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# *Borassus aethiopum* Mart Ripe Fruits' Parts, and Drying Temperature Effect on Its Pulp Protein, Fat, Sugars, Metabolizable Energy and Fatty Acids Profile

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**Abstract** The aim of this work was to study *Borassus aethiopum* Mart dried pulp nutritional value for its incorporation in poultry diets. Firstly, the mature fruits' parts (sepals, peels, pulps, and seeds) were assessed. Secondly, the pulp was dried at 40, 50, 60, 70, and 80°C. Thereafter, analyses were performed for fat, protein, total sugars, Calcium (Ca), phosphorus (P), Magnesium (Mg), and fatty acid profile monitoring. As a result, the fruits weighed 1,591.35 grams, delivered 516.73 and 677.82 grams of pulp and seeds, respectively. Mainly, increasing heat adversely affected the outputs. Consequently, the fat results were 14.12, 12.97, 8.93, 8.89, and 5.56%; protein contents were 11.64, 10.15, 8.97, 8.84, and 8.42%; total sugar deliveries were 6.28, 6.05, 5.26, 5.02, and 4.76% ($P<0.01$). Thereafter, the metabolizable energies were 3,785.22; 3,834.28; 3,616.62; 3,667.03; and 3,608.33 kcal/kg (DM) at 40, 50, 60, 70, and 80°C, respectively. Additionally, Ca contents were 0.51, 0.55, 0.69, 0.77, and 0.81%, while P mean was 0.17%, and the differences were not significant ($P<0.01$). So, Ca/P ratios were 2.79, 3.04, 4.10, 4.71 and 4.95. Finally, fatty acids (FA) profile assessments revealed 22.33% saturated (SFA) and 77.67% unsaturated (UFA), within which 67.59% were monounsaturated (MUFA). Interestingly, the rising heat depressed n-6/n-3 ratios those were 1.1, 1.1, 0.45 and 0.38, respectively at 40, 50, 70 and 80°C. In short, drying did not only enhance the product shelf life but it also improved the nutritional value. Thus, *B. aethiopum* mature fruits' pulps dried at 70°C are good functional foods, with more than 66% MUFA, and energy sources for human and poultry nutrition.

***Keywords:*** *Borassus aethiopum Mart, Fatty acids profile, Metabolizable energy, Minerals, Protein*

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## 1. Introduction

Firstly, as important sources of food after severe droughts in West Africa, and secondly because of their socio-economic additional non-farm income contribution to rural families' wellbeing, palm forests are important in the developing world. In Senegal, even if people enjoy the fibrous pulp, they do prefer the fresh albumen from *B. aethiopum* immature fruits. In addition, all over the world, craftsmen use palm leaves (*Elaeis guineensis*, *B. aethiopum* Mart, *B. flabellifer*, *Phoenix dactylifera*, and *Raphia hookeri*) to make hats, bags, baskets, and many other artisanal articles. In addition, the tree trunks are used to make beehives, fences, and hut roofs in rural areas [1,2]. Unfortunately, regardless these sustainable practices of palm product use, more and more social culture and eating habits lead to palm trees forest destructions. As an illustration, in Côte d'Ivoire, because of sap wine collection on apical pods, *B. aethiopum* trees are killed, leading to the conclusion that some traditional methods are no longer sustainable for *B. aethiopum* and *R. hookeri* forests [3]. Fortunately, when the financial profit in long run is clearly perceived to be higher than the short term one, rural people tend to protect the natural forests, and even they grow the trees [3]. So, *E. guineensis* forests which had high financial and socioeconomic profits were found not to be in danger [3].

Indeed, rural people around *B. aethiopum* forests enjoy its sap wine, so some persons are collecting this juice through the whole year as their main job. We assume that, finding ways to enhance the socio-economic profit of *B. aethiopum* ripe fruits may lead to the protection of its natural forests, or better, the establishment of new farms. Its mature fruit fresh pulp contains, Carotenoids (26.6 mg), Vitamin C (134.82 mg), Magnesium (20.61 mg), Phosphorus (567 mg) and Calcium (107.61 mg) in 100 grams [4]. Interestingly, this fresh pulp was found to be very rich in polyphenols with more than 274.2 mg/100 grams [4]. Accordingly, dried at 70°C until constant weight, and extracting by decoction in distilled water, *B. aethiopum* pulp exhibited 447.87 milligrams gallic acid equivalent per gram of dried matter (mg G. A. Eq./g (DM)) basis [5]. In short, the nutritional value is clearly established.

Due to the climate change effect through rainfall shortage, and unpredictable weather, South Saharan African (SSA) countries are experiencing corn shortage [6]. Actually, overall cereals production is still seriously low, with less than 2 metric tons per hectare [6]. So, the instability in yellow corn availability makes necessary to look for ways of reducing yellow corn incorporation in poultry feed formulation, for alternative energy sources. Therefore, along with the objective of using *B. aethiopum* dried pulp in intensive poultry breeding and contribute to the reduction of malnourished children proportion in rural zones, the study aimed to assess the ripe fruits' parts, dried products protein, fat, total sugar content, and the metabolizable energy. In addition, calcium (Ca), iron (Fe), potassium (K), magnesium (Mg), sodium (Na) and phosphorus (P) contents were assessed. The hypothesis was that the drying temperature affects the dried pulp nutritional value. So, these experiments aimed to ascertain the good drying temperature that keeps a good nutritional value. In short, we believe that, finding ways for an industrial use of *B. aethiopum* mature fruits' dried pulp could help to revalue its esteem among the rural population and thus reduce *B. aethiopum* forests destruction.

# 2. Material and Methods

## 2.1. Samples Preparation

*Borassus aethiopum* fruits were collected in gardens, farms and in nature. Then, they were sorted [2]. Firstly, each whole fruit was weighed. Thereafter it was split into its different components, sepals, peel, pulp, and kernels. Then, again each part was weighed. These results were monitored, so that we could evaluate each part proportion in a whole fruit. Secondly, the pulps were dried in ovens at 40, 50, 60, 70 and 80°C, until reaching a constant weight. Afterward, they were crushed manually in a traditional wooden mortar and sieved [5]. The powder was kept in glass bottles completely wrapped in aluminum paper, put in plastic bags, and kept at room temperature until further analysis. Before an analysis, about 2 grams of powder were warmed up at its previous drying temperature for two hours in a digital screen oven (Froilabo Air Performance, from France).

## 2.2. Dry Matter Percentage

The dry matter determination was performed [7]. The porcelain crucibles were well cleaned and placed in an oven at 105°C for 30 minutes. Then, they were removed, cooled in a desiccator for 15 minutes and each was identified with a reference. Thereafter, each crucible was weighed and its weight was recorded $W_{cr}$. We weighed about 2 grams of sample and put it in the crucible ($W_1$: crucible + sample). The crucible containing the sample was then placed in the oven at 105°C for 24 hours. The next day, it was cooled in the desiccator for thirty (30) minutes and weighed ($W_2$: crucible weight + dried sample at 105°C). Then, the remaining material mass was the dry matter (DM), thus the percentage was computed.

## 2.3. Protein Content

The determination of nitrogen content was done following Kjeldahl method [8]. These steps are shortened as digestion; neutralization-distillation, titration with 0.01N NaOH. When the equilibrium point was reached, the solution turned from red to green. Finally, the amount of nitrogen was assessed. Then, this nitrogen percentage was converted into protein (N*6.25).

## 2.4. Fat Content

A well-mixed and homogenized sample was prepared, and about 1 gram ($M_S$) was weighed in a blotting paper ($M_1$: $M_s$+paper) and placed into an extractor. Then, a flask filled with 250 ml of hexane was placed below the extractor, and above we had a refrigerant. The heating temperature was set at 400°C, and the extraction lasted 2 hours. When it boiled, the hexane rose from the flask to the extractor, got in touch with the paper containing the sample, and extracted the fat. As soon as, the extractor was filled, the hexane went down by siphoning. At the end of the extraction, the paper containing the sample was placed in an oven for 2 additional hours at 105°C. Afterwards, it was cooled in the desiccator and weighed ($M_2$). By weight difference, the total weight loss was determined [8].

## 2.5. Fiber Content

The dietary fiber is the organic matter that remains insoluble after acid and alkaline treatments [7]. This analysis was carried out using the Fibertec apparatus. One gram of sample was weighed ($P_0$) and placed in a crucible of porosity 2, then we added 100 ml of boiling 1.25% sulphuric acid ($H_2SO_4$) solution. The whole was brought to a moderate boil for 30 minutes. Afterwards, the sample in the crucible was filtered, washed 3 times with hot water. Then 100 ml of boiling 1.25% sodium hydroxide (NaOH) solution was added and heated again for 30 minutes. Then, heating was stopped and we filtered and, washed 3 times again with hot water. Finally, acetone was added and allowed to act for 2 minutes and then filtered. The residue was placed into an oven at 103°C overnight. The next day, it was removed, cooled in a silica desiccator and then weighed ($P_1$). Then, it was incinerated in the furnace at 550°C for 2 hours, cooled in the silica desiccator and weighed ($P_2$). The amount of fiber was obtained [7].

## 2.6. Minerals Composition

For minerals assessment, a clean porcelain crucible was weighed ($W_{cr}$), and about 5 grams of sample were put in it ($W_1$, crucible + sample). Following, it was placed in the muffle furnace at 550 °C for 8 hours, thus we obtained the ash. After, the crucible was cooled in the desiccator, weighed and its weight was recorded as $W_2$ (crucible + ash). Then, the portion of mineral was computed [7].

## 2.7. Total Carbohydrates, and Metabolizable Energy (ME)

After the results of dry matter, protein, fat, and ash analysis, the total carbohydrates were evaluated by difference [9]. Again, for the metabolizable energy computation, we used the coefficients related to all vegetable, except lemons, applied on protein, fat and total carbohydrate [9]. So, all contents were reported in percentage on dry matter basis (1). Finally, with [9] (2), we computed the metabolizable energy (ME) in kilocalories per kilogram (kcal/kg (DM)).

$$(\%)Total\ carbohydrates = 100 - \%(protein + fat + water + ash) \quad (1)$$

$$ME_{(kcal/g)} = 3.36 * Protein + 8.37 * Fat + 3.6 * (Total\ Carbohydrates). \quad (2)$$

For a comparison purpose, we also used poultry metabolizable energy assessment model (4) [10]. The starch was evaluated with (3) [11]. In these equations, all data should be in percentage.

$$Starch = 0.9 * (Total\ carbohydrate - Total\ sugars) \quad (3)$$

$$ME_{(MJ/kg)} = 0.155 * Protein + 0.343 * Fat + 0.13 * (Total\ Sugar) + 0.167 * Starch. \quad (4)$$

Where, ME: Metabolizable energy; MJ: Mega joule.

## 2.8. Total Sugars Content

Total sugar assessment methodology was slightly modified to comply with *B. aethiopum* pulp powder high absorbency [12]. So, to 5 grams of sample introduced into a 200 ml flask was added 50 ml of distilled water heated to 60°C. The mixture was then stirred until cooling. After this infusion, the mixture was centrifuged at 4,000 rounds per minute for 10 minutes and the supernatant was filtered with paper filter (Prat Dumas France, ϕ190 mm, Lot nº 106-12-0315, Ref: j019106-100 units). The filtrate was placed into a 100 ml volumetric flask and filled with distilled water to the gauge line. Because of the pulp high sweetness, again, 1 milliliter of the medium was collected, placed in 50 ml volumetric flask, and then filled with distilled water to the gauge line. Subsequently, 100 µl of the extract were collected, and introduced into a test tube. Then, 0.9 ml of distilled water, 1 ml of phenol (5%, w/v) and 5 ml of analytic concentrated sulphuric acid (95%) were added, successively. The mixture was left to stand about 8 hours at room temperature in dark. Finally, we proceeded with JASCO V530 UV/Vis spectrophotometer readings at 490 nm with distilled water as a blank. The total sugar (S) contents were given in micrograms per milliliter (µgS/ml) [12]. The result can be converted into micrograms of total sugars per milligram of sample (µgS/mgSa) by multiplying by a factor of 70 (7 ml/0.1 mg), where 7 ml is the final medium volume used for readings, and 0.1 mg is the corresponding weight of the sample in this final medium. A calibration curve was previously established, based on a range of 1 µg/ml glucose stock solutions prepared under the same conditions as the test (Figure 1). Finally, this content is reported to the dry matter basis (5).

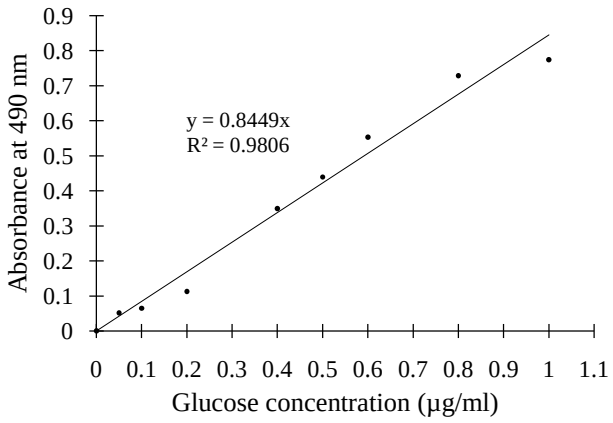


**Figure 1.** Standard curve for total sugars assessment established with glucose solutions

$$Total\ Sugar\ Content = \frac{\mu g.S}{ml} * \frac{70ml}{mg.Sa * DM} = \frac{70\mu g.S}{mg.Sa * DM}. \quad (5)$$

## 2.9. Ca, Mg, K, P and Trace Elements Content

About 2 grams of sample were put in a 30 ml porcelain crucible, which was then placed in a muffle furnace set at 550°C for 2 hours [7]. After cooling the ashes, 2 ml of chloric acid (HCl) solution were added. Then, it was heated on a hot plate at moderate temperature. Thereafter the evaporation, the sample was placed in an oven at 100°C for 1 hour. Then, 2 ml of chloric acid solution were added. Then, the crucible was rinsed, and the solution was filtered into a 100 ml flask. Following the filtration, the extract was collected for Ca, Mg, K and the trace elements (Fe, Na) determination, by using atomic absorption spectrometry. The determination of the phosphorus extract was carried out by Spectro-colorimetry at 400 nm, after the phosphomolybdic complex development.

## 2.10. Fatty Acids Profile

The total fatty acids profiles were carried out at INRA, Joint Research Unit 1348, 35590 Saint-Gilles, Rennes, France. The fatty acid profiles were determined by gas chromatography (GC) method (Agilent 6890N, Bios Analytic, Toulouse, France). The chromatograph was equipped with an injector model 7683. A fused silica capillary column was used (BPX 70, 60 m x 0.25 mm, SGE, Villeneuve-St Georges, France) with a stationary polar phase of 70% cyanopropyl polysilphenylene - siloxane (0.25 µm film thickness). The flame ionization detector

temperature was maintained at 260°C, and that of the injector was 250°C with a split 1:10 ratio. The gas carrier was helium, and the flow rate was constant, 1.5 ml / min. The initial oven temperature was 150°C, then increased from 1.3°C/min to 220°C, then from 40°C / min to 260°C, held at 260°C for 5 min [13].

### 2.11. Statistical Analysis

The data were generated by 3 replicates and submitted to an analysis of variance (ANOVA), using XLSTAT 2014. The least square means were separated according to Duncan multiple range tests in a confidence interval of 99% for the chemical analysis data, and 95% for *B. aethiopum* fresh fruits' parts.

## 3. Results and Discussion

### 3.1. Fruits' Parts

In normal development conditions, when there is no ovary abortion, each normal fruit contains 3 kernels. But, some fruits were found to have one or two kernels only. In the aim to avoid getting hurt by the sharp knife, the small fruits were discarded. So, herein data are about the fruits containing at least 2 kernels (Table 1). The fruit sizes are still statistically much spread in a very large range, regarding Cameroun *B. aethiopum* fruit standards [2]. While we had an average of 1,591.35±459 grams per whole fruit with a coefficient of variation of 28.84%, [2] announced a mass of 1,324.55±86 grams for the heaviest, in Kousseri zone. Looking at our findings, their data were less dispersed.

The large range we got may be due to varied sources. 1) The tree age is important. In fact, old trees tend to bear big fruits while young trees have middle size ones. 2) Human action on environment greatly affects fruit sizes. In fact, without bushfires, trees tend to bear a large number of big fruits, while under bushfires, the fruits are less and have generally an average size. When people burn the forests, bushfires destroy some green leaves, thus reduce the tree photosynthesis ability. Since the fruits are the reserves of the synthesized organic matter, when trees metabolism is reduced, the resulted reserves are slowed down. Accordingly, the biggest fruits were collected in gardens or farms under old trees, while those collected in the wild under annual bushfires were relatively small. So, we got some small fruits weighing 794 grams. 3) The gap on whole fruit mass between Kousseri (Cameroon) and Yamoussoukro (Côte d'Ivoire) may be due to the difference between these zone rainfalls. Since Kousseri is a Sahelo-Soudanian zone (latitude 12°04' North), whereas Yamoussoukro is in a transition zone between the forest and the savannah (latitude 6°49' North), it rains more in Yamoussoukro than in Kousseri, thus the fruits tend to be bigger at Yamoussoukro than those from Kousseri.

In fact, the first edible part for human nutrition is the yellow-orange colored pulp. Then after sowing the ripe fruits, with the hypocotyls, people make some flour [4]. When the peel is taken off, the pulp can be removed from the kernels. Herein results showed an important pulp mass average per whole fruit, 516.73±183 grams (Table 1a). Accordingly, this result is closed to 512±37 grams [2].

**Table 1. Fruits, sepals, peel, pulp and kernels weights and their percentages (a); and Pearson correlation matrix (b) showing the correlation coefficient between the components**

a. Fruits' parts

| Variable | Minimum | Maximum | Mean | SE | Cv (%) |
|---|---|---|---|---|---|
| Fruits (g) | 794.12 | 3,012.20 | 1,591.35 | 458.92 | 28.84 |
| Sepals (g) | 36.00 | 179.04 | 95.33 | 32.86 | 34.47 |
| Peels (g) | 101.06 | 624.40 | 276.54 | 83.70 | 30.27 |
| Pulps (g) | 197.04 | 1,207.41 | *516.73* | *183.00* | 35.41 |
| Seeds (g) | 262.04 | 1,277.35 | 677.82 | 215.57 | 31.80 |
| Sepals (%) | 2.74 | 10.19 | 6.02 | 1.42 | 23.61 |
| Peels (%) | 4.89 | 28.90 | 17.78 | 4.00 | 22.51 |
| Pulps (%) | 22.16 | 61.58 | ***32.26*** | ***5.03*** | 15.59 |
| Seeds (%) | 27.31 | 56.25 | 42.37 | 5.08 | 12.00 |

b. Coefficients of determination ($R^2$)

| Variables | Fruits | Sepals | Peels | Pulps | Seeds |
|---|---|---|---|---|---|
| Fruits | 1 | | | | |
| Sepals | 0.5798 | 1 | | | |
| Peels | 0.5498 | 0.3579 | 1 | | |
| Pulps | *0.8209* | 0.4674 | 0.3312 | 1 | |
| Seeds | *0.8869* | 0.3972 | 0.4187 | 0.6125 | 1 |

Notes: Masses are in grams (g), n=160 fruits, SE: Standard Error, Cv: Coefficient of variation, significance level α=0.05.

This result clearly states that we can expect more than a half kilogram of pulp per normal fruit that weights 1,590 grams. Additionally, this pulp represents almost 32.26±5% of the whole fruit mass. Furthermore, the Table 1b reveals a good correlation coefficient between the whole fruit and its derived pulp mass. Indeed, the coefficient of determination ($R^2$) equals to 82.09%, whereas the whole fruit weight forecasts the kernels mass with more accuracy ($R^2$=88.69%). Hence, a big fruit will allow an important pulp mass, and big seeds. On overall, in exception of the very hard seed hulls, the guinea-pigs (*Cavia porcellus*) and the rabbits (*Oryctolagus cuniculus*) can eat the fresh hard white albumen, sepals and peels. A careful look shows that the sum of the proportion of the four factors is just 98.43% and not 100% because some non-negligible dust is always under the sepals, and of course, after taking them off, the fruits were cleaned again. In addition, during the operations, some pulp was lost on the laboratory tables. Then, these losses represented 1.57%.

### 3.2. Protein (N*6.25), and Fat Content

Looking at protein content, unless the laboratory has sophisticated equipment for analysis, the nitrogen (N) content conversion factor to crude protein is 6.25 [9]. So, the drying temperature effect on the protein trend can be accurately followed through nitrogen (N) behavior (Figure 2a). The results revealed that protein content was inversely proportional to the increasing drying temperature (T). Moreover, looking at the curve shape, 2 intervals are clearly distinguishable. The first goes from 40 to 60°C and

the second from 60 to 80°C. The corresponding flow charts showed very high correlation coefficients between protein percentage and the drying temperature, those were 99.58 and 90.87% for intervals 40-60°C and 60-80°C, respectively (6), and (7).

$$Protein(\%) = -1.3356*T + 12.924; \quad R^2 = 99.58\%, 40 \le T \le 60°C, \tag{6}$$

$$-0.2762*T + 9.294; R^2 = 90.87\% \quad 60 \le T \le 80°C \tag{7}$$

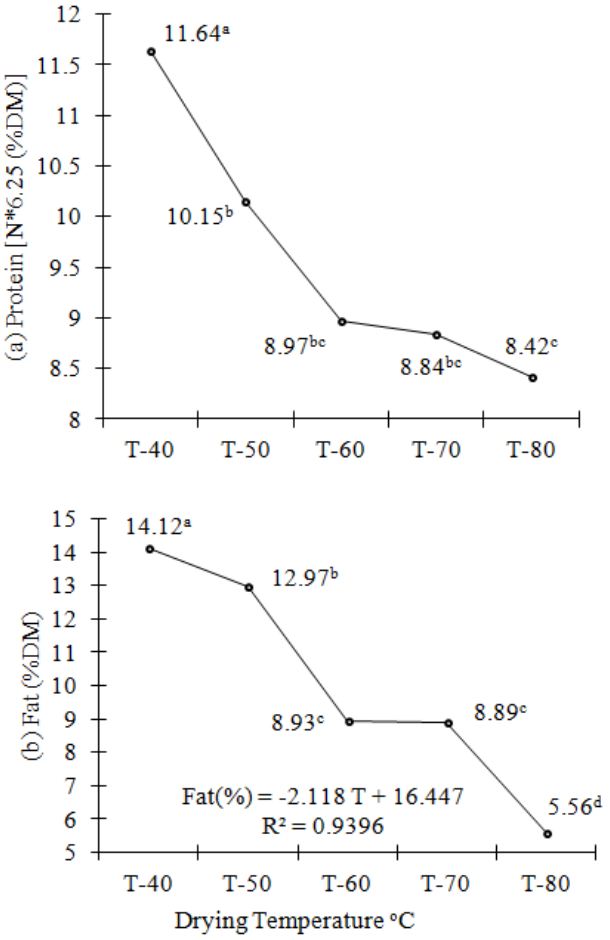


**Figure 2.** Drying temperature effect on (a) Protein and (b) Fat contents. Means with different superscript significantly differ, by Duncan multiple ranges test (P<0.01)

From 40 to 60°C, an increase of 20°C leaded to a decrease of 22.94% of the protein content, because it dropped from 11.64 to 8.97%, and the results were statistically different (P<0.01) (Figure 2a). This trend is in accordance with [14], who argued that proteins may be subjected to denaturation under heat stress. Furthermore, this denaturation may be reversible or irreversible by cleaving hydrogen bridges, ionic and hydrophobic bonds. Likewise, [15] observed that by drying the lactic gel samples at 80, 85, 90 and 95°C, the protein proportions were 4.86, 4.71, 4.49 and 4.04%, respectively. Similarly, when heat treatment was applied to *Citrillus lanatus* seeds for its incorporation in animal feedstuffs, fat and protein contents decreased by 30% from 47.01% to 32.9%, and by 26.94% from 68.03% to 49.70%., respectively [16]. Also, due to its important protein content, the edible mushroom, *Volvariella volvacea* protein content fluctuated greatly under heat treatments [17]. So, during a roasting process, its protein content decreased by 28.14%, from 36.06 to 22.32% [17], respectively from raw to roasted product. Herein results revealed that, from 40 to 60°C the protein denaturation rate was the highest. But, beyond 60°C, the denaturation rate lowered and leaded to non-significant difference at 60, 70 and 80°C, with 8.97, 8.84 and 8.42% of protein, respectively. Nonetheless, at higher drying heat, some more denaturation occurred, so the protein contents were less. By removing some water from the matrix, the heat may lead to some irreversible denaturation. In fact, the unfolded peptide chains may have been stabilized by interacting with other chains [14]. Due to the observed high solubility of the samples during the extractions in distilled water, 70% acetone and 70% methanol media [5], the heat may have caused an irreversible denaturation that destroyed the highly ordered structure [14], so leading to some conversions.

Beside the heat effect on protein, this nutrient content should be considered. Referring to the whole corn grain dried under the sun, its protein content fluctuated between 7.9 and 8.3% [18], even lower 7.2% [19]. Herein outputs ranged between 8.42 (70°C) for the lowest, and 11.64% (40°C) for the highest. So, this dried pulp exhibited a higher protein content than the whole yellow corn grain. Concerning the fat (Figure 2b), the trend was alike protein content following the drying heat. In the experiment drying temperature interval from 40 to 80°C, for each step up of 10°C, the fat ratio dropped for 2.12% (8).

$$Fat(\%) = -2.12*T + 16.447; R^2 = 93.96\%. \tag{8}$$

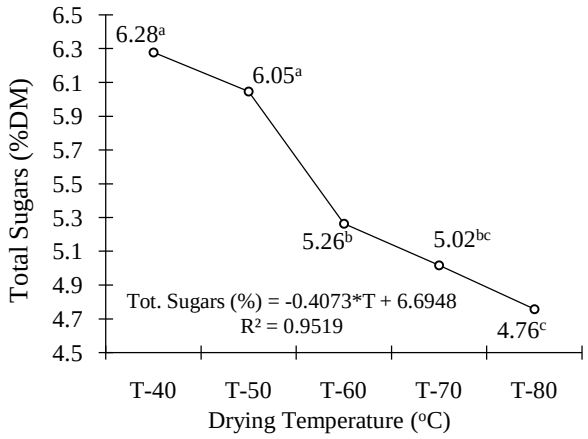


**Figure 3**. Drying temperature effect on total sugars content on dry matter basis. Means with different superscript significantly differ, by Duncan's multiple ranges test (P<0.01)

These decreasing sugar contents alongside an increasing drying temperature agreed with [14], when they assessed the temperature dependence of some sugars relative sweetness. Furthermore, they discovered that during the drying process, while D-Glucose content decreased, following an increasing drying heat, some new products such as fructopyranose and fructofuranose appeared. In the same way, drying Pumpkin (*Cucurbita pepo*) pulp into an oven at 45°C until reaching a constant mass, [20] observed that fructose and glucose contents decreased from 18.87 to 13.47 and from 17.77 to 12.84%, respectively, meaning some losses of 28.59 and 27.76%.

In fact, these non-enzymatic browning reactions between proteins and sugars are well documented [20,21]. To summarize these views, [21] stated that this non-enzymatic glycosylation or glycation is a covalent attachment of sugars to α- or ϵ-$NH_2$ groups of amino acids and proteins to form glycated proteins. Therefore, when a fruit contains non-negligible content of proteins and sugars, during the drying process, the glucose reacts with the proteins. After the Amadori product rearrangements, the final products may be β-furanosyl, or β-pyranosyl [21]. Moreover, fructose can also be engaged in similar reactions, leading to fructoselysine formation [14].

## 3.3. Metabolizable Energy

The metabolizable energy (ME) evaluation follows 2 methods [9]. The first one is based on the total carbohydrates, and the second is based on the available carbohydrates [9]. Due to the sensibility of the models, we chose for the total carbohydrates method, thus, the total ME. Obviously, some undigested dietary fibers may be fermented by the intestine micro flora, and the resulted gases such as the carbon dioxide, hydrogen and methane may participate to intermediary metabolisms [9]. We assumed that, these components are useful and may participate to the whole process. The results (Figure 4) revealed a similarity between the two methods [9,10]. Assuming that, through the years, the metabolizable energy assessment methods were improved with better scientific instruments, we focused on [9] model results. Remarkably, these two models leaded to the same tendency, and better [9] model delivered higher results. Indeed, the maximum gap of 0.54% increase was observed at 50°C, from [10] to [9] model; 3,813.69 and 3,834.28 kcal/kg (DM), respectively. Then, the remaining node gap percentages were 0.46% (3,767.67 versus 3,785.22 kcal/kg), 0.41% (3,601.91 versus 3,616.62), 0.38% (3,653.04 versus 3,667.03), and finally 0.27% (3,598.78 versus 3,608.33 kcal/kg) at 40, 60, 70 and 80°C, respectively.

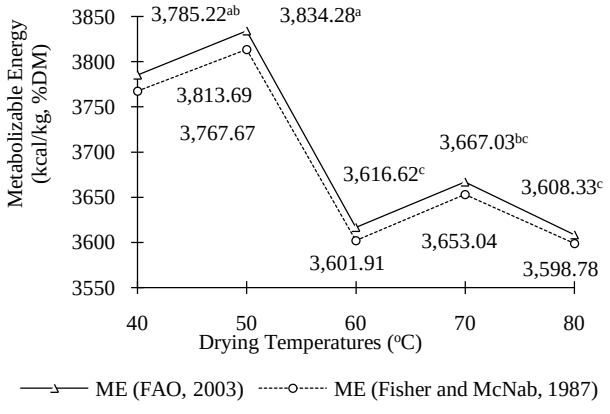


**Figure 4.** Drying temperature effect on metabolizable energy (ME) according to [9] and [10] models. Means with different superscript significantly differ, by Duncan multiple ranges test (P<0.01)

When we were powdering the dried products, the 40°C product was hardly crushable. Whereas, at 50°C, the pulp was easily separated from its fibers whose were remaining relatively hard. So, at 40 and 50°C, during the sieving process, the collected powder was relatively pure, free from small broken fibers. Thus, the flour was smooth. But, at 60, 70 and 80°C, the proportion of broken dietary fiber was important. In fact, at these relative high heats, the well dried fibers were broken in small particles quite easily and passed through the sieve. As a result, at 60, 70 and 80°C the fiber proportions in the sieved products were important, the collected flour was no longer smooth. Thus, the ashes' proportions were higher at 60, 70 and 80°C, whereas they were relatively low at 40 and 50°C.

Accordingly, through the method by difference for total carbohydrate assessment [9], the ME results were relatively higher at 40 and 50°C than those of 60, 70 and 80°C products. In fact, the ash rates were lower at 40 and 50°C than those of 60, 70 and 80°C. Nevertheless, *B. aethiopum* pulp is very energetic, because the lowest ME result recorded at 60°C was 3,616.62 kcal/kg. These *B. aethiopum* dried pulp ME results were similar to those reported for yellow corn [18].

Indeed, [18] found that the whole yellow corn grains, containing 7.9 to 8.3% of crude protein, delivered 3,346 and 3,516 kcal/kg (DM). Also, [19] announced 3,850 kcal/kg for the whole corn grain in Brazil. So, because *B. aethiopum* dried pulp ME fluctuated between 3,785.22 kcal/kg (DM) at 40°C and 3,608.33 kcal/kg at (80°C), it can be a good supplement in poultry feed, as energy source. Observing the similarity between the curves (Figure 4), we plotted the ME [9] on abscissas and ME [10] on ordinates. Then, we found that the derived curve (not shown) was almost a line. Furthermore, the correlation coefficient was very good ($R^2$=99.97%) (9).

$$ME[10] = 0.9636 * ME[9] + 119.44; R^2 = 99.97. \quad (9)$$

The metabolizable energy at 40°C (3,785.22 kcal/kg (DM)) was not statistically different from those obtained at 50°C (3,834.28 kcal/kg (DM)), and 70°C (3,667.03 kcal/kg (DM)) (P<0.01). But, 50 and 70°C energy results were significantly different. Similarly, when [22] assessed *B. aethiopum* pulp proximate nutrient compositions, they reported 3,670 kcal/kg (DM).

## 3.4. Minerals

The samples were firstly dried, then kept for upcoming analysis. Since drying consists in reducing the moisture, the contents of the ingredients that were not influenced by heat increased (Table 2). Alike [4,22], we discovered that *B. aethiopum* pulp is very rich in calcium. In agreement with [23] findings when they worked on corn under different drying temperatures, the calcium (Ca) content increased alongside the increasing drying heat. Unlike the depression they got on phosphorus contents, our results revealed stable outputs (P<0.01). Looking at phosphorus (P) content, it varied in a narrow interval, from 0.18 (40°C) to 0.16% (70-80°C), and these results were not statistically different. Similarly, to [23] observations on Ca/P ratio, Table 2 shows that the ratio significantly increased with the rising heat (P<0.01). Following an unchanged P content, the increasing Ca proportion induced an increasing ratio.

Thus, from 2.79 (40°C) to 4.95% (80°C), the 77.2% increase was significant (P<0.01). This high mineral content of *B. aethiopum* pulp was reported [22].

**Table 2. Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), iron (Fe), Sodium (Na) contents in the dried pulp on dried matter basis (%DM), and Ca/P ratio**

| T | P (%) | K (%) | Ca (%) | Mg (%) | Fe (ppm) | Na (ppm) | Ca/P |
|---|---|---|---|---|---|---|---|
| 40 | 0.18$^{a}$ | 1.03$^{a}$ | *0.51$^{c}$* | *0.18$^{c}$* | 5.11$^{a}$ | *6.04$^{a}$* | *2.79$^{c}$* |
| 50 | 0.18$^{a}$ | 1.19$^{a}$ | *0.55$^{bc}$* | *0.19$^{c}$* | 6.18$^{a}$ | *5.87$^{a}$* | *3.04$^{bc}$* |
| 60 | 0.17$^{a}$ | 1.28$^{a}$ | *0.69$^{abc}$* | *0.25$^{bc}$* | 4.60$^{a}$ | *5.77$^{ab}$* | *4.10$^{ab}$* |
| 70 | 0.16$^{a}$ | 1.22$^{a}$ | *0.77$^{ab}$* | *0.31$^{ab}$* | 4.36$^{a}$ | *4.81$^{bc}$* | *4.71$^{a}$* |
| 80 | 0.16$^{a}$ | 1.29$^{a}$ | *0.81$^{a}$* | *0.40$^{a}$* | 3.26$^{a}$ | *4.58$^{c}$* | *4.95$^{a}$* |
| μ | 0.17 | 1.20 | | | 4.44 | | |
| δ | 0.01 | 0.11 | | | 0.72 | | |

Means within a column, with different superscript significantly differ, by Duncan multiple ranges test (P<0.01). μ: Mean, δ: Standard Error, Confidence interval 99%.

In 100 grams of dried product, [22] got 142.4 mg of K, 41.81 mg of Ca, 64.77 mg of Mg, 3.15 mg of Fe, 17.8 mg of Na, 0.82 mg of Zn, and 1.3 mg of Cu. Regarding the dried pulp nutritional quality for Ca and P, with reference to corn, [19] announced 0.01 and 0.24% for Ca and P contents in corn, respectively. So, Ca/P ratio was 4.17. Thus, when *B. aethiopum* ripe fruit pulp is dried between 60 and 70°C, it may be a good phosphorus source for poultry feeding. Better, its potassium (K) content is higher than that of corn, 1.20% versus 0.28% for *B. aethiopum* pulp and corn, respectively [18]. In fact, Table 2 shows a non-thermal dependence for K, because its increases from 1.03 (40°C) to 1.29% (80°C) were not statistically different (P<0.01). Also, when [24] assessed *Raphia hookeri* fruit pulp minerals content, [24] reported similar important contents for Ca, K, Na, and P. For example, for raw and cooked products, [24] reported 875 and 800 mg for Ca, 1,075 and 675 mg for K, 16 and 13 mg for Na, and finally 76.8 and 63.7 mg for P, in 100 g of pulp.

Regarding Magnesium (Mg), its importance for health issues is widely reported, due to its acts as a cofactor in many biological functions [25]. Since magnesium salts are easily dissolved in water [25], by removing the water from the vegetable cells matrix during the drying process, magnesium content tends to increase. In contrary to [16] who reported a decrease of Mg content after roasting *Citrillus lanatus* seeds. These results show that, the heat affects the palm fruit pulp chemical composition.

## 3.5. Fatty Acids Profile

The drying heat seriously influenced the derived dried pulp fatty acid composition (Table 3). According to [26], an excess saturated fatty acids (SFA) consumption causes heart coronary diseases and increase the low lipoprotein density cholesterol (LDL-C) content in the blood. So, the foods containing an important proportion of unsaturated fatty acids are preferred [26]. In more details, lauric (C12:0), myristic (C14:0) and palmitic (C16:0) fatty acids are the main factors for LDL cholesterol increases in the plasma [26]. Herein results reveal that, all the way long, the unsaturated fatty acids (UFA) contents remained higher than those of SFA. Indeed, UFA and SFA percentages were 78.67, 76.35, 77.16 and 78.50 versus 21.33, 23.65, 22.84, and 21.50 at 40, 50, 70 and 80°C, respectively. Remarkably, within this high UFA proportion, the major role was held by the monounsaturated fatty acids (MUFA), with 69.78%, 67.99%, 66.02%, and 66.57%, in the same preceded heat order. Hence, from 40 to 70°C, the MUFA gradually decreased when the heat increased. Alongside these MUFA results, the polyunsaturated fatty acids (PUFA) contents were 8.89%, 8.36%, 11.14% and 11.93%, respectively, at 40, 50, 70 and 80°C, respectively.

Calling back Lavoisier concept ‘’nothing is lost, nothing is created, everything is transformed’’, a careful look at the changes alongside the increasing drying temperature showed that, MUFA contents were inversely proportional to the increasing heat. From 40 to 70°C, MUFA results lowered, whereas PUFA parts increased, except at 50°C (Table 3, Table 4). For example, from 40°C, MUFA contents decreased by 2.56, 5.39 and 4.6% at 50, 70, and 80°C, respectively (Table 4). This denaturation of MUFA is in accordance with [14] results, because they reported a decrease of Oleic acid proportion (C18:1(9)) from 45.3 to 42.9% when the soya oil was fried. Similarly, [27] observed fatty acids lessening from cold to hot fat extraction. Indeed, [27] reported a reduction from 49.09 to 48.99% for Linoleic acid (C18:2) and from 1.2 to 0.91% for Erucic acid (C22:1), respectively from cold to hot extractions. Alike, Olive oil which UFA contents are between 82.38 and 86.14% [28], can show fluctuations under different drying temperatures. Even for just 10 minutes exposure, from 180 to 220°C, [28] got 0.8% decrease of free fatty acid as percentage of Oleic acid.

**Table 3. *Borassus aethiopum* Mart mature fruit dried pulp Fatty acids profile (% of total fatty acid) under different drying temperatures, and some ratios**

| Fatty acids | Drying Temperature (°C) | | | |
|---|---|---|---|---|
| | 40 | 50 | 70 | 80 |
| Saturated fatty acids (SFA) | 21.33 | 23.65 | 22.84 | 21.50 |
| C12:0 - Lauric | 0.35 | 0.18 | 0.19 | 0.14 |
| C14:0 - Myristic | 0.34 | 0.28 | 0.25 | 0.23 |
| C15:0 - Pentadecanoic | 0.23 | 0.21 | 0.26 | 0.21 |
| *C16:0 - Palmitic* | *16.27* | *16.50* | *16.91* | *15.95* |
| C18:0 - Stearic | 2.48 | 3.41 | 2.84 | 2.70 |
| C20:0 - Arachidic | 0.34 | 0.60 | 0.40 | 0.40 |
| C22:0 - Behenic | 0.32 | 0.83 | 0.59 | 0.58 |
| C24:0 - Lignoceric | 1.01 | 1.64 | 1.40 | 1.28 |
| Unsaturated fatty acids (UFA) | 78.67 | 76.35 | 77.16 | 78.50 |
| *Monounsaturated fatty acids (MUFA)* | *69.78* | *67.99* | *66.02* | *66.57* |
| C16:1, n-9 - Hexadecenoic | 0.33 | 0.31 | 0.41 | 0.41 |
| C16:1, n-7 - Palmitoleic | 5.68 | 5.29 | 4.79 | 4.90 |
| C17:1 - Heptadecenoic | 0.33 | 0.39 | 0.30 | 0.33 |
| C18:1, n-9 - Oleic | 27.46 | 29.04 | 28.10 | 27.54 |
| C18:1, n-7 - Vaccenic | 35.83 | 32.79 | 32.29 | 33.39 |
| C20:1, n-9 - Eicosenoic | 0.15 | 0.16 | 0.13 | 0.00 |
| *Polyunsaturated fatty acids (PUFA)* | *8.89* | *8.36* | *11.14* | *11.93* |
| C18:2, n-6 - Linoleic | 3.04 | 3.37 | 2.63 | 2.56 |
| C18:2, n-? ……... | 3.08 | 1.92 | 2.67 | 2.63 |
| C18:3, n-3 - Linolenic | 2.77 | 3.08 | 5.85 | 6.75 |
| n-6/n-3 | 1.10 | 1.10 | 0.45 | 0.38 |
| MUFA/SFA | 3.27 | 2.87 | 2.89 | 3.10 |
| PUFA/SFA | 0.42 | 0.35 | 0.49 | 0.55 |
| UFA/SFA | 3.69 | 3.23 | 3.38 | 3.65 |

**Table 4. Variations in fatty acid contents (%DM) according to the drying temperature**

| Fatty acids | Drying Temperature (°C) | | | |
|---|---|---|---|---|
| | 40 | 50 | 70 | 80 |
| MUFA | 69.78 | 67.99 | 66.02 | 66.57 |
| *Variation from 40°C (%)* | *0* | *-2.56* | *-5.39* | *-4.6* |
| C16:1, n-7 - Palmitoleic | 5.68 | 5.29 | 4.79 | 4.90 |
| *Variation from 40°C (%)* | *0* | *-6.87* | *-15.67* | *-13.73* |
| C18:1, n-7 - Vaccenic | 35.83 | 32.79 | 32.29 | 33.39 |
| *Variation from 40°C (%)* | *0* | *-8.48* | *-9.88* | *-7.21* |
| C18:3, n-3 - Linolenic | 2.77 | 3.08 | 5.85 | 6.75 |
| *Variation from 40°C (%)* | 0 | +11.19 | +111.19 | +143.68 |

For an adaptation of the fungi *Neurospora crassa*, and *Paecilonyces persicinus* to their living environments, [29] discovered that their polyunsaturated fatty acid contents decreased when the living medium temperature increased. Specifically, Linoleic (C18:2), and Linolenic (C18:3) acid contents decreased by 7 and 19% for *Neurospora crassa*, and by 35.9 and 10.8% for *Paecilonyces persicinus*, respectively [29]. In contrary, in the aim to keep the cell membrane fluidity, the monounsaturated (C18:1) fatty acid content increased, by a hydrogenation process in these fungal organisms [29]. But, when it comes to a drying process, it is about a desaturation. So, two hydrogen and one oxygen atoms ($H_2O$) from a fatty acid are removed, and a carbon-carbon double bond is created. Consequently, herein, Linolenic (C18:3, n-3) fatty acid content increased gradually by 11.19, 111.19 and 143.68%, from 2.77% (40°C) to 3.08% (50°C), 5.85% (70°C) and 6.75% (80°C), respectively (Table 4). These Linolenic acid (C18:3, n-3) increases may be due to Palmitoleic (C16:1, n-7) and Vaccenic (C18:1, n-7) acids decrease. In fact, from 40 to 50, 70 and 80°C, these acid contents lessened by 6.87, 15.67, 13.73 and 8.48, 9.88, 7.21% for Palmitoleic (C16:1, n-7) and Vaccenic (C18:1, n-7) acids, respectively. These results agree with [20] conclusion for the unsaturated fatty acids such as Oleic, and linoleic acids. With consistency, under an increasing heat stress, these unsaturated fatty acid contents decrease [20].

### 3.6. Ratio n-6/n-3

The coronary heart diseases may be related to an inappropriate imbalance between n-6 and n-3 fatty acids, by increasing thrombotic and inflammatory states [26]. Additionally, [26] notified that, the lack of n-3 leads to hypertension, and immune disorders. Similarly, [30] summarized that a high n-6/n-3 ratio should be avoided. Moreover, because no trouble has been associated with a high content of n-6 [30], then the meals should have important n-3 contents. Table 3 shows that, when n-6 content was decreasing, that of n-3 was increasing. As a result, n-6/n-3 ratio quickly decreased, from 1.1 (40-50°C) to 0.45 and 0.38 at 70 and 80°C, respectively.

## 4. Conclusion

The nutritional value of *B. aethiopum* Mart mature fruit dried pulp is highly influenced by the drying temperature. In fact, it is due to its high content of sugars (6.28% and 5.02%), fat (14.12% and 8.89%), proteins (11.64%, and 8.84%), respectively at 40 and 70°C. During drying, covalent bonds of sugars to α- or ϵ-$NH_2$ groups of amino acids and proteins were formed, and leaded to glycated proteins. Hence, both protein and sugars contents decreased. In addition, because of its high percentage of unsaturated fatty acid (≥76.35%, which is the lowest at 50°C), this pulp may be helpful for an eventual palm oil (*E. guineensis*) enrichment, because that one has too much saturated fatty acids. Moreover, drying did seriously improve the product nutritional quality by depressing the n-6/n-3 ratio. Finally, the dried pulp is highly energetic, with more than 3,599 kcal/kg (DM). Thus, *B. aethiopum* dried pulp may be a good product for children malnutrition reduction in rural areas, and an important energy source for poultry nutrition.

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