

Physicochemical, Nutritional Characterisation and Technofunctional Properties of Ripe Black Velvet Tamarind (*Dialium guineense* Willd) Pulp Marketed in Korhogo, Côte d'Ivoire

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Abstract The black tamarind tree (*Dialium guineense* Willd) is a wild forest resource whose fruit plays a major socio-economic role in Korhogo, in northern Côte d'Ivoire. Despite its popularity amongst local consumers, scientific data on its technological and nutritional value remain limited. This study characterised the physico-chemical and nutritional potential of the pulp of the ripe fruit and assessed its techno-functional properties with a view to better utilising this resource in the agri-food sector. Samples of ripe fruit were collected from wholesalers at three (3) markets in the city of Korhogo. After extracting the pulp, standard physico-chemical analyses were carried out and the nutritional profile was assessed. The water absorption capacity, oil absorption capacity and swelling capacity of the resulting powder were measured to determine its techno-functional properties. This pulp was found to be acidic, with a low pH (3.25 ± 0.04 to 3.40 ± 0.01) and high titratable acidity (2.13 ± 0.06 to 3.17 ± 0.06 g/100 g), combined with a low moisture content (16.69 ± 0.10 to $18.67 \pm 0.15\%$). It was characterised by a high content of sugars (33.17 ± 0.15 to 36.93 ± 0.50 g/100 g), vitamin C (8.33 ± 2.89 to 10.00 ± 0.00 mg/100 g dry matter) and essential minerals, notably potassium (495.44 ± 0.01 to 575.85 ± 0.01 mg/kg), calcium (82.16 ± 0.01 to 83.99 ± 0.01 mg/kg) and iron (29.66 ± 0.01 to 66.37 ± 0.01 mg/kg). From a technological perspective, the powder exhibited good water absorption capacity (1.76 ± 0.09 to 1.91 ± 0.07 g/g), high swelling capacity (27.10 ± 0.20 to $31.13 \pm 1.12\%$) and improved oil absorption capacity (2.16 ± 0.08 to 2.78 ± 0.27 g/g). This fruit is therefore a first-rate nutritional source for combating micronutrient deficiencies. Its techno-functional properties, notably its high oil absorption capacity and swelling power, make it an ingredient of choice for stabilising food emulsions, preserving the softness of baked goods and improving the creaminess of preparations. Furthermore, its good interaction with water allows for controlled hydration of doughs, thus offering real potential for the formulation of locally produced, fortified foods with an optimal texture.

Keywords: *Dialium guineense*, pulp, nutritional value, technofunctional properties, food valorisation, Korhogo

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1. Introduction

Food security and the diversification of sources of natural ingredients are major challenges for the agri-food industry in sub-Saharan Africa [1]. Given the sector's heavy reliance on imported raw materials, the utilisation of non-timber forest products (NTFPs) is attracting growing scientific interest with a view to developing new

formulated foods [2]. Among these indigenous resources, the black tamarind tree (*Dialium guineense* Willd, Fabaceae family) stands out for its biological and socio-economic importance in West Africa [3].

In Côte d'Ivoire, and more specifically in the Guinean savannahs of the Poro region, its wild fruit, commonly known as 'chat noir' in French and 'Kô sira' in Malinké, is subject to intensive seasonal harvesting, and its sale at the markets in Korhogo represents a significant economic activity for rural communities [2]. Despite its considerable

local popularity, however, this fruit is mainly consumed in the form of confectionery or in traditional drinks, and it suffers from high post-harvest perishability and virtually non-existent industrial processing. However, according to recent research, its pulp has nutritional and biological potential, characterised by a high soluble sugar content, marked titratable acidity, a profile rich in essential micronutrients and a high concentration of secondary metabolites [3,4]. These characteristics give it remarkable properties, making it well-suited to the development of functional foods that promote general wellbeing. The successful incorporation of the pulp as a bio-ingredient into complex food matrices requires a thorough understanding of its technological behaviour. To date, although the overall composition of this fruit's pulp is fairly well documented [1], data on the technological behaviour of its flour as a formulation agent remain patchy [5].

This study, carried out as part of efforts to promote the industrial utilisation of plant-based food resources in Côte d'Ivoire, aims to conduct an in-depth nutritional characterisation and to assess the techno-functional properties of this fruit's pulp.

2. Materials and Methods

2.1. Plant Material

2.1.1. Sampling

The plant material used in this study consisted of ripe fruits of the velvety black tamarind (*Dialium guineense* L.), purchased in June 2026 from local wholesalers at three (3) markets (the Grand Marché 'GM', the Koko Small Market 'KK' and the Sinistré Small Market 'ST') in the town of Korhogo (Côte d'Ivoire), situated at the geographical coordinates 9°25' N and 5°37' W. At each market, three (3) different vendors were selected at random. One (1) kilogramme of ripe fruit showing no visible signs of spoilage was collected from each vendor. The samples were packed in clean polyethylene bags, labelled according to their origin, and then transported to the laboratory for processing.

2.1.2. Preparation of Fruit Powder

The fruit purchased was first sorted by hand to remove debris and any broken or damaged fruit. They were then shelled by hand to separate the outer husk from the pulp surrounding the seed; the pulp was then carefully removed from the seeds, spread in a thin layer on perforated trays and air-dried at room temperature (30 °C) for 72 hours. After drying, it was ground using an unglazed porcelain laboratory mortar (Haldenwanger, Germany) and then sieved through a 250 µm mesh sieve. The resulting powder was packaged in airtight vials and stored at room temperature until analysis.

2.2. Methods

2.2.1. Physicochemical and Nutritional Analyses of the Fruit Pulp

2.2.1.1. Determination of Colourimetric Parameters

The colour of the powder was measured using a precision colourimeter (PCE-CSM 10, Germany) in accordance with the tristimulus colourimetry method. After calibrating the colourimeter to ensure its accuracy, its aperture was pressed firmly against two (2) grams of the sample to prevent any light leakage. The L*, a* and b* coordinates were then displayed on the screen: the lightness L* (ranging from 0 for black to 100 for white), the a* chromaticity index (ranging from negative green to positive red) and the b* chromaticity index (ranging from negative blue to positive yellow).

2.2.1.2. Determination of pH and Titratable Acidity

The pH was determined using a standardised method. Ten (10) grams of pulp were dispersed in 100 ml of distilled water in an Erlenmeyer flask whilst stirring continuously for 30 minutes. After decanting, the pH of the supernatant was measured using a digital pH metre (METTLER TOLEDO, Switzerland) calibrated with pH 4.0 and 7.0 buffer solutions.

The titratable acidity of this same supernatant was determined by acid-base titration according to the method described in [6]. In the presence of three (3) drops of phenolphthalein, 10 mL aliquots placed in an Erlenmeyer flask were titrated with a 0.1 N sodium hydroxide (NaOH) solution. The persistent pink colour change was used to determine the volume of NaOH required to neutralise the acidity of the various samples. The results, expressed in g/100 g, were calculated using the following equation (1):

$$\text{Titrable acidity} = N_b \times V_b \times \frac{0.9}{V_e} \times 100 \quad \text{Eq. (1)}$$

where N_b is the normality of the NaOH, V_b is the volume of NaOH required for the titration, and V_e is the volume of the sample.

2.2.1.3. Determination of Moisture and Dry Matter Content

The moisture content was determined using the oven-drying method, in accordance with [7]. A test sample of 5 g of powder was placed in a pre-weighed capsule and then dried in an oven at 105 °C until a constant mass was reached over a period of 24 hours. The loss in mass was used to calculate the moisture content (%) using the following equation (2):

$$\text{Moisture content} = \frac{(M_1 - M_2)}{(M_1 - M_0)} \times 100 \quad \text{Eq. (2)}$$

where M_0 is the mass of the empty crucible, M_1 is the

mass of the empty crucible plus the fresh sample, and M_2 is the mass of the crucible plus the dried sample.

$(M_1 - M_2)$ is the mass of water evaporated during drying.

$(M_1 - M_0)$ represents the gross mass of the fresh sample before drying.

Dry matter content (%) was obtained by difference, as shown in following Eq. (3):

$$\text{Dry matter content} = 100 - \text{Moisture content Eq. (3)}$$

2.2.1.4. Determination of Ash Content and Mineral Profile

The total ash content was determined by incineration in accordance with the method described in [7]. A mass of 2 g of powder was weighed into a porcelain crucible and then calcined in a muffle furnace (NABERTHERM GmbH, Germany) at 600 °C for four (4) hours until white ash was obtained. The ash content (%) was calculated using the following equation (4):

$$\text{Ash content} = \frac{(M_2 - M_1)}{M_0} \times 100 \quad \text{Eq. (4)}$$

where M_0 is the mass of the crucible, M_1 is the mass of the crucible plus the ash, and M_2 is the mass of the test sample.

For the mineral composition (calcium, magnesium, potassium, iron, zinc), the mineral content of the dehydrated fruit pulp was determined by dry ashing in a furnace, following a procedure adapted from the method described in [8]. The final quantification of the mineral elements in the resulting acidic solutions was carried out by high-frequency inductively coupled plasma optical emission spectrometry (ICP-OES), in accordance with the guidelines in [9]. To this end, 5 mL of 1 N nitric acid was added to the cooled ash, and the mixture was then evaporated to dryness on a sand bath. To this residue, 5 mL of 1 N hydrochloric acid was added, and the mixture was returned to the oven at 400 °C for 30 minutes. Following this step, 10 mL of 0.1 N hydrochloric acid was added to the residue. The resulting mixture was transferred to a 50 mL volumetric flask, and the crucible was rinsed three (3) times with 10 mL of 0.1 N HCl, after which the flask was made up to volume. Once the mixture had stabilised, the supernatant was filtered through 0.45 µm Whatman filter paper, and the mineral elements were quantified by ICP-OES.

2.2.1.5. Determination of Total Sugar and Reducing Sugar Content

Total sugars were quantified using the phenol-sulphuric acid method described in [10]. Absorbance was measured at 490 nm on a UV/VIS spectrophotometer (JENWAY 6305, UK) against a blank, and the concentrations (% dry matter) were calculated using a glucose calibration curve.

Reducing sugars were determined using the 3,5-dinitrosalicylic acid (DNS) method as described in [11]. The absorbance of the coloured complex formed after heating in a boiling water bath was measured at 540 nm on a UV/VIS spectrophotometer (JENWAY 6305, UK) against a blank. The mean values were expressed as a percentage of dry matter (% DM).

2.2.1.6. Determination of Total Lipid Content

The lipid content was determined by continuous extraction using a Soxhlet apparatus (SIAB, England), in accordance with the method described in [12]. Five (5) grams of dried powder were placed in an extraction cartridge. The lipids were extracted for 6 hours using hexane (or petroleum ether) as the solvent. The solvent was then removed using a rotary evaporator, after which the flask containing the oil was dried in an oven at 103 °C and weighed to determine the percentage of fat using the following equation (5), based on mass:

$$\text{Total lipid content} = \frac{(M_1 - M_0)}{P_e} \times 100 \quad \text{Eq. (5)}$$

where M_0 is the mass of the empty vial, M_1 is the mass of the vial and its residue, and P_e is the mass of the sample.

2.2.1.7. Determination of Crude Protein Content

The protein content was determined using the method described in [7], which comprises three (3) stages: digestion, distillation and titration. A 1 g sample of powder was subjected to hot digestion in the presence of concentrated sulphuric acid (H_2SO_4) and a Kjeldahl catalyst until a clear solution was obtained. After alkalising the solution with NaOH, the ammonia released was distilled off and collected in a boric acid solution, then titrated with hydrochloric acid (0.1 N HCl). The nitrogen content (%N) was determined using the following equation (6):

$$\%N = \frac{V_a \times N_a \times 14,007}{1000 \times P_e} \times 100 \quad \text{Eq. (6)}$$

where V_a is the volume of acid used for the titration, N_a is its normality and P_e is the mass of the sample portion analysed.

The total nitrogen content thus obtained was multiplied by the universal conversion factor of 6.25 to obtain the crude protein content.

2.2.1.8. Determination of Crude Fiber Content

The crude fibre content of the pulp was determined using the method described in [13]. Three (3) grams of pulp (P_e) were added to 325 mL of a reaction mixture consisting of sulphuric acid (0.28 N), distilled water and potassium hydroxide in a ratio of 1:0.6:1 (v/v/v). After heating, the residue was collected by filtration through a bed of asbestos, thoroughly washed, then dried at 140 °C for 120 min. The crucible and its contents were weighed (P_1), then calcined at 900 °C for 30 min. The loss in mass resulting from calcination (P_2) corresponded to the quantity of crude cellulose present in the sample. As the mass of asbestos was 0.02 g (P_{am}), the crude fibre content per 100 g was calculated using the following equation (Equation (7)):

$$CF = \frac{(P_1 - P_2) - P_{am}}{P_e \times DM} \times 100 \quad \text{Eq. (7)}$$

$P_e \times DM$ is the exact mass of dry matter introduced.

2.2.1.9. Determination of Carbohydrate Content

The carbohydrate content of the pulp (g/100 g of dry matter) was calculated using equation (8) below:

$$\text{Carbohydrates} = 100 - [\text{Moisture content} + \text{protein} + \text{lipids} + \text{fiber} + \text{ash}] \quad \text{Eq. (8)}$$

2.2.1.10. Determination of Energy Value

The total energy value (expressed in kcal/100 g of powder) was calculated theoretically by applying the specific coefficients for macronutrients, as used by [14], using the following equation (9):

$$\text{Energy value} = [(4 \times \text{Protein (\%)}) + (9 \times \text{Lipids (\%)}) + (4 \times \text{Carbohydrates (\%)})] \quad \text{Eq. (9)}$$

2.2.2. Analysis of Polyphenolic Compounds, Vitamins and Antioxidant Activity of Fruit Pulp

2.2.2.1. Extraction of Phenolic Compounds

One (1) gram of sample was extracted under constant stirring with 10 mL of 80 % (v/v) ethanol at room temperature for two (2) hours. The mixture was centrifuged at 4,000 rpm for 15 minutes. The supernatant was collected, filtered and stored at 4°C away from light for the determination of polyphenols, flavonoids and antioxidant activity.

2.2.2.1.1. Determination of Total Polyphenol Content

The total polyphenol content was determined by mixing a 0.5 mL aliquot of extract with 2.5 mL of Folin-Ciocalteu reagent. After 5 minutes' incubation, 2 mL of a sodium carbonate solution (7.5 % Na₂CO₃, (w/v)) was added. The mixture was incubated for 30 minutes at room temperature, protected from light. Absorbance was measured at 765 nm using a UV/VIS spectrophotometer (JASCO V-530, Japan). The results were expressed in milligrams of gallic acid equivalent (mg GAE) per gram of dry matter.

2.2.2.1.2. Determination of Total Flavonoid Content

The total flavonoid content was determined by mixing a 1 mL aliquot of the extract with 1 mL of a 2 % aluminium chloride solution. After 15 minutes' incubation at room temperature in the dark, the absorbance was measured using a UV/VIS spectrophotometer (JASCO V-530, Japan) at 415 nm. The contents were expressed in milligrams of quercetin equivalent (mg QE) per gram of dry matter.

2.2.2.2. Determination of Vitamin C content

The vitamin C content was determined by titration using the 2,6-dichlorophenolindophenol (DCPIP) reagent, in accordance with the method described by [15]. A 5 g sample of pulp powder (Pe) was weighed out. This sample was quantitatively transferred to a volumetric flask and extracted using 50 mL (V) of a 3 % (w/v) metaphosphoric acid solution. The mixture was thoroughly homogenised to ensure complete extraction of ascorbic acid, then filtered through Whatman filter paper. 10 mL of the clear filtrate was decanted and transferred to a clean Erlenmeyer flask. The aliquot was titrated, using a burette, with the DCPIP standard solution, whilst stirring continuously until a distinct pale pink colour appeared and persisted for 15 seconds. The precise volume of DCPIP solution used to

reach the end point (Ve) was recorded. The vitamin C content (mg/100 g) of the sample was determined using the following expression (Equation (11)):

$$\text{Vitamin C content} = \frac{T_{\text{DCPIP}} \times V_e \times 5}{P_e} \times 100 \quad \text{Eq. (11)}$$

with Ve: volume of standardized DCPIP solution used for the titration (mL); T_{DCPIP}: titer of the DCPIP solution; Pe: initial weight of the fruit powder test sample (5 g) and 5: dilution factor, derived explicitly from the volume ratio (V_{total} / V_{aliquot}).

2.2.2.3. Determination of Vitamin A Content

The vitamin A content was estimated by determining the β-carotene content using the method described in [16]. Five (5) mL of hexane were added to a mixture consisting of 1 g of sample, 2.5 mL of 96° ethanol and 0.1 mL of hydroquinone solution (20 g of hydroquinone in 100 mL of 95° ethanol). The mixture, homogenised after vigorous vortexing, was transferred to vials and then centrifuged at 3000 rpm for 20 min.

The supernatant was collected in test tubes and protected from light using aluminium foil. A series of β-carotene standards (µg/100 g) was prepared in parallel from a 10 µg/mL stock solution. 4 mL of supernatant were placed in a cuvette, and the optical density was measured at 450 nm on a UV/VIS spectrophotometer (T80, China) against a blank. The β-carotene content was calculated using equation (12) below, based on a calibration curve with the regression equation OD₄₅₀ = 0.0163 Q, R² = 0.9988:

$$\beta\text{-carotene content} = \frac{Q \times F}{P_e} \times 100 \quad \text{Eq. (12)}$$

where F is the dilution factor, Pe is the test portion and Q is the amount of β-carotene in each tube.

The vitamin A content (µg/100 g) of the samples was determined according to the method of [17] by dividing the β-carotene content by 6.

2.2.3. Determination of Technofunctional Properties of Fruit Pulp

2.2.3.1. Determination of Water Absorption Capacity and Water Solubility Index

The water absorption capacity (WAC) and the water solubility index (WSI) were evaluated simultaneously according to the method of [18]. 1 g of fruit pulp (M₀) was weighed in a previously weighed centrifuge tube (M₁) and mixed with 10 mL of distilled water. The suspension was vigorously swirled every 5 min over a period of 30 min, then centrifuged at 3000 RPM for 20 min. The supernatant was carefully decanted and the tube containing the wet pellet was weighed again (M₂) and then dried in an oven at 105 °C. until a constant mass (M_s). The WAC (g/g) was calculated using the following equation. (13):

$$\text{WAC} = \frac{M_2 - M_1 - M_s}{M_0} \quad \text{Eq. (13)}$$

WSI was calculated as a percentage of the initial mass of the sample (M₀) using the following equation 14:

$$WSI = \frac{M_0 - M_S}{M_0} \times 100 \quad \text{Eq. (14)}$$

2.2.3.2. Determination of Oil Absorption Capacity

The oil absorption capacity (OAC) was evaluated according to the method of [18]. 1 g of pulp (M_0) was weighed in a centrifuge tube previously weighed (M_1) and mixed with 10 mL of refined vegetable oil. The suspension was vigorously swirled every 5 min over a period of 30 min, then centrifuged at 3000 RPM for 20 min. The supernatant was carefully decanted and the tube containing the wet pellet was weighed again (M_2). The OAC (g/g) was calculated using the following equation (15):

$$OAC = \frac{M_2 - M_1 - M_0}{M_0} \quad \text{Eq. (15)}$$

2.2.3.3. Determination of Water Dispersibility

The dispersibility was measured according to the method of [19]. A mass of 10 g of powder was placed in a 100 mL graduated test tube. Distilled water was added to reach a total volume of 100 mL. The cylinder was vigorously shaken by hand for 30 seconds, then left to rest on a flat surface for 30 min. The sediment volume (SV) was recorded. The dispersibility was expressed using the following equation 16:

$$\text{Dispersibility} = 100 - \text{SV} \quad \text{Eq. (16)}$$

2.2.4. Statistical Analysis

The experimental unit in this study is defined as the sample of black tamarind (*Dialium guineense*) fruit pulp. For each of the physicochemical or biochemical parameters evaluated, laboratory analyses were performed in three (3) independent replicates (triplicate) to ensure the precision and reproducibility of the measurements.

The collected raw data were entered, codified, and structured using Microsoft Excel (2016 version). The results are expressed as means accompanied by their standard deviations (Mean $\pm$ Standard Deviation). Statistical processing and analyses were executed using SPSS software (IBM SPSS Statistics, version 25).

Prior to any modelling, the normality of data distribution and the homogeneity of variances were formally verified. A one-way analysis of variance (one-way ANOVA) was subsequently applied to test for the existence of statistically significant differences between the different pulp samples under study. Where the ANOVA revealed significant global effects, a multiple comparison procedure of the means was conducted using Tukey's post hoc test. For all statistical tests applied, the significance threshold was set at 5%, such that differences are considered statistically significant for any p-value < 0.05.

3. Results and Discussion

3.1. Physicochemical and Nutritional Parameters of Black Tamarind Fruit Pulp

Table 1 summarizes the results obtained for a complete set of physico-chemical, mineral and nutritional parameters measured on the basis of samples taken from three (3) Korhogo markets.

Inter-market variability: For almost all the parameters studied, the statistical analysis revealed significant differences between three (3) batches ($p < 0.05$), with the notable exception of pH and reducing sugars, for which the values remained relatively homogeneous from one site to another. Such variability, already documented for other wild non-domesticated woody fruits of the region such as the black plum (*Vitex doniana*) [20] or, on a wider geographical scale, *Saba senegalensis* in Burkina Faso. Its phytochemical composition varies markedly from batch to batch [21], reflecting the combined influence of the geographical origin of the harvested wild fruits, the stage of maturity reached at harvest, and sometimes the heterogeneous conditions of handling and exposure of the pulp on market stalls before sale.

Colourimetric characteristics: The CIELAB trichromatic coordinates (L^* , a^* and b^*) showed that, for the parameter L^* , the ST and GM powders had a higher luminosity than KK, which was very slightly darker. For the parameter a^* , KK displayed the highest value ($+2.72 \pm 0.01$) and ST the lowest ($+1.73 \pm 0.01$). For the b^* parameter, KK ($+37.78 \pm 0.01$) stood out with a more pronounced orange-yellow tint. These results mathematically reflect the overall orange-brown colour observed visually. The high L^* value observed in all the samples is consistent with the averages (82 to 85) obtained by [1] for the baobab pulp (*Adansonia digitata*). According to [22] on the powder of néré pulp (*Parkia biglobosa*), this tendency to lightening could be explained by the diffraction of light on powdery matrix particles. The indices a^* (red component, $+1.73 \pm 0.01$ to $+2.72 \pm 0.01$) and b^* (yellow component, $+36.80 \pm 0.01$ to $+37.78 \pm 0.01$) confirm a dominant yellow-brown chromaticity, in accordance with the macroscopic description generally accepted for this species [3]. In terms of chromaticity, the intensity of the yellow component of these samples is significantly higher than that observed by [23] for the accessions of black velvet tamarin from Senegal (b^* average of 22.40 ± 1.15). This strong coloration would indicate, for these samples, an excellent intrinsic concentration of β -carotene and an optimal preservation of the hydrophobic pigments against solar radiation during local artisanal drying, according to [4].

pH and titratable acidity: The analysis of the acidity of the sample revealed an overall very acidic matrix, with pH values ranging from 3.25 ± 0.04 (GM) to 3.40 ± 0.01 (ST). The analysis of variance at the significance level of 5% revealed a significant difference ($p = 0.00077$) between the pH value observed for ST and those of GM and KK, which are significantly identical.

The titratable acidity followed a reverse trend to this decrease, showing maximum contents of 3.17 ± 0.04 g/100 g for GM and minimum contents of 2.13 ± 0.06 g/100 g for ST. The ANOVA shows a significant difference ($p < 0.00001$) at the significance threshold of 5% between the mean obtained for ST and those of GM and KK. The comparative analysis nevertheless reveals a clear physico-chemical gradient between the samples, marking an increase in the pH concomitant with a sharp

decrease in the titratable acidity.

The strongly acidic pH observed in the three (3) samples corresponds closely to the fundamental data published by [1,24] for the ripe pulp of *Dialium guineense*, characterised by a typical pH between 3.10 and 3.50. This marked acidity could be explained by a naturally high concentration of black velvet tamarind in free organic acids, mainly tartaric, citric and malic acids [23,25]. Such a level of acidity would constitute an effective natural barrier against the development of alteration microorganisms. This pH nevertheless remains significantly lower than that of the common tamarind (*Tamarindus indica*) whose pH is close to 2.95 and whose titratable acidity can reach 18.52 g of tartaric acid equivalent per 100 g of pulp [26].

Moisture and dry matter content: the results showed that the black tamarind pulp is characterized by a low moisture content (between 16.69 ± 0.11 and $18.67 \pm 0.15\%$) and a high proportion of dry matter (more than 81%). The dry matter content values recorded were $83.31 \pm 0.11\%$ for GM, $81.33 \pm 0.15\%$ for KK and $81.39 \pm 0.03\%$ for ST. The analysis of variance (ANOVA) showed a significant difference ($p < 0.000001$) at the significance level of 5%. GM therefore contains more organic and mineral materials than KK and ST respectively.

The recorded moisture contents correspond well to the humidity ranges reported by [1, 24] for the ripe peeled fruits of *Dialium guineense* (13% and 20%). These moderate values ensure a sufficiently low water activity to inhibit bacterial proliferation and highlight the direct impact of the exposure conditions. These pulps are richer in water than jujube (*Ziziphus mauritiana*), whose moisture reported in the dried fruits does not exceed 5.16% [27]. Nevertheless, they remain significantly less hydrated than the pulp of baobab (*Adansonia digitata*), the content of which has been estimated at 13.41% by [28].

Total sugar content and reducing sugar content: total sugars accounted for more than a third of the dry mass of the pulps studied. The statistical analysis revealed, for the total sugar content, a significant difference at the threshold of 5% between the content of the sample ST and the contents of the two (2) other samples, KK and GM which are significantly identical ($p < 0.00001$). ST stood out with a maximum accumulation of total sugars equal to 36.93 ± 0.50 g/100 g DM.

For reducing sugars, the statistical analysis showed that the recorded means were not significantly different ($p = 0.09876$) at the 5% threshold.

The reducing sugar/total sugar ratio, which varied between 60 and 75% depending on the sample, indicates a pulp in which simple sugars largely dominate the carbohydrate profile. The richness in soluble carbohydrates of these samples confirms the status of this fruit as a major source of energy among the non-woody forest resources of the sub-Saharan zone. The concentrations of total and reducing sugars recorded correspond consistently to the ranges reported by [1,23] which note that the total soluble solids and the carbohydrates of the ripe pulp of black velvet tamarind are conventionally between 30% and 45% of the dry mass. These total sugar contents are higher than the average of 6.13% recorded for the pulp of the Saba liana (*Saba senegalensis*) harvested in the Korhogo region by [29]. [4]

have demonstrated that the marked predominance of reducing sugars is a biochemical characteristic of this fruit, giving it its characteristic aromatic profile, combining immediate sweetness and natural acidity of the matrix.

Ash content and mineral composition: the average values of the ash content of the samples constitute a global indicator of their mineral richness, ranging between $2.23 \pm 0.03\%$ (KK) to $2.40 \pm 0.05\%$ (GM). The statistical analysis revealed a significant difference at the 5% threshold ($p = 0.00002$).

Detailed examination of the mineral profile shows a clear predominance of potassium (495.44 ± 0.01 to 575.85 ± 0.01 mg/kg), followed by calcium (82.16 to 83.99 mg/kg), iron (29.66 ± 0.01 to 66.37 ± 0.01 mg/kg), magnesium (33.99 ± 0.01 to 43.19 ± 0.01 mg/kg), and finally zinc, present in very minor quantities (0.11 ± 0.01 to 0.68 ± 0.01 mg/kg). These ash contents are lower than the contents reported (6.16%) for jujube (*Ziziphus mauritiana*) by [26] and (3.43 to 3.64%) for black plum (*Vitex doniana*) by [20]. These results of mineral profile are consistent with those of [30], which showed that the pulp of black velvet tamarind is an interesting source of minerals such as calcium, potassium, sodium and magnesium. This hierarchy, dominated by potassium, is consistent with that described by [3,31], according to these authors, the pulp of *Dialium guineense* is particularly rich in potassium, ahead of calcium and magnesium. This mineral richness would give this pulp an important nutritional interest for human nutrition [32].

Carbohydrates, proteins and total lipids: the global biochemical profile confirms the essentially carbohydrate nature of the pulp, with carbohydrate contents ranging from 92.74 ± 0.00 g/100 g DM for GM to 93.97 ± 0.00 g/100 g DM for KK. This carbohydrate predominance directly determines the caloric profile of this pulp.

The calculated energy value was calculated at 383.69 ± 0.00 kcal/100 g for KK, 385.91 ± 0.00 kcal/100 g for GM and 395.08 ± 0.00 kcal/100 g for the ST sample. Unlike carbohydrates, nitrogen and lipid fractions were found to be minor in three (3) matrices.

For the protein parameter, the statistical analysis revealed a significant difference at the 5% threshold between the protein contents of the samples ($p = 0.00002$). The GM sample stood out with a content of 3.13 ± 0.00 g/100 g, which is almost three (3) times the concentrations recorded for KK (1.21 ± 0.00 g/100 g) and ST (1.06 ± 0.00 g/100 g).

As regards the lipids, the GM and KK powders showed particularly low concentrations, of 0.27 ± 0.00 g/100 g and 0.33 ± 0.00 g/100 g, respectively. The ST sample, however, stood out with a more pronounced fat content, reaching 2.12 ± 0.00 g/100 g.

An overwhelming proportion of carbohydrates (greater than 92 g/ 100 g MS) confirms that the pulp of *Dialium guineense* constitutes a plant tissue for the accumulation of carbohydrates. These very high levels are in agreement with the results reported by [33]. This richness in soluble sugars would give this pulp a remarkable caloric density (approximately 383 to 395 kcal/100 g).

Crude fibers and energy value: The lowest concentration of crude fibers was recorded for GM (1.45 ± 0.05 g/100 g), closely followed by ST (1.53 ± 0.03 g/100 g). The highest content was recorded for KK (2.24 ± 0.05 g/100 g).

The energy value, on the other hand, turned out to be high for all the samples ranging from 383.69 kcal/100 g (KK) to 395.08 kcal/100 g (ST), the latter batch benefiting from both its higher total sugars and lipids content.

The crude fiber content of the pulp remains comparable to the content (1.67%) of jujube (*Ziziphus mauritiana*) according to the results of [27].

As regards the energy value, the values recorded here

clearly exceed the 270 kcal/100 g reported by [26] for the common tamarind (*Tamarindus indica*). This high energy density, combined with its low moisture content, would make this pulp a food of choice for complementary nutritional use, especially in rural areas where it is traditionally used as an easily transportable and low-perishable snack, especially during the agricultural lean season.

Table 1. Physicochemical, nutritional and energy parameters of black tamarind fruit pulp

Parameter	GM	KK	ST	p-value	FDR-adjusted p-value
Colour (L*)	84.11 ± 0.01 ^a	83.50 ± 0.01 ^b	84.12 ± 0.01 ^a	4.97 × 10 ⁻¹⁰	7.23 × 10 ⁻¹⁰
Colour (a*)	+ 2.58 ± 0.01 ^b	+ 2.72 ± 0.01 ^a	+ 1.73 ± 0.01 ^c	3.28 × 10 ⁻¹¹	9.84 × 10 ⁻¹¹
Colour (b*)	+ 36.90 ± 0.01 ^b	+ 37.78 ± 0.01 ^a	+ 36.80 ± 0.01 ^b	1.14 × 10 ⁻⁵	1.40 × 10 ⁻⁵
pH	3.25 ± 0.04 ^a	3.29 ± 0.02 ^a	3.40 ± 0.01 ^b	7.74 × 10 ⁻⁴	9.28 × 10 ⁻⁴
Titrate acidity (g/100 g)	3.17 ± 0.06 ^a	2.67 ± 0.06 ^a	2.13 ± 0.06 ^b	1.87 × 10 ⁻⁶	3.75 × 10 ⁻⁶
Moisture (%)	16.69 ± 0.10 ^a	18.67 ± 0.15 ^b	18.61 ± 0.03 ^b	8.41 × 10 ⁻⁷	2.02 × 10 ⁻⁶
Dry matter (%)	83.31 ± 0.10 ^a	81.33 ± 0.15 ^b	81.39 ± 0.03 ^b	8.41 × 10 ⁻⁷	2.02 × 10 ⁻⁶
Total sugars (g/100 g DM)	33.27 ± 0.15 ^a	33.17 ± 0.15 ^a	36.93 ± 0.50 ^b	9.59 × 10 ⁻⁶	1.64 × 10 ⁻⁵
Reducing sugars (g/100 g DM)	22.13 ± 0.78 ^a	25.33 ± 0.62 ^a	22.27 ± 0.27 ^a	9.87 × 10 ⁻²	1.07 × 10 ⁻¹
Ash content (%)	2.40 ± 0.05 ^a	2.23 ± 0.03 ^b	2.27 ± 0.06 ^b	1.85 × 10 ⁻⁵	1.85 × 10 ⁻⁵
Ca (mg/kg)	83.99 ± 0.01 ^a	82.31 ± 0.01 ^b	82.16 ± 0.01 ^c	9.08 × 10 ⁻¹³	1.81 × 10 ⁻¹²
Mg (mg/kg)	43.19 ± 0.01 ^a	33.99 ± 0.01 ^c	36.81 ± 0.01 ^b	9.11 × 10 ⁻¹⁷	2.91 × 10 ⁻¹⁶
K (mg/kg)	575.85 ± 0.01 ^a	521.71 ± 0.01 ^b	495.44 ± 0.01 ^c	2.10 × 10 ⁻²²	1.68 × 10 ⁻²¹
Fe (mg/kg)	60.73 ± 0.01 ^b	29.66 ± 0.01 ^c	66.37 ± 0.01 ^a	1.67 × 10 ⁻²⁰	8.93 × 10 ⁻²⁰
Zn (mg/kg)	0.11 ± 0.01 ^c	0.41 ± 0.01 ^b	0.68 ± 0.01 ^a	5.56 × 10 ⁻¹³	1.27 × 10 ⁻¹²
Total lipids (%)	0.27 ± 0.00 ^c	0.33 ± 0.00 ^b	2.12 ± 0.00 ^a	7.64 × 10 ⁻¹³	9.17 × 10 ⁻¹²
Total protein (%)	3.13 ± 0.00 ^a	1.21 ± 0.00 ^b	1.06 ± 0.00 ^c	2.35 × 10 ⁻⁵	3.14 × 10 ⁻⁵
Carbohydrates (g/100 g DM)	92.74 ± 0.00 ^c	93.97 ± 0.00 ^a	92.94 ± 0.00 ^b	1.21 × 10 ⁻¹¹	6.04 × 10 ⁻¹¹
Crude fibre (%)	1.45 ± 0.05 ^b	2.24 ± 0.05 ^a	1.53 ± 0.03 ^b	1.47 × 10 ⁻¹⁰	2.36 × 10 ⁻¹⁰
Energy value (kcal/100 g)	385.91 ± 0.00 ^b	383.69 ± 0.00 ^c	395.08 ± 0.00 ^a	6.23 × 10 ⁻¹⁷	2.49 × 10 ⁻¹⁶

GM: Grand Marché of Korhogo; KK: Koko small market; ST: Sinistré small market;

3.2. Phenolic Compounds and Vitamins of Black Tamarind Fruit Pulp

The contents of total polyphenols, total flavonoids and the contents of vitamins A and C of the three (3) samples are presented in Table 2.

Phenolic compounds: the total polyphenol content showed a significant difference between the sample averages ($p < 0.05$). The GM sample recorded the highest content (4.62 ± 0.02 mg GAE/g) while ST obtained the lowest content (2.72 ± 0.01 mg GAE/g).

An identical classification was observed for total flavonoids. GM again displayed the highest content (8.38 ± 0.00 mg EQ/g), approximately 1.7 times the levels of KK and ST. the GM sample therefore seems to be the richest in phenolic metabolites, which makes it a priori the most interesting raw material for nutraceutical or food valorization.

The total polyphenol contents of the pulps evaluated in this study are lower than those reported by [34] for the seeds of this fruit in Côte d'Ivoire (dried seeds: 4.91 to 5.35 mg GAE/100 g; roasted seeds: 491 to 535 mg GAE/100 g). However, they are higher than the averages (40.2 ± 1.8 µg GAE/g) reported by [35] for the pulp of this fruit.

The total flavonoid contents obtained here far exceed the values (0.3 to 0.5 mg/g) reported in the pulp and seeds

of the black velvet tamarind by [1], as well as those obtained by [33] for its seeds (0.08 to 0.12 mg/100 g).

The relative classification of the samples (GM > KK > ST) for these two (2) parameters is consistent with previous work carried out on other wild fruits from West Africa and according to which the variation in the content of phenolic compounds would be strongly linked to the geographical origin of the fruits, the type of soil, the microclimate and the stage of maturity at harvest [20,36].

Profile of antioxidant vitamins A and C: a significant difference ($p < 0.05$) was observed between the averages of vitamin A. The KK sample presented the highest concentration (28.50 ± 0.15 µg/100 g), while GM recorded the lowest value (13.54 ± 0.04 µg/100 g).

The vitamin C contents of the three (3) samples, which were significantly identical, varied between 8.33 ± 2.89 mg/100 g (KK) and 10.00 ± 0.00 mg/100 g (GM and ST). The relative stability of vitamin C in the pulp is consistent with the results of the work of [1] who argues that the pulp of *Dialium guineense* would maintain a stable balance of organic acids in the ripe state to ensure its biological viability. [38] through their study have shown that the ascorbic acid of this fruit is protected from oxidation by the combined presence of flavonoids and endogenous phenolic compounds acting as natural thermochemical shields.

Table 2. Polyphenolic compound and vitamin content of black tamarind fruit pulp

Parameter	GM	KK	ST	p-value	FDR-adjusted p-value
Total polyphenols (mg GAE/g)	4.62 ± 0.02 ^a	3.24 ± 0.02 ^b	2.72 ± 0.01 ^c	3.73 × 10 ⁻¹¹	6.64 × 10 ⁻¹¹
Total flavonoids (mg QE/g)	8.38 ± 0.00 ^a	5.04 ± 0.01 ^b	4.84 ± 0.01 ^c	1.61 × 10 ⁻¹⁴	4.31 × 10 ⁻¹⁴
Vitamin A (µg/100 g)	13.54 ± 0.04 ^c	28.50 ± 0.15 ^a	20.96 ± 0.50 ^b	4.94 × 10 ⁻⁹	1.98 × 10 ⁻⁸
Vitamin C (mg/100 g)	10.00 ± 0.00 ^a	8.33 ± 2.89 ^a	10.00 ± 0.00 ^a	4.21 × 10 ⁻¹	4.21 × 10 ⁻¹

GM: Grand Marché of Korhogo; KK: Koko small market; ST: Sinistré small market.

3.3. Technofunctional Properties of Black Tamarind Fruit Pulp

The technofunctional properties of the pulp of the three (3) samples designated GM, KK and ST, are recorded in Table 3. For the water absorption capacity (WAC), the analysis of variance showed that the means obtained do not present a significant difference. These averages were between 1.76 ± 0.09 g/g and 1.91 ± 0.07 g/g. This water absorption capacity obtained here is consistent with the observations of [39], which attribute this property to the natural biochemical composition of the pulp, particularly rich in soluble sugars and structural polysaccharides such as pectins.

With regard to the oil absorption capacity (OAC), the analysis of variance showed a significant difference between the mean obtained for ST and the means for GM and KK which did not present a significant difference at the 5% threshold. The KK sample presented the highest value (2.78 ± 0.27 g/g), followed by GM (2.58 ± 0.05 g/g). On the other hand, the ST sample showed a significantly lower OAC (2.16 ± 0.08 g/g). These values corroborate the results of [40,41]. According to which the oil absorption capacity would be more closely related to the protein fraction and the porosity of the particles. Such a level would confer on the pulp of this fruit a potential interest as an agent for retaining fat-soluble aromas and as a texturizing agent in fatty products.

With regard to the water solubility index (WSI), the analysis of variance showed a significant difference between the values obtained for all the samples. The GM sample showed the highest WSI (31.13 ± 1.12%), followed by KK (28.77 ± 0.45%) and finally ST, which recorded the lowest value (27.10 ± 0.20%). The values of this water solubility index observed here are clearly lower than the 72% reported by [42] for the powders of pulp of the common tamarind (*Tamarindus indica*) dried by atomization.

The dispersibility in water showed a profile opposite to that of WSI, also marked by significant differences between the means of the three (3) samples. The ST sample dispersed better in water (72.00 ± 1.00%) than the GM (69.67 ± 0.58%) and KK (67.33 ± 0.58%) samples. The significant variability observed for this parameter between GM, KK and ST for this parameter, is consistent with the work carried out by [43] on other fruit powders from West Africa, where the locality of harvest is a

recognized factor of variation of functional properties and composition.

GM has displayed the highest WSI, reflecting rapid hydration and a high volume extension of its hydrocolloids. Conversely, the ST sample combines the lowest WSI and the highest dispersibility. This phenomenon could be explained by the solid-liquid interaction mechanisms described by [19] according to which a more moderate swelling of the particles would allow them to be separated and distributed more uniformly in the solvent; whereas an excessively rapid swelling kinetics would generally induce a decrease in the dispersibility, which could confirm the results obtained for GM and KK.

Table 3. Technofunctional properties of black tamarind fruit pulp

Parameter	GM	KK	ST	p-value	FDR-adjusted p-value
WAC (g/g)	1.76 ± 0.09 ^a	1.81 ± 0.09 ^a	1.91 ± 0.07 ^a	1.65 × 10 ⁻¹	1.65 × 10 ⁻¹
OAC (g/g)	2.58 ± 0.05 ^a	2.78 ± 0.27 ^a	2.16 ± 0.08 ^b	9.53 × 10 ⁻³	1.02 × 10 ⁻²
WSI (%)	31.13 ± 1.12 ^a	28.77 ± 0.45 ^b	27.10 ± 0.20 ^c	1.29 × 10 ⁻³	1.48 × 10 ⁻³
Water dispersibility (%)	69.67 ± 0.58 ^b	67.33 ± 0.58 ^c	72.00 ± 1.00 ^a	3.53 × 10 ⁻⁷	4.71 × 10 ⁻⁷

GM: Grand Marché of Korhogo; KK: Koko small market; ST: Sinistré small market. WAC: Water Absorption Capacity; OAC: Oil absorption capacity; WSI: water Solubility Index.

4. Conclusions

This research work made it possible to carry out an in-depth study on the physico-chemical, nutritional characterisation and the technofunctional properties of the pulp of the ripe fruit of the black tamarind tree marketed on the markets of the city of Korhogo. The analyses carried out confirm the high nutritional value of this local non-woody forest resource, in particular by its richness in soluble sugars and structural polysaccharides such as pectins. The evaluation of the technofunctional aptitudes of the different batches of samples revealed distinct and complementary behaviors, opening the way to targeted industrial applications. In conclusion, these findings provide a scientific valuation of the pulp of black velvet tamarind (*Dialium guineense*) originating from northern Côte d'Ivoire. Furthermore, they demonstrate that its formulation into a stable powder represents a promising alternative for mitigating post-harvest losses. This study provides local agri-food processors with solid technical bases to replace or supplement the use of texturizing additives imported by a high-performance local resource. In order to extend this work and effectively support the deployment of the pulp of the ripe fruit of the black tamarind tree on the agri-food market, this study could expand to a higher number of marketing points of this fruit. In addition, several research axes such as the study of stability and shelf life as well as the evolution of nutritional and technofunctional properties during prolonged storage under different temperature conditions, deserve to be explored.

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