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RESEARCH ARTICLE

Carbohydrate and fibre fractions of the fruit of *Hyphaene coriacea* Gaertn.: compositional characterisation and potential nutritional interest

[version 1; peer review: 1 approved with reservations]

- NAZMOUL ¹, Hery RANDRIANATORO², Zo RANDRIAMAHATODY²,
Olga Rachel RAKOTOMANANA³, Danielle Aurore Doll RAKOTO¹

¹University of Antananarivo Faculty of Science, Antananarivo, Madagascar²Madagascar National Research Centre of the Environment, Antananarivo, Madagascar³National Centre for Applied Research of Rural Development, Antananarivo, Madagascar

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Abstract

Background

The fruit of *Hyphaene coriacea* Gaertn., consumed in Madagascar, remains poorly documented in compositional terms. This study aimed to characterise its main carbohydrate and fibre fractions in relation to their potential nutritional interest for glycaemic control.

Methods

Ripe fruits collected in Morondava in February 2021 were dried, ground and analysed on a dry matter basis. Total carbohydrates were calculated by difference. Total sugars, reducing sugars, sucrose and starch were determined using appropriate chemical methods. Crude fibre was measured by the Weende method and lignin was estimated by near-infrared spectroscopy (NIRS). Analyses were performed in triplicate.

Results

Total carbohydrates represented $87.80 \pm 1.44\%$ dry matter, including $53.59 \pm 3.09\%$ residual carbohydrate fraction. Total sugars were low ($3.91 \pm 0.00\%$), with no detectable reducing sugars. Sucrose reached $3.71 \pm 0.00\%$, starch $13.56 \pm 0.27\%$, crude fibre $34.21 \pm 1.66\%$, and estimated lignin $18.08 \pm 0.65\%$.

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1. **Eliana Bistrice Giuntini**, University of São Paulo, São Paulo, Brazil

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Conclusions

The fruit exhibits a low content of soluble sugars and a high proportion of structural constituents, suggesting potential nutritional interest for glycaemic control, which remains to be confirmed by biological and clinical studies.

Keywords

Hyphaene coriacea Gaertn., dietary fiber; carbohydrate fractions, carbohydrate digestibility, glycemic control, postprandial glycemia, diabetes, compositional analysis



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Corresponding author: - NAZMOUL (lnazmoul@gmail.com)

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1. Introduction

Carbohydrates are a major source of dietary energy, yet their metabolic effects differ according to their chemical structure, degree of polymerisation, and digestibility (Slavin, 2013a; Cummings and Stephen, 2007). In contrast to digestible carbohydrates, dietary fibres escape enzymatic digestion in the small intestine and reach the colon, where they may be partially fermented by the gut microbiota (Soliman, 2019). Owing to their physicochemical properties, dietary fibres are involved in several mechanisms that may influence the postprandial glycaemic response, notably delayed gastrointestinal transit, modulation of nutrient absorption, and improvement of metabolic control. Consistently, epidemiological and interventional data indicate that a high intake of dietary fibre is associated with improved glycaemic control and a reduced risk of type 2 diabetes (Reynolds et al., 2019; Weickert and Pfeiffer, 2018; Threapleton et al., 2013; Blaak et al., 2020).

The nutritional interest of carbohydrate-rich foods depends, however, not only on their total carbohydrate content, but also on the nature of the available sugars and their association with fibre fractions within the food matrix. Foods characterised by a low proportion of rapidly available sugars and a high proportion of cell wall components, such as cellulose and lignin, may be of particular interest in nutritional approaches aimed at attenuating the postprandial glycaemic response (Slavin, 2005; Dhingra et al., 2012; McRae, 2018). In this perspective, the combined characterisation of available carbohydrate fractions and fibrous constituents represents an important step in evaluating the nutritional potential of a plant-derived food.

Among still poorly documented plant resources, traditionally consumed palm fruits constitute a group of interest. Although several species are valued in local food systems, their detailed carbohydrate and fibre profiles often remain insufficiently characterised (Slavin, 2005; Wong and Jenkins, 2007). *Hyphaene coriacea* Gaertn. (Arecaceae) is consumed in several regions of Africa, including Madagascar, where the fruit is used fresh or in processed form, particularly as flour (Dransfield et al., 2008). Despite this food use, the main carbohydrate fractions and fibrous components of *H. coriacea* Gaertn. fruit have not been characterised comprehensively, which limits the objective assessment of its nutritional interest in the context of glycaemic control.

The present study was therefore undertaken to characterise the main carbohydrate and fibre fractions of the whole fruit of *H. coriacea* Gaertn. We hypothesised that this fruit would display a low content of rapidly available sugars together with a substantial proportion of structural fibre fractions, consistent with potential nutritional relevance in dietary approaches targeting glycaemic control. By providing original compositional data, this study aims to improve knowledge of the nutritional value of *H. coriacea* Gaertn. fruit and to establish an analytical basis for future investigations into its relevance in food-based strategies oriented towards glycaemic control.

2. Materials and methods

2.1. Plant material

Ripe fruits of *H. coriacea* Gaertn. were collected on 25 February 2021 in Morondava, Menabe region, Madagascar, in a coastal plain area (20°16'16.8" S; 44°18'26.5" E), corresponding to the period of maximum fruiting of the species. Sampling was performed from approximately ten palm trees growing naturally under comparable environmental conditions. Fruits were selected on the basis of external morphology and physiological maturity, including size, colour, ripening stage, and overall integrity. Fruits showing visible signs of mechanical damage, parasitic infestation, or pathological deterioration were excluded.

Botanical identification was established on the basis of diagnostic morphological characteristics and comparison with authenticated reference material. A voucher specimen (NZ 01) was prepared and deposited at the National Centre for Pharmaceutical Application and Research (CNARP), Antananarivo, Madagascar.

After collection, the fruits were transported to the laboratory for processing. Foreign matter and external debris were removed, and the plant material intended for analysis was rinsed with clean water. Samples were then shade-dried at ambient temperature (25 to 30 °C) for 30 days until constant weight was obtained, in order to reduce moisture content while limiting thermal degradation. The dried material was subsequently cut into small pieces, mechanically ground, and sieved to obtain a fine and homogeneous powder suitable for subsequent biochemical analyses.

The powder obtained from the whole fruits was thoroughly homogenised, accurately weighed, and divided into aliquots for the different analyses. Each aliquot was stored in a hermetically sealed container and labelled with the species name, plant material type, collection date, and sampling site to ensure traceability. Samples were maintained under controlled laboratory conditions, protected from light and moisture, until analysis.

2.2. Reagents

Unless otherwise stated, the chemical reagents used in this study were of analytical grade and were obtained mainly from Sigma-Aldrich, Prolabo, Merck, and Labosi. The amounts, concentrations, and operating conditions are provided in the relevant methodological sections. Owing to the partial unavailability of procurement records, some catalogue numbers could not be documented retrospectively in full.

2.3. Determination of total carbohydrate and residual carbohydrate fraction contents

2.3.1. Analytical principle

Total carbohydrate content was calculated by difference from proximate composition data. Because protein, lipid, and ash contents were expressed on a dry matter basis, total carbohydrates were estimated on the same basis as the residual fraction obtained after subtraction of these constituents from 100%. This value corresponds to total carbohydrates calculated by difference and includes the fibrous fraction. In accordance with international food composition frameworks, the interpretation of carbohydrates calculated by difference depends on the analytical definition of fibre used. In order to obtain an operational indicator of the carbohydrate fraction not accounted for by crude fibre, the crude fibre value was subtracted from total carbohydrates. However, because crude fibre does not measure all dietary fibre and is not equivalent to total dietary fibre, this value was interpreted only as an approximate estimate of the carbohydrate fraction not included in crude fibre, and not as a formal measure of available carbohydrates (FAO, 2003).

2.3.2. Calculation procedure

The following equations were applied on a dry matter basis:

$$\text{Total carbohydrates (\%, DM)} = 100 - (\text{Proteins} + \text{Lipids} + \text{Ash})$$

$$\text{Residual carbohydrate fraction (\%, DM)} = \text{Total carbohydrates} - \text{Crude fibre}$$

The determinations of the other proximate constituents, namely moisture, total proteins, total lipids and ash, were performed independently according to standard analytical procedures for food composition.

2.4. Determination of total sugars, reducing sugars and sucrose contents

2.4.1. Analytical principle

Reducing sugars were determined by the Luff–Schoorl method, a classical iodometric titration method based on the reduction of copper (II) in alkaline medium by sugars bearing a free carbonyl group. After heating with the Luff–Schoorl reagent, the amount of residual unreduced copper was determined by iodometric titration with sodium thiosulfate, and reducing sugar content was obtained using the method's conversion tables and expressed as glucose equivalents. Total sugars were determined after acid hydrolysis of non-reducing sugars according to the same titrimetric principle. Sucrose content was calculated from the difference between total sugars after inversion and reducing sugars before inversion, using the conventional factor of 0.95 (AOAC, 2000b). It therefore represents an indirect estimate of sucrose rather than a direct measurement.

2.4.2. Procedure

2.4.2.1. Preparation of the solution

A 2.5 g sample was introduced into a 250 mL volumetric flask and treated with 200 mL of 40% (v/v) ethanol. The mixture was stirred for 1 h in order to extract soluble sugars. Clarification was then carried out by successive addition of 5 mL of Carrez I solution (zinc acetate and glacial acetic acid) and 5 mL of Carrez II solution (potassium ferrocyanide), with stirring for approximately 30 s after addition of Carrez I and 1 min after addition of Carrez II. The volume was then brought to the mark with 40% ethanol, the mixture was homogenised and filtered. Two hundred millilitres of the filtrate were taken and evaporated to approximately half volume in order to remove most of the ethanol. The residue was then transferred quantitatively into a 200 mL volumetric flask using hot water, cooled, brought to volume with distilled water, homogenised and filtered if necessary. The resulting solution was used for the determination of reducing sugars and, after inversion, total sugars.

2.4.2.2. Determination of reducing sugars

For the assay of reducing sugars, an aliquot of the prepared solution not exceeding 25 mL and containing less than 60 mg of reducing sugars expressed as glucose was taken. If necessary, the volume was adjusted to 25 mL with distilled water. The determination was then carried out according to the Luff–Schoorl method.

2.4.2.3. Determination of total sugars after inversion

For the determination of total sugars, 50 mL of the test solution were pipetted and transferred into a 100 mL volumetric flask. A few drops of methyl orange were added, and 4 N hydrochloric acid was introduced gradually, with continuous stirring, until a distinct red endpoint was reached. Subsequently, 15 mL of 0.1 N hydrochloric acid were added. The flask was placed in a boiling water bath for 30 min in order to perform inversion. After rapid cooling to approximately 20 °C, 15 mL of 0.1 N sodium hydroxide were added to neutralise the medium. The volume was made up to 100 mL with distilled water and homogenised. An aliquot not exceeding 25 mL and containing less than 60 mg of reducing sugars expressed as glucose was then taken; if necessary, it was adjusted to 25 mL with distilled water before assay by the Luff–Schoorl method.

2.4.2.4. Titration

The assay was carried out by introducing into a 300 mL Erlenmeyer flask 25 mL of Luff–Schoorl reagent and 25 mL of the clarified sugar solution originating either from the reducing sugar determination step or from the total sugar determination after inversion. Two pumice granules and 1 mL of 3-methylbutan-1-ol were added to regularise boiling and limit foaming. The mixture was brought to the boil in approximately 2 min, then maintained at boiling for 10 min under a reflux condenser. After immediate cooling under cold water and standing for approximately 5 min, 10 mL of 30% potassium iodide solution followed by 25 mL of 3 N sulfuric acid were added carefully. The liberated iodine was then titrated with 0.1 N sodium thiosulfate until a pale yellow colour was obtained; after addition of starch indicator, titration was continued to the endpoint.

A blank test was carried out under the same titration conditions, replacing the sample solution with 25 mL of distilled water, without a boiling step.

2.4.2.5. Calculation and expression of results

Reducing sugar and total sugar contents were determined from the difference between the volume of sodium thiosulfate used for the blank (V_b) and that used for the test sample (V_e), according to the following relationship:

$$\Delta V = V_b - V_e$$

The ΔV value was then converted, using the Luff–Schoorl conversion table, into an equivalent glucose mass expressed in milligrams. In accordance with the method, the results for reducing sugars and total sugars after inversion are first expressed as glucose.

Reducing sugar content, expressed as a percentage of the sample, was calculated according to the following general relationship:

$$\text{Reducing sugars (\%, expressed as glucose)} = (C \times V_0 \times D) / (10 \times M \times V_a)$$

Total sugars after inversion, expressed as a percentage of the sample, were calculated according to the following relationship:

$$\text{Total sugars (\%, expressed as glucose)} = (C' \times V_0 \times V_2 \times D) / (10 \times M \times V_1 \times V_a)$$

Where C is the glucose-equivalent mass (mg) corresponding to reducing sugars read from the Luff–Schoorl table, C' is the glucose-equivalent mass (mg) corresponding to total sugars after inversion, M is the sample mass (g), V_0 is the total volume of the extract, V_1 is the volume taken for inversion, V_2 is the final volume after inversion, V_a is the volume of solution subjected to assay, and D is any additional dilution factor.

Sucrose content was calculated as follows:

$$\text{Sucrose (\%)} = [\text{Total sugars (\%)} - \text{Reducing sugars (\%)}] \times 0.95$$

Where 0.95 is the conventional conversion factor used to express as sucrose the increase in reducing sugars observed after inversion.

2.5. Determination of starch content

2.5.1. Analytical principle

Starch content was determined using the polarimetric method. This method is based on measuring the optical rotation generated by optically active carbohydrates released after acid hydrolysis of starch. Two polarimetric determinations were carried out: the first measured the total optical rotation of all soluble optically active compounds after hydrolysis, whereas the second quantified the optical rotation of substances soluble in 40% (v/v) ethanol and not attributable to starch. The difference between these two measurements, corrected using the specific optical rotation of starch, was used to estimate the starch content of the sample (AOAC, 2000a).

2.5.2. Procedure

2.5.2.1. Measurement of total optical rotation

A 2.5 g sample was treated with 25 mL of 3.6 N hydrochloric acid and heated in a boiling water bath for 15 min in order to hydrolyse starch and solubilise the hydrolysis products. After hydrolysis, the solution was clarified by successive addition of 5 mL of Carrez I reagent and 5 mL of Carrez II reagent, with stirring. Filtration was then performed. The filtrate was subsequently collected and brought to volume. The optical rotation of the clarified solution was measured using a polarimeter fitted with a 200 mm tube at a controlled temperature of 20 °C. The value obtained, denoted P, represents the total optical rotation of the soluble optically active substances present in the sample.

2.5.2.2. Measurement of the optical rotation of substances soluble in 40% ethanol

A 5 g sample was extracted with 80 mL of 40% (v/v) ethanol in order to solubilise optically active substances soluble in this medium. The extract was filtered, and 50 mL of the filtrate were taken and acidified with 10 mL of 3.6 N hydrochloric acid. The solution was heated in a boiling water bath for 15 min, then clarified by successive addition of 5 mL of Carrez I reagent and 5 mL of Carrez II reagent, with stirring. After mixing, filtration was carried out. The filtrate was then collected and brought to volume. The optical rotation of the solution was measured under the same conditions as for the first determination. The value obtained, denoted P', represents the contribution of substances soluble in 40% ethanol.

2.5.2.3. Calculation and expression of results

Starch content was calculated according to the following equation:

$$\text{Starch content (\%)} = [2000 (P - P')]/[\alpha]D_{20}^{\circ}$$

Where 2000 is the conversion factor applied under the conditions of the method, P is the total optical rotation, P' is the optical rotation of substances soluble in 40% (v/v) ethanol, and $[\alpha]D_{20}^{\circ}$ is the specific optical rotation of starch, taken as 184°.

2.6. Determination of crude fibre content

2.6.1. Analytical principle

Crude fibre content was determined by the Weende method, a classical gravimetric method used in proximate analysis of plant materials. In this approach, the sample is subjected to successive acid and alkaline hydrolyses in order to eliminate soluble constituents, notably sugars, starch, proteins and part of the hemicellulosic fraction. The resulting insoluble residue, consisting mainly of cellulose, lignin and other associated insoluble structural compounds, is then dried, weighed, incinerated and weighed again. Crude fibre content is calculated from the loss in mass observed during incineration of the dried residue (AOAC, 2000c).

2.6.2. Procedure

2.6.2.1. Acid hydrolysis

A 3 g test portion was mixed with 200 mL of 0.26 N sulfuric acid solution. The suspension was heated under reflux for 30 min in order to solubilise acid-labile constituents. After hydrolysis, the mixture was vacuum-filtered through a fritted

glass filter of porosity No. 1, previously prepared with a thin layer of sand. The residue was washed with hot distilled water until complete elimination of residual acid.

2.6.2.2. Alkaline hydrolysis

The insoluble residue obtained after acid hydrolysis was quantitatively transferred to a clean vessel and treated with 200 mL of 0.23 N potassium hydroxide solution. A few drops of antifoaming agent were added, then the mixture was rapidly brought to the boil and maintained under reflux for 30 min. After alkaline digestion, the suspension was vacuum-filtered through the same fritted glass filter. The residue was washed several times with hot distilled water until neutral pH was obtained, then rinsed with 25 to 30 mL of acetone to facilitate drying.

2.6.2.3. Drying and ashing

The residue was transferred into a dried and weighed crucible. The assembly was placed in an oven at 103 °C until constant mass. After cooling in a desiccator, the crucible was weighed and the obtained mass was denoted X1. The crucible was then placed in a muffle furnace at 550 °C for 3 h in order to incinerate the residual organic matter. After cooling in a desiccator, it was weighed again and the obtained mass was denoted X2.

2.6.2.4. Calculation and expression of results

Crude fibre content was calculated according to the following equation:

$$\text{Crude fibre content (\%)} = [(X1 - X2)/m] \times 100$$

Where X1 represents the mass (g) of the crucible and residue after oven-drying at 103 °C to constant mass, X2 represents the mass (g) of the crucible and residue after ashing at 550 °C, and m represents the mass (g) of the initial sample, excluding the crucible, before any treatment.

2.7. Estimation of lignin content

2.7.1. Analytical principle

Lignin content was estimated by near-infrared spectroscopy (NIRS), a rapid and non-destructive analytical technique based on absorption of near-infrared radiation by vibrational overtones and molecular combination bands, mainly associated with C–H, O–H and N–H functional groups. In plant matrices, NIRS can be used to predict certain structural constituents when spectral data are interpreted using chemometric calibration models established from reference analytical methods. In the present study, lignin values were therefore obtained as NIRS-predicted estimates and not by direct chemical determination (Blanco and Villarroya, 2002; Archibald and Kays, 2000).

2.7.2. Operating procedure

A finely ground and homogeneous sample was prepared in order to improve reproducibility and stability of acquisition. Spectral measurements were carried out using a near-infrared spectrometer operating over a wavelength range of 1100 to 2500 nm. The recorded spectra were processed using the instrument's internal chemometric algorithms and interpreted on the basis of a pre-existing calibration database established from reference analytical procedures, including AOAC-based methods (AOAC, 2002) as well as the modified Van Soest method (Goering and Van Soest, 1970). Lignin content was subsequently predicted from the calibration model selected by the system on the basis of the available performance indicators, notably the coefficient of determination (R^2), the root mean square error of prediction, and the distribution of residuals.

2.8. Calculation and interpretation of carbohydrate-to-fibre ratios

In order to provide an integrated description of the balance between carbohydrate fractions and structural fibres, several ratios related to carbohydrate composition and likely to assist in interpreting the potential effect of fibre on glycaemic regulation were considered (Jenkins and Jenkins, 1985; Morimoto et al., 2018). Each ratio was calculated as the quotient of the mean value of the numerator by the mean value of the corresponding denominator. These ratios were used as descriptive compositional indices intended to facilitate interpretation of the relative predominance of structural fibres over rapidly available carbohydrate fractions.

2.9. Descriptive estimation of the energy contribution of the carbohydrate fraction

The energy contribution of the carbohydrate fraction was considered descriptively on a dry matter basis. However, total carbohydrates determined by difference include the fibrous fraction; consequently, direct application of the general

Atwater factor of 4 kcal/g to this value does not strictly correspond to the energy of available carbohydrates (Atwater and Bryant, 1900; Merrill and Watt, 1973). Accordingly, the energy estimate was interpreted cautiously as a theoretical value for the overall carbohydrate fraction rather than as a direct measure of metabolisable energy attributable exclusively to digestible carbohydrates. Conversion to kilojoules was performed using the standard factor 1 kcal = 4.184 kJ. This approach was used only to provide an additional descriptive reference for interpretation of the compositional profile.

The calculation was performed as follows:

$$\text{Theoretical energy of the total carbohydrate fraction (kcal/100 g DM)} = \text{Total carbohydrates} \times 4$$

$$\text{Theoretical energy of the total carbohydrate fraction (kJ/100 g DM)} = \text{Energy (kcal/100 g DM)} \times 4.184$$

When an approximation of the non-fibrous carbohydrate fraction was considered, it could only be regarded as indicative, based on the residual carbohydrate fraction obtained by subtracting crude fibre from total carbohydrates. This value was, however, interpreted only as a descriptive index, since crude fibre is not equivalent to total dietary fibre.

2.10. Data processing and analysis

Analytical results were expressed as mean $\pm$ standard deviation (SD) of three repeated determinations. Coefficients of variation (CV, %) and 95% confidence intervals were calculated for descriptive purposes. Data processing and statistical calculations were performed using XLSTAT software, version 2014. Given the limited number of replicates, statistical treatment was restricted to descriptive analysis.

3. Results

The results relating to the carbohydrate composition, crude fibre and lignin contents, derived carbohydrate-to-fibre ratios, and the estimated theoretical energy contribution of the carbohydrate fraction of *H. coriacea* Gaertn. fruit are presented below.

3.1. Carbohydrate composition

Table 1 presents the contents of the main carbohydrate fractions of *H. coriacea* Gaertn. fruit, expressed on a dry matter basis.

3.2. Fibre composition

Table 2 presents the crude fibre and lignin contents of *H. coriacea* Gaertn. fruit, expressed on a dry matter basis.

3.3. Estimated theoretical energy contribution of the total carbohydrate fraction

The estimated theoretical energy contribution of the total carbohydrate fraction was 351.20 kcal/100 g dry matter, equivalent to 1469.42 kJ/100 g dry matter.

3.4. Carbohydrate ratios

The derived ratios related to carbohydrate composition are presented in Table 3.

3.5. Fibre-to-carbohydrate ratios

The ratios between fibre fractions and carbohydrates are presented in Table 4.

Table 1. Carbohydrate composition of *H. coriacea* Gaertn. fruit.

Analysed components	Mean $\pm$ SD (%)	Range	CV (%)	95% CI
Total carbohydrates	87.80 $\pm$ 1.44	86.28 to 89.14	1.64	84.23 to 91.38
Residual carbohydrate fraction	53.59 $\pm$ 3.09	50.41 to 56.59	5.77	45.91 to 61.28
Total sugars	3.91 $\pm$ 0.00	–	–	–
Reducing sugars	ND	–	–	–
Sucrose	3.71 $\pm$ 0.00	–	–	–
Starch	13.56 $\pm$ 0.27	13.29 to 13.83	1.99	12.89 to 14.23

Notes. SD, standard deviation; CV, coefficient of variation; CI, confidence interval; ND, not detected.

Table 2. Crude fibre and lignin contents of *H. coriacea* Gaertn. fruit.

Analysed components	Mean $\pm$ SD (%)	Range	CV (%)	95% CI
Crude fibre	34.21 $\pm$ 1.66	32.55 to 35.87	4.85	30.09 to 38.33
Lignin	18.08 $\pm$ 0.65	17.39 to 18.68	3.59	16.46 to 19.69

Notes. SD, standard deviation; CV, coefficient of variation; CI, confidence interval.

Table 3. Main ratios related to carbohydrate composition.

Ratios	Values
Residual carbohydrate fraction/Total carbohydrates	0.61
Total sugars/Residual carbohydrate fraction	0.07
Sucrose/Residual carbohydrate fraction	0.07
Starch/Residual carbohydrate fraction	0.25

Table 4. Main fibre-to-carbohydrate ratios.

Ratios	Values
Lignin/Residual carbohydrate fraction	0.34
Crude fibre/Residual carbohydrate fraction	0.64
Lignin/Total sugars	4.62
Crude fibre/Total sugars	8.75

4. Discussion

The fruit of *H. coriacea* Gaertn. exhibited a compositional profile dominated by total carbohydrates, within which starch constituted a notable identified fraction, whereas soluble sugars remained weakly represented. At the same time, crude fibre and estimated lignin reflected a plant matrix rich in structural constituents. Taken together, these findings describe a whole fruit with marked cell wall organisation. The physiological implications of this architecture, notably for carbohydrate digestibility and the postprandial glycaemic response, nevertheless require confirmation by dedicated functional studies.

Total carbohydrate content reached $87.80 \pm 1.44\%$ DM, a value higher than those reported for other species of the same genus. For comparison, the pulp of *Hyphaene thebaica* has been reported to contain lower carbohydrate levels, ranging from 68.47% (Datti et al., 2020) to 69.33% (Alagbe, 2024). Marked variation has also been described according to the anatomical part of the fruit analysed, with values of 72.5% in the flesh and 44.2% in the epicarp (Aboshora et al., 2014), whereas some analyses of the mesocarp have reported contents as high as 83.7% (Bello et al., 2021).

The residual carbohydrate fraction, estimated at $53.59 \pm 3.09\%$ DM, indicates that a substantial proportion of total carbohydrates is not accounted for by the crude fibre fraction. This estimate should, however, be interpreted with caution, since the crude fibre method reflects only a limited part of total dietary fibre. Consequently, the resulting value cannot be assimilated to a direct measure of available carbohydrates and may lead to overestimation of the fraction that is actually digestible and absorbable.

Overall, the carbohydrate values obtained for *H. coriacea* Gaertn. fall within the ranges reported for related palm species while also highlighting certain compositional specificities. The discrepancies observed across studies are probably attributable, to a large extent, to the nature of the plant fraction analysed. Most studies devoted to *H. thebaica* have focused on the pulp, generally richer in soluble carbohydrates, whereas the present study examined the whole fruit, including structural and partially lignified cell wall tissues. Additional sources of variation may also be invoked, notably fruit maturity stage, environmental conditions, genetic background, and the analytical approaches employed (Ullah et al., 2023; Rivera et al., 2016).

The combined profile of total carbohydrates and the residual carbohydrate fraction in *H. coriacea* Gaertn. fruit suggests a matrix dominated by structurally integrated carbohydrate fractions. The accessibility of these polysaccharides to digestive

enzymes may be limited by their incorporation into a dense plant matrix, which could contribute to slowing their hydrolysis and, potentially, attenuating the postprandial glycaemic response. This interpretation nevertheless remains indirect and is based on compositional rather than functional data. It remains, however, consistent with previous work describing the metabolic effects of complex carbohydrates and dietary fibre (Slavin, 2013b; Reynolds et al., 2019), as well as with nutritional recommendations favouring carbohydrate sources with a low glycaemic index (Jenkins et al., 2002).

The fruit displayed very low levels of soluble sugars, with total sugars reaching $3.91 \pm 0.00\%$ DM, no detectable reducing sugars, and sucrose accounting for $3.71 \pm 0.00\%$ DM, indicating a very limited contribution of simple sugars and the absence of detectable reducing sugars under the analytical conditions used. This result does not, however, allow the conclusion that free glucose or fructose are absolutely absent.

Available data indicate that *H. thebaica* contains higher levels of soluble sugars than those quantified in the present study. Farag and Paré (2013) showed that sucrose was the principal soluble sugar in *H. thebaica*, with concentrations reaching 219 mg g^{-1} . It has also been established that variation in free sugar content depends strongly on the anatomical fraction analysed, tissue organisation, and fruit maturity stage (Cakpo et al., 2020), which provides a plausible explanation for the lower values observed here, since the analysis was performed on the whole fruit rather than on the pulp alone. The high density of cell wall tissues, enriched in pectins, celluloses and hemicelluloses, is indeed known to limit solute diffusion and restrict the accessibility of intracellular sugars within the plant matrix (Voragen et al., 2009).

In palm species, sugar accumulation profiles are also influenced by fruit ripening, with simple sugar concentrations generally increasing during maturation, as reported in *Phoenix dactylifera* (Diboun et al., 2015). In addition, post-harvest treatments, particularly drying and storage, may induce quantitative or qualitative changes in free sugar composition. Methodological factors may likewise contribute to the discrepancies observed across studies, since colorimetric or titrimetric assays have more limited analytical specificity than chromatographic approaches, which allow more sensitive and selective characterisation of individual sugars (Nielsen, 2010).

Despite these low soluble sugar levels compared with *H. thebaica*, the values obtained in the present study remain consistent with the compositional characteristics of a whole fruit rich in cell wall-derived constituents and possibly corresponding to a distinct physiological stage (Seymour et al., 2013). Such structural organisation, dominated by cell wall polysaccharides and characterised by a low abundance of simple sugars, could contribute to limiting rapid postprandial increases in blood glucose. Although sucrose is a soluble disaccharide, its effective accessibility to digestive enzymes may be reduced when embedded within a dense plant matrix, which could delay its hydrolysis and the subsequent appearance of glucose in the circulation (Slavin, 2013b; Giuntini et al., 2022).

Consequently, the low simple sugar content measured in *H. coriacea* Gaertn. fruit suggests a potentially limited contribution to rapid glycaemic responses. Such a profile, comparable to that observed in foods naturally low in simple sugars, is generally associated with slower intestinal absorption kinetics (Beckles, 2012) and lower glycaemic potential (Reynolds et al., 2019).

Starch content in *H. coriacea* Gaertn. fruit reached $13.56 \pm 0.27\%$ DM, indicating that starch represents a substantial, although not predominant, fraction of total carbohydrates. In the absence of comparable starch data for other species of the genus *Hyphaene*, this value should above all be regarded as a compositional reference within palm fruits characterised by limited starch accumulation. Within the Arecaceae family, starch contents are indeed highly variable, with values reaching 80 to 90% DM in *Bactris gasipaes* (Alves et al., 2015; Rosário et al., 2025). By contrast, ripe fruits of *P. dactylifera* are largely dominated by soluble sugars and dietary fibre, with starch being virtually absent (Booij et al., 1992; Al-Karmadi and Okoh, 2024).

The starch content observed in *H. coriacea* Gaertn. fruit thus lies in the lower range of values reported for Arecaceae species and may reflect both the relatively high content of structural fibre in the whole fruit and differences related to analytical approaches (Ferrari et al., 2020). From a physiological perspective, starch generally persists at moderate levels in tissues at less advanced stages of maturation, whereas simple sugars become predominant at later ripening stages, a pattern frequently reported in Arecaceae fruits (Chandrasekaran and Bahkali, 2013).

The intermediate starch level observed in *H. coriacea* Gaertn. fruit probably reflects the combined influence of physiological and structural factors. Fruit developmental stage plays an important role, since starch accumulated during the early phases of growth is progressively converted into soluble sugars through activation of amylolytic enzymes during ripening (Li et al., 2021). In addition, the presence of a dense lignocellulosic matrix may reduce the accessibility of starch granules to extraction solvents and digestive enzymes, thus affecting both analytical recovery and hydrolysis rate (Hansen et al., 2013; Zhang et al., 2020).

The starch fraction quantified in the present study is therefore consistent with the presence of carbohydrate components likely to be digested more slowly than rapidly available simple sugars. Depending on its physicochemical organisation within the matrix, part of this fraction may exhibit limited enzymatic accessibility. Such structural constraints could contribute to slower glucose release during digestion and, consequently, to a more moderate postprandial glycaemic response (Jenkins et al., 1981; Miao et al., 2015). However, resistant starch was not directly measured in the present study, and any inference regarding its presence, digestive fate, or colonic fermentation remains hypothetical. If a fraction of this starch were indeed to escape digestion in the small intestine and reach the colon, its microbial fermentation could lead to the production of short-chain fatty acids, notably butyrate and propionate, metabolites associated with favourable effects on insulin sensitivity and carbohydrate metabolism (Birt et al., 2013; Robertson et al., 2005).

The fruit of *H. coriacea* Gaertn. exhibited a marked lignocellulosic profile, characterised by a crude fibre content of $34.21 \pm 1.66\%$ DM and an estimated lignin content of $18.08 \pm 0.65\%$ DM.

In date palms (*P. dactylifera*), the fibre fraction is likewise largely dominated by cellulose, hemicelluloses and lignin, with insoluble components accounting for most of the total dietary fibre (Sejpal et al., 2025; Ibrahim et al., 2021). In several cultivated varieties, total dietary fibre contents range from 3.2 to 7.4 g/100 g fresh fruit, of which more than 90% correspond to insoluble lignocellulosic components (Okonkwo et al., 2025). Such structural organisation contributes to rigidity of the cell wall tissues and directly influences fruit texture, mechanical hardness, and the accessibility of carbohydrates to digestive enzymes.

The lignocellulosic values obtained for *H. coriacea* Gaertn. fruit fall within the compositional range reported for highly fibrous palm tissues, although they appear higher than most published values. This observation remains plausible insofar as the present study was conducted on the whole fruit, including the pericarp and other structurally reinforced tissues. Several factors may contribute to these elevated levels. From an anatomical perspective, the predominance of lignocellulosic bundles and thickened cell walls is a major determinant of fibre abundance (Asp et al., 1983). The presence of vascular elements and sclerenchymatous tissues may also increase the proportion of structural polysaccharides (Al-Shahib and Marshall, 2003). In addition, estimation of lignin by NIRS may introduce a degree of uncertainty, particularly in highly lignified matrices, depending on calibration quality and the physical characteristics of the sample, notably its residual moisture content (Cozzolino et al., 2001; Foley et al., 1998). Finally, the low water content of the samples and the concentration effect associated with drying are likely to increase the relative proportion of fibre when results are expressed on a dry matter basis (Al-Farsi and Lee, 2008).

The high abundance of insoluble fibre, cellulose and lignin in *H. coriacea* Gaertn. fruit suggests the presence of a dense plant matrix likely to restrict the accessibility of digestive enzymes to carbohydrate substrates. Such structural constraints are known to modulate gastrointestinal processes, notably by slowing gastric emptying, increasing satiety, and limiting the extent of carbohydrate hydrolysis, which may contribute to attenuating postprandial glycaemic responses (Taghipoor et al., 2014; Stephen et al., 2017). Evidence from controlled clinical studies further indicates that diets enriched in insoluble or mixed fibres are associated with reductions in fasting blood glucose, glycated haemoglobin, and certain markers of insulin resistance (Reynolds et al., 2020). In this context, the compact lignocellulosic architecture of the fruit could constitute an important factor influencing carbohydrate digestion kinetics (Cho et al., 2013).

The compositional characteristics observed for *H. coriacea* Gaertn. fruit show certain analogies with those reported for several plant-derived foods recognised for the metabolic relevance of their carbohydrate and fibre fractions. For example, the pulp of *Adansonia digitata*, characterised by high fibre content and relatively low levels of simple sugars, has shown the ability to attenuate postprandial glycaemic responses (Rita et al., 2022; Silva et al., 2023). Likewise, pectins from *Citrus sinensis* increase intestinal viscosity and delay carbohydrate absorption, mechanisms incorporated into certain nutritional recommendations (Blanco-Pérez et al., 2021; FSANZ, 2016). In addition, galactomannans derived from *Trigonella foenum-graecum*, which are highly viscous soluble fibres, have been reported to reduce glycated haemoglobin and slow glucose absorption (Neelakantan et al., 2014). Taken together, these observations support the hypothesis that *H. coriacea* Gaertn. fruit may be of nutritional interest in the context of glycaemic control, although its specific physiological effects remain to be confirmed experimentally.

Total carbohydrates accounted for 87.80% DM in *H. coriacea* Gaertn. fruit and, on this basis, constituted the principal fraction contributing to the estimated theoretical energy value. This compositional profile indicates that the fruit is predominantly composed of carbohydrates when expressed on a dry matter basis, while also containing a substantial proportion of crude fibre (34.21% DM). Taken together, these elements support the relevance of considering this fruit as a structurally complex plant matrix, potentially pertinent within balanced dietary patterns aimed at glycaemic regulation. This interpretation is consistent with the previously cited literature highlighting the combined influence of carbohydrate quality and fibre on postprandial glycaemic responses.

Analysis of carbohydrate ratios further clarifies the qualitative balance of the carbohydrate fraction. The proportion of the residual carbohydrate fraction remained moderate relative to total carbohydrates (residual carbohydrate fraction/total carbohydrates = 0.61), whereas the contribution of simple sugars to the residual carbohydrate fraction remained low (total sugars/ residual carbohydrate fraction = 0.07; sucrose/ residual carbohydrate fraction = 0.07). Such ratios suggest a low contribution of rapidly absorbable carbohydrates, generally associated with rapid postprandial glycaemic excursions (FAO/WHO, 1998). In addition, the moderate contribution of starch (starch/residual carbohydrate fraction = 0.25) is compatible with a potentially more gradual release of glucose than that expected in a matrix dominated by simple sugars (Englyst et al., 1992).

The fibre/carbohydrate ratios further revealed a clear predominance of structural fractions, particularly crude fibre (0.64) and lignin (0.34), relative to the residual carbohydrate fraction. Such a compositional balance could contribute to delaying carbohydrate digestion and reducing enzymatic accessibility within the plant matrix (Livesey, 2001).

When expressed relative to total sugars, the high ratios observed for crude fibre (8.75) and lignin (4.62) further underline the low density of rapidly assimilable sugars within the fruit matrix. Taken together, these quantitative relationships are consistent with a potential attenuation of postprandial glycaemic responses, primarily mediated by the modulatory effects of structural fibres on carbohydrate absorption kinetics, without implying a demonstrated hypoglycaemic effect under in vivo conditions (FAO/WHO, 1998).

Taken together, the calculated ratios provide a coherent quantitative framework for integrated interpretation of the compositional data. They should not, however, be considered direct predictors of clinical outcomes, but rather descriptive compositional indicators reflecting the balance between carbohydrate fractions and structural fibres within the fruit matrix.

This study provides the first detailed compositional data on *H. coriacea* Gaertn. fruit, including characterisation of its carbohydrate fraction and structural fibre fractions. These findings contribute to advancing knowledge on still under-explored palm fruits and establish a basis for future research in functional nutrition, particularly with regard to carbohydrate quality and dietary strategies relevant to glycaemic regulation. They notably highlight the importance of investigating in greater detail the digestibility, structural organisation and fermentability of fibre fractions, as well as their potential influence on parameters related to the glycaemic index.

From a nutritional perspective, the compositional characteristics of the fruit, as analysed in dried and powdered form, suggest potential applicability in dietary patterns aimed at moderating postprandial glycaemic responses, enhancing satiety, and supporting body weight regulation. Beyond nutritional considerations, the valorisation of *H. coriacea* Gaertn. as a local food resource may also be of socio-economic interest by contributing to food security and promoting the use of endogenous plant species in community-based approaches to metabolic health.

Nevertheless, several limitations of the present study should be acknowledged. First, the findings are based exclusively on compositional analyses and do not include direct assessment of carbohydrate digestibility under either in vitro or in vivo conditions. Second, the specific nature of the starch fraction, rapidly digestible starch, slowly digestible starch, or resistant starch, was not determined, despite its important role in modulating postprandial glycaemic responses. Third, the absence of detailed characterisation of soluble fibre fractions limits interpretation of the potential physiological effects. In addition, because crude fibre quantification captures only a limited portion of total dietary fibre, the calculated content of the residual carbohydrate fraction may overestimate the proportion of carbohydrates that is actually available for digestion. Moreover, the predominance of insoluble and potentially poorly fermentable structural fractions requires further investigation in order to clarify their metabolic relevance. Finally, the use of an NIRS-based prediction for lignin quantification may introduce estimation uncertainty, which underlines the need for validation by reference analytical methods.

These limitations identify several priority directions for future research. Further work should aim to characterise starch fractions in order to refine understanding of carbohydrate hydrolysis kinetics and glucose release profiles. In vitro digestibility assays simulating gastrointestinal conditions would be useful to evaluate the resistance of the lignocellulosic matrix to enzymatic degradation. In vivo studies, initially in animal models and subsequently in humans, will be required to confirm effects on postprandial glycaemia and to define relevant intake levels. Finally, assessment of technological processing approaches, including cooking, milling, drying and granulation, would help identify the nutritionally most relevant forms of the fruit while preserving, as far as possible, its functional properties.

Data availability

The underlying data are available on Zenodo: Raw and processed analytical data on carbohydrate fractions and dietary profile of *Hyphaene coriacea* Gaertn., <https://doi.org/10.5281/zenodo.18844583> (NAZMOUL, 2026). Data are available under the terms of the Creative Commons Attribution 4.0 International licence (CC BY 4.0).

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Eliana Bistriche Giuntini

University of São Paulo, São Paulo, Brazil

Dear authors,

The article presents partial data on the fruit composition of **Hyphaene coriacea** Gaertn., which is consumed in Madagascar—partial because the data cover only carbohydrates, whereas the researchers possess data on other nutrients that are of great importance to disseminate. Data on biodiversity foods are highly valuable, particularly when they include analytically determined carbohydrate fractions. However, the present study is weakened by the combination of direct analytical measurements with values derived from calculations based on concepts that are no longer considered scientifically appropriate.

The estimation of available carbohydrates by difference is inherently dependent on dietary fiber values obtained by the enzymatic–gravimetric method, and the use of the residual carbohydrate fraction lacks clear analytical meaning in the current context. Since this fraction is not directly measured and accumulates the uncertainties associated with other proximal chemical components, in addition to the outdated determination of crude fiber, its inclusion adds limited scientific value to the dataset.

Even though the authors acknowledge the various limitations of this fraction, the equations used to derive residual carbohydrate values, as well as the corresponding data presented in the tables, should be removed. References to these calculated fractions throughout the manuscript should also be reconsidered, with greater emphasis placed on the analytically determined carbohydrate components.

If the researchers did not determinate moisture content, I suggest taking a representative sample, determining the moisture content, and converting the values from a dry basis to a whole basis, because no one consumes food on a dry basis. This will increase interest in the presented data and add value to the study, given that there are already issues with crude fiber.

2.3.1. Remove this sentence: “In accordance with international food composition frameworks, the interpretation of carbohydrates calculated by difference depends on the analytical definition of

fibre used. In order to obtain an operational indicator of the carbohydrate fraction not accounted for by crude fibre, the crude fibre value was subtracted from total carbohydrates. However, because crude fibre does not measure all dietary fibre and is not equivalent to total dietary fibre, this value was interpreted only as an approximate estimate of the carbohydrate fraction not included in crude fibre, and not as a formal measure of available carbohydrates (FAO, 2003)."

Replace with: Total carbohydrates were calculated by difference. Since crude fiber does not represent all dietary fiber, it was not possible to obtain available carbohydrate values by difference (FAO, 2003).

OBS: The analytical methods used to determine moisture (method), protein (method), lipids (method), and ash (method) should be cited and presented in g 100 g⁻¹.

2.3.2 Remove the equation: Residual carbohydrate fraction (% DM) = Total carbohydrates - Crude fibre

The use of a residual carbohydrate fraction (calculated by difference) is of limited value, as it does not represent a directly measured component and incorporates the analytical errors associated with all other constituents of the proximate chemical composition.

2.9 About energy calculation: The energy value is only meaningful when it is calculated considering all nutrients present in the food on a whole-food basis. Therefore, although the primary focus of this study is carbohydrates, it is important to present the proximal composition data on a whole-food basis and to calculate the energy value using total carbohydrate content. Subsequently, in the Discussion section, these values can be compared with the energy estimates obtained by summing soluble sugars and starch. Energy calculations should preferably be based on analytically determined carbohydrate fractions, such as soluble sugars and starch, along with the other measured macronutrients.

I suggest reading and discussing the article by Menezes et al. (2015): Impact of dietary fiber energy on the calculation of food total energy value in the Brazilian Food Composition Database.

Furthermore, a simple conversion from kcal (usual unit) to kJ (correct unit) is not recommended. Instead, energy values should be calculated using the appropriate conversion factors, namely 17 kJ g⁻¹ for carbohydrates and proteins and 37 kJ g⁻¹ for lipids.

In light of the above considerations, I recommend an extensive review of the data and an appropriate discussion.

References

1. Menezes E, Grande F, Giuntini E, Lopes T, et al.: Impact of dietary fiber energy on the calculation of food total energy value in the Brazilian Food Composition Database. *Food Chemistry*. 2016; **193**: 128-133 [Publisher Full Text](#)

Is the work clearly and accurately presented and does it cite the current literature?

Yes

Is the study design appropriate and is the work technically sound?

Partly

Are sufficient details of methods and analysis provided to allow replication by others?

Yes

If applicable, is the statistical analysis and its interpretation appropriate?

Not applicable

Are all the source data underlying the results available to ensure full reproducibility?

Yes

Are the conclusions drawn adequately supported by the results?

Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Food chemical composition, Food composition databases, glycemic response

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

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