (Gülçin et al., 2010). In contrast, flavonoids, with their diverse range, inhibit or slow oxidation processes generated by free radicals and reactive oxygen species (ROS) within the body (Jucá et al., 2020). Additionally, zinc, akin to flavonoids, acts as an inhibitor of NADPH oxidase, leading to reduced ROS generation. Zinc also serves as a cofactor for superoxide dismutase (SOD), an enzyme that catalyzes the dismutation of $O\_{2}^{. -}$ to H2O2. Furthermore, zinc induces the production of metallothionein, which is rich in cysteine and serves as an excellent detoxification agent for $HO^{.}$ (Prasad, 2014).

Fig. 1. Antioxidant activity of leaves and fruits of *Corchorus olitorius* and *Abelmoschus esculentus* (the lowercase letters assigned to the top of each bar, which are distinct for each plant matrix, indicate a significant difference at the probability threshold of **P < .05)**

1. **CONCLUSION**

The aim of this study was to determine the powders derived from the leaves and fruits of *Corchorus olitorius* and *Abelmoschus esculentus*, which simultaneously exhibit high antioxidant activity, high nutrient density, and reduced energy density. The powders from *C. olitorius* fruits and *A. esculentus* leaves exhibit high energy density (due to high available carbohydrate and total lipid content and maximum energy intake), low nutrient density, and high contents of total ash and crude fiber. These powders are primarily intended for patients seeking weight gain management. The powders from *C. olitorius* leaves exhibit moderate nutrient density (with elevated copper, calcium, phosphorus, and protein contents), low energy density, high total polyphenol and condensed tannin contents, and high antioxidant activity. These powders are prioritized for managing chronic diseases and addressing mineral and protein deficiencies. The powders from *A. esculentus* fruits exhibit high nutrient density (with elevated iron, zinc, magnesium, potassium, and sodium contents), reduced energy density, and high total flavonoid content and antioxidant activity. These powders are primarily intended for managing chronic diseases and mineral deficiencies. Only the powder from *A. esculentus* fruits exhibited high antioxidant activity, high nutrient density, and reduced energy density on average. It is more advisable than the other powders for meeting the needs of patients with chronic diseases, specifically those who are overweight or obese.

**DISCLAIMER (ARTIFICIAL INTELLIGENCE)**

Authors hereby declare that no generative AI technologies such as large language Models (ChatGPT, Copilot, etc.) and text to image generators have been used during the writing or editing of this manuscript.

**CONSENT AND ETHICAL APPROVAL**

It is not applicable

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**COMPETING INTERESTS**

Authors have declared that no competing interests exist

**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 original draft; **Assiéné Oyong Damase Serge**: Data analysis, Review original draft**; Nyangono Biyegue Fernande**: Supervision, Methodology, Review original draft

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