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Total Polyphenols, Total Flavonoids, Condensed Tannins, and Antioxidant Activity of *Borassus aethiopum* (Arecaceae) ripe fruits' Peels, and Peel-Pulps, Dried at Different Temperatures

Kan Adonise Yao [a*], Tagouèlbè Tiho [a], Nahoulé Silué [b], Nogbou Emmanuel Assidjo [c] and Kisselmina Youssouf Koné [c]

[a] Department of Agriculture and Animal Science, Graduate School of Agriculture, Institut National Polytechnique Félix Houphouët Boigny, P.O. Box 1313, Yamoussoukro, Côte d'Ivoire.
[b] Agropastoral Management Institute (IGA), Laboratory of Animal Production and Health, Université Péléforo Gon Coulibaly de Korhogo, P.O. Box 1223, Korhogo, Côte d'Ivoire.
[c] Department of Food Science, Graduate School of Agriculture, Institut National Polytechnique Félix Houphouët Boigny, P.O. Box 1313, Yamoussoukro, Côte d'Ivoire.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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**Corresponding author: E-mail: kanadoniseyao@gmail.com;*

ABSTRACT

Aims: To measure their possible beneficial contributions on the rabbits' health, *Borassus aethiopum* ripe fruits' peels and combined peel-pulp were dried at 60, 65, 70 and 75^{o}C.
Place and Duration of Study: On January and February 2023, *Borassus aethiopum* ripe fruits were collected within the graduate school of agronomy at the National Polytechnic Institute Felix Houphouët Boigny in Yamoussoukro, Côte d'Ivoire.
Methodology: The unspoiled fruits were peeled. One sample was composed of peels without the pulps, and a second was composed of peel and pulp combined. Following, they were dried during 5 days in ovens. Then, the products were crushed, and sieved. Thereafter, the products were extracted with distilled water through maceration and decoction for 1 hour. Afterwards, total phenols (TP), total flavonoids (TF), condensed tannins (TC) contents, and antioxidant activity (AOA) were assessed.
Results: The best extracts were obtained through decoction. Moreover, the peels presented the highest TP extract for 0.082+/-0.001 mg GAE/g at 70^{o}C. Whereas the lowest TP extract was observed in the combined peel-pulp dried at 70^{o}C for 0.067+/-0.001 mg GAE/g. However, concerning the TF, the peel-pulp dried at 75^{o}C gave the best extracts through maceration, for 0.0450+/-0.007 mg QE/g. Globally, results revealed that the peels contain higher flavonoid contents than the combined peel-pulp. Regarding AOA, the extracts had much higher free radical scavenging capacity in the peels than in the combined peel-pulp parts. The highest antioxidant activity was observed with the peels dried at 70^{o}C for 6.653+*/-0.075* µmol TE/g, while the lowest value was observed with the combined peel-pulp dried at 70^{o}C for 1.996+*/-0.075* µmol TE/g. With condensed tannins, the best output was obtained with the peel dried at 60^{o}C for 0.468+/-0.003 µg CatE/g.
Conclusion: *Borassus aethiopum* ripe fruits' parts can be dried between 65 and 70^{o}C. So, they could be good sources of fibres and phytochemicals for rabbits' diets.

Keywords: Antioxidant activity; Borassus aethiopum; condensed tannins; rabbits; total polyphenols.

1. INTRODUCTION

Borassus aethiopum is a giant palm tree with a very hard false trunk, fasciculate roots, and long fan-shaped leaves. The plant is almost cosmopolitan, and its different parts are used in many fields such as economic, ecological, food and health [1]. Indeed, medicinal plants are a group of plants with great socio-economic importance because they contain active components used in the treatment of various diseases [2]. In addition, on the health level, *Borassus aethiopum* ripe fruits' extracts were able to neutralize *Staphylococcus aureus* and *Bacillus subtilis* bacteria [3]. *Borassus aethiopum* ripe fruits' pulp is rich in lipids and reducing sugars, which makes its conservation difficult because of fermentation problems under the sun [4,5]. Similarly, its carotenoid and vitamin contents are very high, indicating it as an important source of vitamins A and C [5]. Specifically, the pulp is also rich in minerals such as calcium, magnesium, and phosphorus [4,5]. Since ancient times, in view of preserving foods products, drying is one of the adequate preservation methods. Indeed, this process remains a common practice [6]. However, drying poor technique mastery leads to the nutritional and therapeutic values losses [7]. Moreover, *Borassus aethiopum* has significant anti-inflammatory and antioxidant properties [3,8]. Hence, this work hypothesis was that the drying temperature of the peels and combined peel-pulp would affect the resulting products' nutritional values. So, the subsequent objectives were to find the best drying temperature that would allow the best extractions and the fruit part that would contain more phenolic compounds including total polyphenols, total flavonoids, condensed tannins et the derived antioxidant activity.

2. MATERIALS AND METHODS

2.1 *Borassus aethiopum* Ripe Fruits' Collection

The fruits were collected within the graduate school of agronomy at the National Polytechnic Institute Felix Houphouët Boigny in Yamoussoukro, Côte d'Ivoire, and the surrounding areas. Then the fruits were carefully sorted, and the rotten ones were discarded. In

fact, the first step was to separate the peel and the pulp from the core. Then, the second step was to peel the fruit with the peel and the pulp together. Afterwards, the two components, including the peel and peel combined with the pulp, were dried in an oven at 60, 65, 70 and 75^{o}C for 5 days, until constant masses were reached [8]. Then the dried products were ground. Finally, through a laboratory sieve (Iso 3310-1BODY 36 LMESHS-Steel/RF S/N 04003699, Body = 200 mm × 50 mm), large particles were removed. The powders were put in glass bottles and kept in a dry place, protected from light until the analysis [8].

2.2 Samples Extraction

The powders were extracted by maceration and decoction, using only distilled water as a solvent. In a 100 mL bottle, 60 mL of solvent for the macerations, and 120 mL of solvent for decoctions were added to 1 g of powder. This attitude on different solvent volumes was adopted because of the extracts' darkness the through decoctions. During the extractions, the mixture was put on a magnetic stirrer. A magnetic bar was immersed in each mixture consisting of distilled water and the sample [8].

2.3 Maceration

Macerations were performed on RSLAB 5NC Multiplot 10 magnetic stirrer, and the plate rotation speed was set at 1100 rotations per minute. Next, a magnetic bar was dipped into each mixed solution. The various Erlenmeyer flasks were closed with aluminum foil to avoid solution evaporation. By increasing the durations recommended by Shewale and Rathod [9] by 30 min, the extractions lasted 1 hour. Finally, the different solutions were filtered with clean cotton and placed in the refrigerator before the analyses.

2.4 Decoction

A closed-circuit device was made by joining a cooling system and a heating system. It was used to perform the decoction extraction mode. Thus, the mixture was heated on an electric oven stirrer Agimatic-N, from West Germany), set at 100^{o}C. Here, 1g of sample was immersed in 120 mL of distilled water. In fact, putting 1 g of product in 60 mL of solvent led to a very dark extract, thus too concentrated for accurate analysis. However, during the calculations a dilution factor has been applied on decoction results. After observing the first bubble boil, the mixture boiled for 30 minutes, and the heater was turned off. Thereafter, the solution remained on the assembly for an additional 15 minutes to collect the last drops [8]. Secondly, the flask was removed from the stirrer-heater, and the whole was left for an additional 15 minutes for cooling. Finally, the solution was filtered.

2.5 Total Polyphenols Assessment

Yeddes et al. [10] method was lightly modified and used for the determination of total polyphenols. Succinctly, 2.5 mL of the Folin-Ciocalteu's reagent was added to 30 µL of extract. The mixture was then placed in the dark in a room at room temperature for 2 minutes. Then, 2 mL of sodium carbonate solution with a concentration of 75 g.L-1 was added. Then, the mixture was put for 15 minutes in a water bath at 50°C and cooled with tap water. Absorbance was read at 760 nm on a spectrophotometer with distilled water as a blank. A calibration line was made with gallic acid at different concentrations. The concentration of total polyphenols was expressed in milligrams per liter of gallic acid equivalent extract (mg GAE/mL). This concentration can be converted into mg GAE/g, by multiplying the concentration read on the spectrophotometer by 1/9.06 (Equation 1).

$$F_c\left(mg\frac{GAE}{g}\right) = R_c * \frac{1}{9.06*10^3}$$ (Equation 1, for macerations)

F_c stands for Final content.
R_c stands for Read content on the spectrophotometer.

Concerning the decoction extracts, the maceration conversion factor will be multiplied by 2 due to the volume of solvent which is 120 mL (Equation 2).

$$F_c\left(mg\frac{GAE}{g}\right) = R_c * \frac{1}{18.12*10^3}$$ (Equation 2, for decoctions the dilution factor is applied)

2.6 Total Flavonoids Assessment

The determination of total flavonoids was carried out according to Marinova et al. [11] method. In a 25 mL flask, 2.5 mL of the extract was added, then 0.75 mL of 5% sodium nitrate (NaNO2) was added. In addition, 0.75 mL of Aluminum Chloride ($AlCl_3$) was added. Then, the mixture was placed in the dark for 6 minutes. After this time, 5 mL of sodium hydroxide (NaOH, 1N) was added, and

the volume was completed with distilled water to 25 mL. Finally, the absorbance was read at 510 nm on a spectrophotometer. A calibration curve has been established. The total flavonoid contents of the extracts were expressed in mg of quercetin equivalent per liter (mg QE/L). This result can be converted to (mg QE/g) with equation 3 for macerations and equation 4 for decoctions.

$$F_c\left(mg\frac{QE}{g}\right) = R_c * \frac{1}{0.6}$$ (Equation 3; for maceration)

$$F_c\left(mg\frac{QE}{g}\right) = R_c * \frac{1}{1.2}$$ (Equation 4; for decoction the dilution factor is applied)

2.7 Condensed Tannins Evaluation

Condensed tannins were determined by the Vanillin method in an acid medium [12]. This method is based on the ability of vanillin to react with condensed tannin units in the acid presence to produce a colored complex measured at 500 nm. The vanillin reactivity with tannins only involves the polymer first unit. In 50µL of extract, 3 mL of 4% methanolic vanillin were added. Then, 1.5 mL hydrochloric acid (HCl) solution was added to the mixture. Then, the mixture was incubated in the dark for 15 minutes before reading in the spectrophotometer at 500 nm. Catechin was used as a standard and the results were expressed in microgram of catechin equivalent per millilitre (µg CatE/mL). This result was converted into microgram of Catechin Equivalent per gram (µg CatE/g) with equations 5, and 6. Abbassia et al. [13] discovered that, for condensed tannins assessment, distilled water was more efficient than methanol, ethanol, and acetone.

$$F_c\left(\frac{\mu g\ E.Cat}{g}\right) = R_c * \frac{1}{5.5}$$ (Equation 5, macerations)

$$F_c\left(\frac{\mu g\ E.Cat}{g}\right) = R_c * \frac{1}{11}$$ (Equation 6, for decoction the dilution factor is applied

2.8 Antioxidant Activity of Extracts

Among many ways to assess antioxidants activities, Awika et al. [14] highlighted the fact that 2,2'-azinobis-3-ethylbenzothiazoline-6-sulfonic acid (ABTS) is inexpensive and easy to use, and most importantly, its pH is stable. The method is based on the ability of compounds to reduce the radical-cation $ABTS^{*+}$ (2,2-azimobis-3-ethylbenzothiazoline-6-sulfonic acid). The test was carried out according to Teow et al. [15] method. The radical-cation $ABTS^{*+}$ was produced by reaction of 8 mM ABTS (87.7 mg in 20 mL of distilled water) and 3 mM of potassium persulfate (0.0162 g in 20 mL of distilled water) in a 1:1 ratio (v/v). The mixture was then incubated in the dark for 12-16 hours at room temperature. This $ABTS^{*+}$ solution was diluted with methanol to obtain a solution whose absorbance was at 734 nm. Thus, 3.9 mL of this dilute solution of $ABTS^{*+}$ was added to 100 µL of the extract. Afterwards, the mixture was put in the dark for 6 minutes. The residual absorbance of the $ABTS^{*+}$ radical was then measured at 734 nm in UV-visible spectrophotometer and should be between 20 and 80% of the absorbance of the blank. The concentrations were expressed in µmol Trolox equivalent per liter of extract (µmol Trolox E./L). The activity of the compounds is expressed in Equivalent Trolox (Trolox E.) which corresponds to the concentration of Trolox. Thus, the higher the E. Trolox value, the more effective the antioxidant. The concentration is converted into (µmol TE/g). The inhibition rate I (%) of $ABTS^{*+}$ was obtained with equation 7.

$$I(\%) = \frac{Abscontrol - AbsExtract}{\text{Abscontrol}} * 100$$ Equation 7

With Abscontrol is the absorbance of the diluted $ABTS^{*+}$ solution
AbsExtract is the absorbance of the extract.

With the spectrophotometer the concentration was given in micromole of Trolox equivalence (TE) of the extract per liter, converted in micromole TE per gram (Equation 8 and 9).

$$F_c\left(\mu mol\frac{TE}{g}\right) = R_c * \frac{1}{2.4}$$ (Equation 8, maceration)

$$F_c\left(\mu mol\frac{TE}{g}\right) = R_c * \frac{1}{4.8}$$ (Equation 9, for decoction the dilution factor is applied)

2.9 Statistical Analysis

The results were generated in triplicate. Subsequently, for the statistical tests, the results were subjected to a factorial analysis of variance (ANOVA II), using XLSTAT 2014. Least square means were separated according to the Newman-Keuls method in a 95% confidence interval. After examining the one-factor effect on the extracts, the results were given in terms of the interaction between the dried products drying temperatures and the extraction methods.

3. RESULTS AND DISCUSSION

3.1 Total Polyphenol Content

According to Visioli et al. [16] polyphenols are a large group of phytochemicals in fruits. Table 1 summarizes total polyphenols' contents according to the products that were the peels (Pe) and the peels plus the pulps (Pe+Pu) dried at 60, 65, 70 and 75^{o}C. Looking at the peels, and the peels combined with the pulps, the extracts significantly differ according to drying temperatures. Herein results show 4 different groups, following of least square means. Particularly, among the peels, the highest extraction was obtained at 70^{o}C, for 0.051±0.001 mg GAE/g of dried product. From 65 to 70^{o}C, total phenolic compound extraction increased by 0.005 mg GAE/g, and this gap represented an increase of 10.87% ($p<0.0001$). Moreover, from 60 to 65^{o}C and 65 to 70^{o}C, total phenols' extractions increased by 0.005 mg GAE/g at each step ($P<0.001$).

This increasing output alongside an increasing drying temperature may be because the hard peels became drier, so more friable. Then, it became easier to ground them and free more phytochemicals. Generally, the pulp portion acted as diluting the peels phytochemicals' contents. Because of the high protein content in *Borassus aethiopum* pulp [4], the polyphenols are sequestered [17]. So, a high drying temperature destroyed the proteins in pulps, and the polyphenols are released. Indeed, at 60, 65, and 70^{o}C, important protein content in the peels combined with the pulps limited total phenols' extraction. So, the drying temperature is an important factor that influences the products' nutritional values.

Obviously, *Borassus aethiopum* peels contain much more polyphenols compared to the peels combined with the pulps. For example, when these parts were dried at 70^{o}C, the peels released 0.051+/-0.001 mg GAE/g while the peels combined with the pulps delivered 0.040+/-0.001 mg GAE/g. Notably, this 0.011 mg GAE/g, which represented 27.50% increase from the peels combined with the pulps was highly important ($P<0.001$). These same tendencies were reported elsewhere. For instance, when Muralidhara et al. [18] examined the phenols content in mango fruits' peels and pulp. In fact, *Mangifera indica* var Neelum delivered 119.30 and 357.92 mg GAE/100 g, respectively for pulp and peels, thus an increase of 200.02% from pulp to peels [18]. Similarly, Lenucci et al. [19] concluded that phenolic compound contents in peels compared to that in pulp can reach 4 folds. Moreover, besides these fruits containing coloured pulp covered by peels, Costanzo et al. [20] reported that *Citrus reticulata* peels and pulps differ greatly on polyphenols contents. As an illustration, they extracted 0.9 mg GAE/g from the pulp, and 4.2 mg GAE/g from the peels, more than 4 folds.

Referring to Slimen et al. [21] work on prickly, the polyphenol quantities were much greater in the peels than in the pulp. Mainly, the polyphenol content in the peels of spiny *Opuntia ficus indica* was three times that of the pulp. Also, polyphenols content in the spineless skin was 2.21 times higher than that of the pulp. Similar results were observed for *Opuntia stricta*, whose peel polyphenols content was 1.66 times higher than that of pulp [10]. Again, peach fruits (Prunus) revealed that the total phenolic compounds amount ranged from 11.1 to 128.5 mg GAE/100 g fresh weight for pulp extracts and from 42.7 to 211.4 mg GAE/100 g for peels extracts [22]. In apricot varieties, Fan et al. [23] revealed that the peels polyphenol content was 1 to 3 times higher than that of the pulp tissues. According to Visioli et al. [16] polyphenols contribute to the organoleptic quality of foods derived from plants (colour, astringency, aroma, bitterness). These molecules play an important role by acting directly on fruits and vegetables nutritional quality, and their impact on consumer health through antioxidant effect, protective effect against the appearance of certain cancers. The beneficial effect of polyphenols on cardiovascular health has been attributed in part to their direct effect on blood vessels, more specifically on the endothelium.

Turning to the extraction mode, total polyphenols extracted relied heavily on the extraction mode, whose were the maceration and the decoction (Table 1, Fig. 1). Namely, for peels extraction from maceration to decoction at 70^{o}C, the polyphenols' extracts increased from 0.021+/-0.001 mg GAE/g to 0.082 mg GAE/g. This important increase was 290.48% yield improvement ($P<0.001$). Despite the protein presence in the pulp, the extractions of the portions of peels combined with the pulps were also improved. Indeed, when peels combined with pulps were dried at 65^{o}C, the polyphenols extracts were improved by 706.82%, from 0.009+/-0.001 mg GAE/g to 0.071+/-0.001 mg GAE/g. In fact, the decoction efficacy has been

well documented for decades. For example, Reynoso-Camacho et al. [24] mentioned that the citrus by-products' decoction allows important phytochemicals extraction. Furthermore, Touré et al. [25] compared decoction and maceration extractions on *Parkia biglobosa* parts, and concluded that from maceration to decoction, the extracts were improved by 49.03%.

Without a doubt, decoction was the best extraction method for total polyphenols. Summing up, the best drying temperature was 70°C, and the most valuable product was the peels for total polyphenols' content. Indeed, at 70°C, and through the decoction the peels delivered 3.85 times the amount collected through maceration.

3.2 Total Flavonoids Contents

According to Stoclet and Schini-Kerth [26], flavonoids are the most abundant polyphenolic compounds found in plants. Mainly, these flavonoids contained in fruits, leaves and bark have protective effects against various conditions [26]. Herein results revealed that the combination of peel and pulp were better source of total flavonoids (Table 2). In fact, the combined peels and pulp delivered 0.302+/-0.005 mg QE/g versus 0.256+/-0.005 mg QE/g, and the gap was an increase of 17.97% (P<0.001). Certainly, high protein, fat and reducing sugar contents inhibit the extraction of phytochemicals [4]. Also, a high drying heat destroys protein, fat and reducing sugars contents [4]. Drying at 75°C for 5 days led to a severe dry of peels. During drying, the peels rolled up and closed the pulp internally, thus protecting it against severe heat. So, the pulp was well dried and less exposed to the heat. Thus, the well dried internal pulp was a good source of total flavonoid while drying at 75°C. Admittedly, 75°C was not a good drying temperature for the peels, because they allowed only 0.132+/-0.005 mg QE/g.

Table 1. Total polyphenol contents (mg AGE/g) (mg GAE/g) according to the products

Product	µ +/-SE (mg GAE/g)	Products comparison	p-values
(Pe)70	0.051+/-0.001[a]		
(Pe)65	0.046+/-0.001[b]	(Pe)70 vs (Pe)65	<0.0001
(Pe+Pu)75	0.043+/-0.001[c]	(Pe)65 vs (Pe+Pu)75	0.0008
(Pe)60	0.041+/-0.001[d]	(Pe+Pu)75 vs (Pe)60	0.0203
(Pe)75	0.040+/-0.001[d]	(Pe)60 vs (Pe)75	0.1660
		(Pe+Pu)75 vs (Pe)75	0.0015
(Pe+Pu)60	0.040+/-0.001[d]	(Pe)75 vs (Pe+Pu)60	1
		(Pe+Pu)75 vs (Pe+Pu)60	0.0028
(Pe+Pu)70	0.040+/-0.001[d]	(Pe+Pu)60 vs (Pe+Pu)70	0.5249
		(Pe+Pu)75 vs (Pe+Pu)70	0.0008
(Pe+Pu)65	0.040+/-0.001[d]	(Pe+Pu)70 vs (Pe+Pu)65	0.8985
		(Pe+Pu)75 vs (Pe+Pu)65	0.0008

µ: Least square mean, SE: standard error,
Pe: Peel; Pe+Pu: Peel+Pulp; 60, 65, 70, and 75 (drying temperatures, °C).
[a, b, c, d]: Least square means bearing different superscripts in the column [µ +/-SE] differ significantly (P<0.05)

Table 2. Total flavonoid contents (mg QE/g) according to the products

Products	µ +/-SE (mg QE/g)	Products comparison	p-values
(Pe+Pu)75	0.302+/-0.005[a]		
(Pe)65	0.256+/-0.005[b]	(Pe+Pu)75 vs (Pe)65	<0.0001
(Pe)60	0.218+/-0.005[c]	(Pe)65 vs (Pe)60	<0.0001
(Pe)70	0.204+/-0.005[d]	(Pe)60 vs (Pe)70	0.0465
(Pe+Pu)60	0.169+/-0.005[e]	(Pe)70 vs (Pe+Pu)60	<0.0001
(Pe)75	0.132+/-0.005[f]	(Pe+Pu)60 vs (Pe)75	<0.0001
(Pe+Pu)65	0.131+/-0.005[f]	(Pe)75 vs (Pe+Pu)65	0.9182
		(Pe+ Pu)60vs (Pe+Pu)65	<0.0001
(Pe+Pu)70	0.093+/-0.005[g]	(Pe+Pu)65 vs (Pe)70	<0.0001

µ: Least square mean, SE: standard error,
Pe: Peel; Pe+Pu: Peel+Pulp; 60, 65, 70, and 75 (temperatures, °C).
[a, b, c, d, e, f, g]: Least square means bearing different superscripts in the column [µ +/-SE] differ significantly (P<0.05)

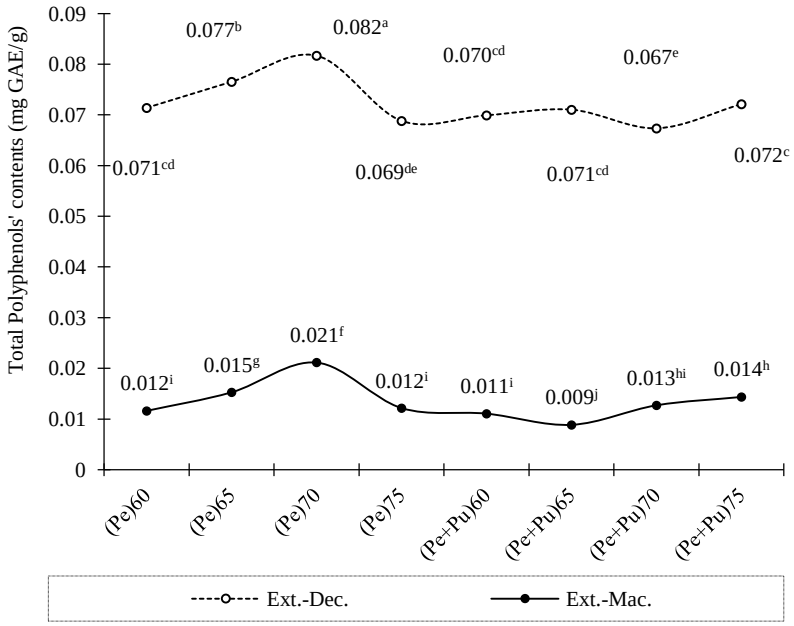

Fig. 1. Total polyphenols' contents (mg GAE/g) according to the extraction mode

σ=0.001; Pe: Peel; Pe+Pu: Peel+Pulp; 60, 65, 70, and 75 (Temperatures, °C).

a, b, c, d, e, f, g, h, i, j: Least square means bearing different superscripts differ significantly (P<0.05).

Looking at the peels (Sh, Fig. 2), from 65 to 75°C, an important loss was observed from 0.256+/-0.005 to 0.132+/-0.005 mg QE/g; resulting in a loss of 48.44%, which was significant (P<0.001). After the first position, only peels followed with moderate drying temperatures. Especially, 65, 60, and 70°C products delivered 0.256, 0.218, and 0.204+/-0.005 mg QE/g, respectively (Table 2, 0.001<P≤0.0465). Importantly, each variation of 5°C led to significant differences in extractions (P<0.001). Yeddes et al. [10] showed that flavonoid contents in peels of *Opuntia ficus* indica was higher than in pulps, 4-folds higher for the thornless and 2.30-folds higher for the spiny. In different peach varieties' peel extracts, flavonoid contents ranged from 21.9 to 94.9 mg EQ/100 g, while these amounts decreased in pulp extracts to 5 to 58.9 mg QE/100g [23]. So, the flavonoid contents determined in the peach peels were 1 to 3 times higher than those of the corresponding pulps [23]. This concentration is an asset for health, since flavonoids, by their function, protect blood vessels from cholesterol-related damage [10,23].

The extraction method had a huge impact on the extracts (Fig. 2). When the products were dried at severe heats, the maceration gave the best extracts. Conversely, when the products were obtained at moderate heat, the decoction gave the best extracts. So, the additional heat during the decoction tended to destroy the flavonoids because they are very sensible to the heat [27]. In fact, when the extraction time is set, phytochemicals extract tends to increase from low drying temperatures, reach a high extracts level, and then decrease alongside the drying temperature elevation [27]. To resume, Md-Yusof et al. [27] (2019) found that, when extracting total flavonoids in a medium of 80% of ethanol, the best drying temperature was 55°C. Above and below this reference of 55°C, the extracts decreased. This tendence of reaching a top extract surrounded by low extracts was also observed [28]. When the peels combined with pulps were dried at 75°C, an additional heat by boiling at 100°C during the decoction destroyed the flavonoids. In contrast, when they were extracted during maceration, at room temperature, the results were the best among others. So, peels combined with pulps dried at 75°C delivered 0.450+/-0.007 mg QE/g through maceration, while this quantity dropped to 0.154+/-0.007 mg QE/g through the decoction (Fig. 2, P<0.001).

Taking care only of the peels, total flavonoids extracted at 60, 65, 70 and 75°C were 0.311, 0.203, 0.192, and 0.097+/-0.007 mg QE/g, respectively. So, it may be concluded that, with pure peels, boiling at 100°C during the decoction revealed that alongside an increasing drying

temperature, the total flavonoids were destroyed increasingly. But drying at 60°C needed additional boiling during decoction to give an efficient result. Doubtless, drying at 60°C, the decoction improved the total flavonoids extract by 2.48 times, from 0.125 with the maceration to 0.311+/-0.007 mg QE/g with the decoction.

Borassus aethiopum ripe fruits' peels are good source of fibres, its fibrous pulp is rich in carotenoids, and it's a good source of reducing sugars too [4,29]. According to Gonzalez et al. [29], the rabbit body temperature fluctuates between 39.3 and 40.5°C, while ambient temperature goes from 5 to 35°C. So, its internal digestives fluids could be a good place for maceration at a moderate corporal temperature. Thus, drying the peels or the peels combined with the pulps at 65, 70 and 75°C could allowed good feedstuffs for rabbits. So, flavonoids antibacterial and many other feed advantages could be beneficial to rabbits.

3.3 Condensed Tannins Content

According to Naumann et al. [30], tannins are divided into 2 groups, whose are hydrolysable tannins (HT) and condensed tannins (CT). While hydrolysable tannins are gallic or ellagic acid esters linked to glucose, the condensed tannins or pro-anthocyanidins consist of flavan-3-ol subunits linked together to form oligomers and polymers. Altogether, HT and CT are defined as astringent, medium to high molecular weight polyphenolic compounds that bind and precipitate soluble proteins. So, their actions are important in the body. Moreover, Mueller-Harvey et al. [31] reported that, due to bacteria resistance to antibiotics, condensed tannins are alternatives for animals' gut health. Better, when the forages distributed to ruminants is rich in condensed tannins, the feed improved growth, milk, wool production, and fertility [31]. Most important is the ability of such forages to combat the effects of gastrointestinal parasitic nematodes [31].

Like the global behaviour during polyphenols assessments, peels are richer in condensed tannins than the combined peels-pulps portions (Table 3, Fig. 3). The condensed tannins behave like flavonoids. In fact, they were heat sensitive, from 60 to 75°C. In details, from 60 to 65°C, looking at the peels, CT extracts dropped from 0.248+/-0.002 to 0.153+/-0.002 µg CatE/g. This gap was 38.31% loss (P<0.001). Again, from 70 to 75°C, the peels CT extracts declined from 0.190+/-0.002 to 0.096+/-0.002 µg CatE/g, and it was 49.47% drop (P<0.001). Progressively, the best extracts from the combined peels-pulps portion appeared at 60, 70 and 75°C, with a unique 0.058+/-0.002 µg CatE/g value.

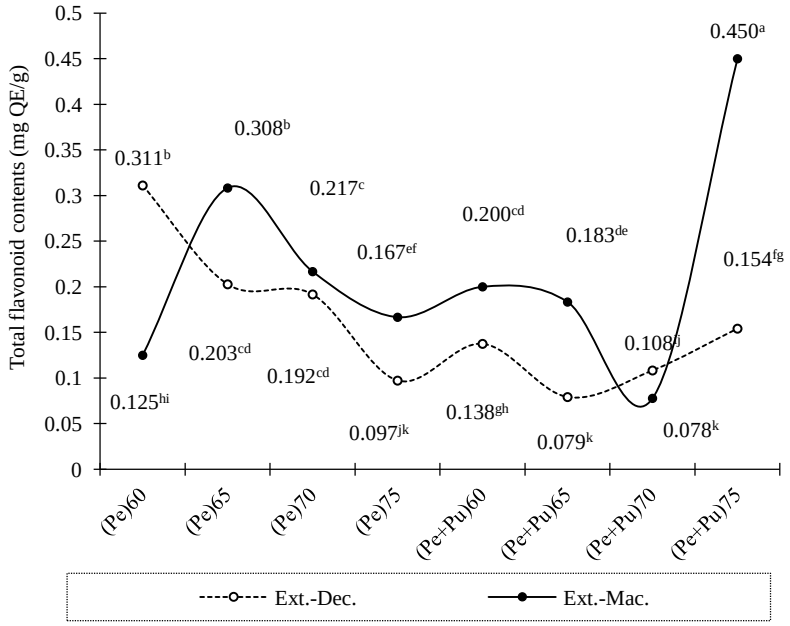

Fig. 2. Total flavonoids' contents (mg QE/g) according to the extraction mode

σ=0.007; Pe: Peel; Pe+Pu: Peel+Pulp; 60, 65, 70, and 75 (Temperatures, °C).

a, b, c, d, e, f, g, h, i, j, k: Least square means bearing same superscripts do not differ significantly (P<0.05)

Table 3. Condensed tannins contents (µg CatE/g) according to the products

Products	µ +/-SE (µg CatE/g)	Products comparison	p-values
(Pe)60	0.248+/-0.002[a]		
(Pe)70	0.190+/-0.002[b]	(Pe)60 vs (Pe)70	<0.0001
(Pe)65	0.153+/-0.002[c]	(Pe)70 vs (Pe)65	<0.0001
(Pe)75	0.096+/-0.002[d]	(Pe)65 vs (Pe)75	<0.0001
(Pe+Pu)60	0.058+/-0.002[e]	(Pe)75 vs (Pe+Pu)60	<0.0001
(Pe+Pu)75	0.058+/-0.002[e]	(Pe+Pu)60 vs (Pe+Pu)75	0.9677
(Pe+Pu)70	0.058+/-0.002[e]	(Pe+Pu)75 vs (Pe+Pu)70	0.8132
(Pe+Pu)65	0.034+/-0.002[f]	(Pe+Pu)70 vs (Pe+Pu)65	<0.0001

µ: Least square mean, SE: standard error,
Pe: Peel; Pe+Pu: Peel+Pulp; 60, 65, 70, and 75 (drying temperatures, °C).
[a, b, c, d, e, f]: Least square means bearing different superscripts in the column [µ +/-SE] differ significantly

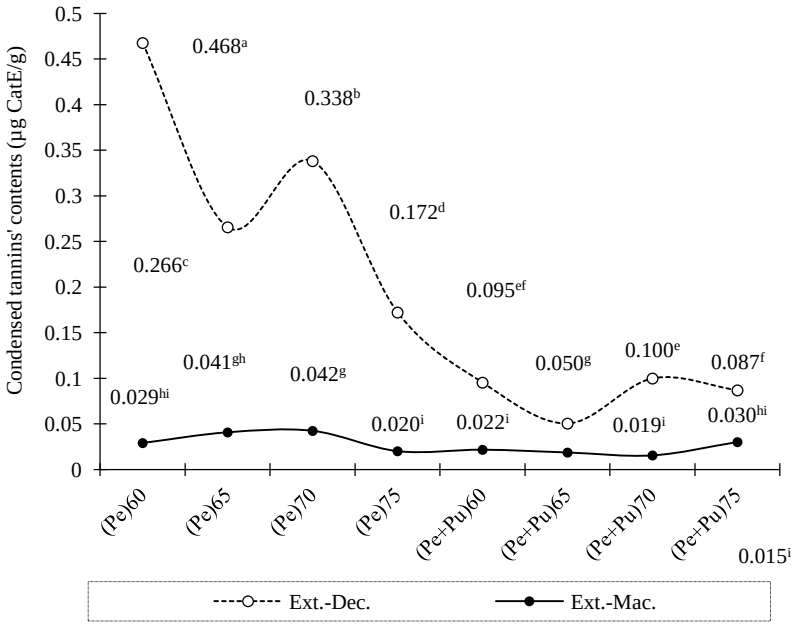

Fig. 3. Condensed tannins' contents (µgCatE/g) according to the extraction mode
σ=0.003; Pe: Peel; Pe+Pu: Peel+Pulp; 60, 65, 70, and 75 (Temperatures, °C).
[a, b, c, d, e, f, g, h, i]: Least square means bearing same superscripts do not differ significantly (P<0.05)

Rashmi et al. [32] concluded that the peels had 125-155% more tannin than the pulp, among mango varieties. Tannins values varied between 8 and 14 mg/g based on dry weight in the peel among the mango varieties, while in the pulp it was 3.5 to 10.6 mg/g based on dry weight. At different fruit maturity levels, tannins were observed more in the peels than in the pulp. Elsewhere, Morales et al. [33] found that condensed tannin contents of the different mango varieties ranged from 84.3 to 161.5 mg EC/100g dry weight. Moreover, Suleria et al. [34] showed that avocado peels contained a slightly higher tannin content than its pulp.

Abbassia et al. [13] work on Silybum marianum leaves showed that the solvent water had the highest contents of condensed tannins than methanol, ethanol, and acetone. Indeed, the condensed tannins gave a value of 3.86 mg TAE/g for the decoction and 2.30 mg TAE/g for the maceration with solvent water [15]. So, distilled water was a good medium for extraction. Maceration is not an appropriate method to assess condensed tannins (Fig. 3). Without a doubt, 60°C was the best drying temperature. Because CT extracts were 0.468+/-0.003 µg CatE/g with decoction, while with maceration this result was 0.029+/-0.003 µg CatE/g, 16.14 times lower than the precedent (P<0.001). Besides 60°C, the following good drying temperature was 70°C. Again, from maceration to decoction, CT extracts went from 0.042+/-0.003 to 0.338+/-

0.003 µg CatE/g, an increase of 8.05 times (P<0.001).

3.4 Antioxidant Activities

The antioxidant activities were higher with peels than that of peels combined with pulps (Table 4). Particularly, on peels level, two drying temperatures delivered similar results. For instance, when the peels were dried at 65 and 70°C, the antioxidant activities were 3.237+/-0.053 and 3.347+/-0.053 µmol TE/g, respectively (P=0.1543). Following, drying the peels at 75°C destroyed their phytochemicals by burning them. So, the extracts dropped from 3.347+/-0.053 to 1.898+/-0.053 µmol TE/g, meaning 43.29% loss, equivalent to 1.449+/-0.053 µmol TE/g (P<0.001). The combined peel-pulp parts' best drying temperature were 65 and 75°C. In effect, at 65 and 75°C, the peels combined with the pulps' antioxidant extracts were 2.027+/-0.053 and 1.995+/-0.053 µmol TE/g, respectively (similar, P=0.2137). Already, Arazo et al. [35] indicated that *Gaillonia tinctoria* fruits peel extracts had the highest antioxidant capacity and reached a maximum value of 2.7µM at 10µg/mL, compared to their pulps.

For example, Stojanovic et al. [22] tested peels and pulps of several peach varieties. They concluded that, all peach varieties peels' extracts showed significantly higher scavenging activities ranging from 0.2 to 0.4 µmol TE/100g fresh weight compared to pulp extract which ranged from 0.1 to 0.3 µmol TE/100g fresh weight. In the same way, Fratianni et al. [36] analysed the peels and pulps extracts of three *Citrus* varieties were. The results showed that the peels of the different varieties of *Citrus* have a trapping activity much higher than that of the pulp [36]. Similarly, the radical scavenging activity of the quince peel was higher than that of the flesh, with the lowest IC50 value of 52.34+/-7.3 µg/mL [37]. Again, Costanzo et al. [20] worked on *Citrus reticula* blanco and showed that the ability to trap free radicals is very significant. Specifically, the highest antioxidant capacity was observed in the peels compared to the pulps with respectively 17 µmol TE/g fresh weight and 4.8 µmol TE/g fresh weight [20].

Admittedly, the extraction method was important. Since all extractions lasted 30 min, the decoction was more effective (Fig. 4). In similarity with polyphenols, and condensed tannins, extracting through the decoction gave the best results for each dried product. Increasing the drying temperature from 65 to 70°C, and extracting the phytochemicals through decoction, significantly impacts the peels' antioxidant activity. Succinctly, the antioxidant activity increased by 3.42%, equivalent to a gain of 0.22+/-0.075 µmol TE/g, from 6.433 to 6.653+/-0.075 µmol TE/g (P=0.0473). Not only did the decoction improved the extraction, but also revealed that the peels phytochemicals' contents were higher than those of the combined peel-pulp parts.

While the maceration outputs lined up with the x line, the decoction results rose, and fluctuated between 2 and 7 µmol TE/g. So, the product obtained at 60°C extracts were 0.037+/-0.075 µmol TE/g and 4.322+/-0.075 µmol TE/g, respectively for maceration and decoction. Thus, the decoction permitted 116.81 folds the peels' extracts obtained through the maceration. Likewise, the extracts from the peels dried at 70°C, went from 0.041 to 6.653+/-0.075 µmol TE/g, respectively for maceration and decoction. Equally, the decoction result was 162.27 times higher than that of maceration.

Table 4. Antioxidant activities (µmol TE/g) according to the products

Products	µ +/-SE (µmol TE/g)	Products comparison	p-value
(Pe)70	3.347+/-0.053[a]		
(Pe)65	3.237+/-0.053[a]	(Pe)70 vs (Pe)65	0.1543
(Pe)60	2.180+/-0.053[b]	(Pe)65 vs (Pe)60	<0.0001
(Pe+Pu)65	2.027+/-0.053b[c]	(Pe)60 vs (Pe+Pu)65	0.0502
(Pe+Pu)75	1.995+/-0.053b[c]	(Pe+Pu)65 vs (Pe+Pu)75	0.2137
(Pe)75	1.898+/-0.053[c]	(Pe)60 vs (Pe)75 (Pe+Pu)75 vs (Pe)75	0.0038 0.2067
(Pe+Pu)60	1.691+/-0.053[d]	(Pe)75 vs (Pe+Pu)60	0.0099
(Pe+Pu)70	1.014+/-0.053[e]	(Pe+Pu)60 vs (Pe+Pu)70	<0.0001

µ: Least square mean, SE: standard error,
Pe: Peel; Pe+Pu: Peel+Pulp; 60, 65, 70, and 75 (drying temperatures, °C).
[a, b, c, d, e]: Least square means bearing different superscripts in the column [µ +/-SE] differ significantly (P<0.05)

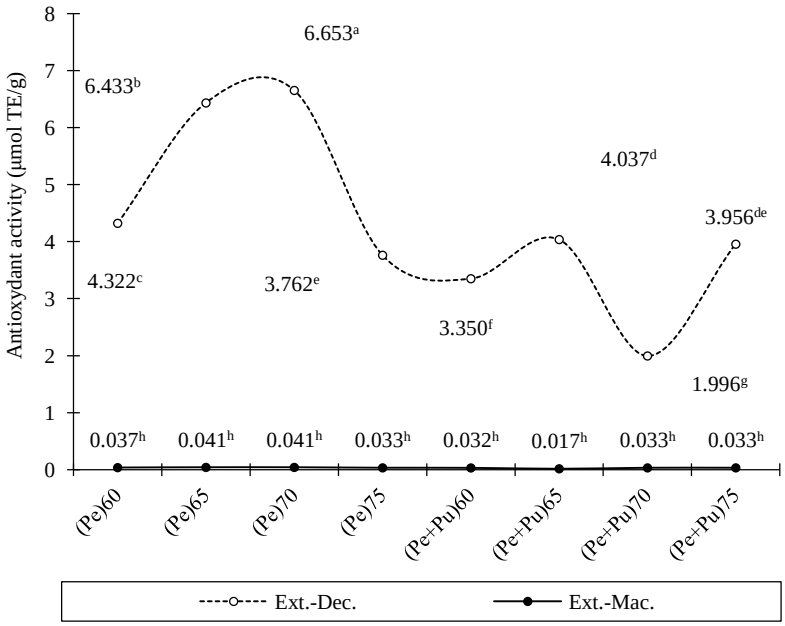

Fig. 4. Antioxidant activity (µmol TE/g) according to the extraction mode

σ=0.075; Pe: Peel; Pe+Pu: Peel+Pulp; 60, 65, 70, and 75 (Temperatures, °C).

a, b, c, d, e, f, g, h: Least square means bearing same superscripts do not differ significantly (P<0.05)

4 CONCLUSIONS

Borassus aethiopum fruits can be classified among the natural resources that provide the rural people food and off-farm incomes. This fruit has a high-water content and has the particularity of being good sources of sugars, vitamin C, minerals, and fibre. Locally, people use *Borassus aethiopum* products for different purposes such as therapeutic, drink as sap wine, and ripe fruits' pulps consumption. Drying the ripe fruits' pulps and peels is a good preservation method to avoid different losses. When it comes to assessing the nutritional value of *Borassus aethiopum* ripe fruits' dried products, the drying temperature and the extraction method are very important. To sum up, at the first stage, the drying temperatures should range between 65 and 70°C. Thereafter, at the second stage, when the extractions are performed with distilled water, the decoction is the best, compared to the maceration. The best polyphenols extracts were obtained with the peels dried at 70 and 65°C for 0.082 and 0.077+/-0.001 mg GAE/g, respectively (P<0.001). When the portions of peel-pulp were dried, the best drying temperature was 75°C, and the output was 0.072+/-0.001 mg GAE/g. This gap of 0.010+/-0.001 mg GAE/g was significant (P<0.001). Naturally, these important extracts were sustained by high antioxidant activities. So, dried at 70 and 65°C, the peel decoction extracts' antioxidant activities were 6.653 and 6.433+/-0.075 µmol TE/g, respectively (P<0.001). Due to condensed tannins (CT) effects on gastrointestinal parasitic nematodes, they were examined in the extracts. Interestingly, the products extracts were rich in condensed tannins. Particularly, the peels' extracts were richer than the combined peel-pulp portions. Furthermore, the decoction was the best method to extract the condensed tannins. So, the dried peels at 60, 65 and 70°C allowed the extraction of 0.468, 0.338 and 0.266+/-0.003 µg CatE/g, respectively. Moreover, within these drying temperatures, from a step to another, the difference was significative (P<0.001). To conclude, firstly *Borassus aethiopum* ripe fruits are good sources of polyphenols. Moreover, when the fruits' parts are dried at a temperature between 65 and 70°C, they may provide important condensed tannins. Secondly, ripe fruits contain some fibrous orange-yellow pulp, thus rich in carotenoids. So, this natural resource can be a good fibre source for rabbits, and the dried fruits' parts could be beneficial for rabbit gut and gastrointestinal health. In perspective, the peels may be sliced in fine parts, dried at room temperature, and assess its nutritional value.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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