

# The antibacterial activity and biochemical composition of *Adansonia Digitata* edible parts

Edible parts of  
*Adansonia*  
*Digitata*

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Ouafae El Yahyaoui, Bahia Bouabid and Nabil Ait Ouaziz  
*Natural Resources and Sustainable Development Lab, Department of Biology,  
Faculty of Science, Université Ibn Tofail, Kenitra, Morocco*

Mohamed El Bakkali  
*Université Ibn Tofail, Kenitra, Morocco*

Hanae El Harche  
*Laboratory of Plant, Animal and Agro-Industry Productions, Department of Biology,  
Faculty of Sciences, Université Ibn Tofail, Kenitra, Morocco*

Lalla Aicha Lrhorfi  
*Natural Resources and Sustainable Development Lab, Department of Biology,  
Faculty of Science, Université Ibn Tofail, Kenitra, Morocco*

Kamal Nakari  
*Laboratory of Medical Analysis IBN SINA, Kenitra, Morocco, and*

Rachid Bengueddour  
*Natural Resources and Sustainable Development Lab, Department of Biology,  
Faculty of Science, Université Ibn Tofail, Kenitra, Morocco*

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## Abstract

**Purpose** – Within the framework of the valorization of natural resources, a characterization of the biochemical composition of the edible parts of *Adansonia Digitata* is applied. The antibacterial effect against bacteria is also realized and compared to some synthetic antibiotics.

**Design/methodology/approach** – The biochemical characterization is carried out according to the norms of the French Association of Normalization, methods of Association of Official Analytical Chemists (AOAC International) and gas chromatography (GC). The antibacterial activity is tested by disk diffusion on a solid medium. Parametric tests are used to compare the differences between groups and heat maps to show the expression of the mean inhibitions according to the studied parameters. Multivariate logistic modeling is applied to study the effect of extracts and antibiotics on bacteria.

**Findings** – Biochemical characterization showed a variable importance of proteins, fibers and total sugars, with the presence of highly desired fatty acids such as palmitic, oleic, stearic, linoleic and  $\alpha$ -linolenic acids. This gives the tested parts important energy values, especially in the seeds very rich in fatty acids. Methanol proved to be a better extraction solvent than dichloromethane. Antibacterial activity showed that pulp and leaves extracted with methanol had quite similar inhibitory activities against *Enterococcus faecalis* ATCC29212 and that this effect was better than some antibiotics. Multivariate analysis showed that the leaves had a similar effect to antibiotics, and a significant effect against *Staphylococcus aureus* ATCC29213.

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**Originality/value** – This important activity and the attractive nutritional value of this plant could justify its extensive use in the traditional pharmacopoeia.

**Keywords** *Adansonia digitata*, Biochemical composition, Gas chromatography, Antibacterial activity, Synthetic antibiotics, Multivariate analysis

**Paper type** Research paper

## Introduction

*Adansonia Digitata* L. named also “Baobab”, belongs to the *Malvaceae* family and is a majestic tree revered for its medicinal and nutritional values (Barakat, 2021). He is a globally known high-valued multipurpose tree. (Musyoki *et al.* 2022). It has long been that the baobab tree has a very interesting profile of biochemical compounds that are beneficial to human health (Sibibe & Williams, 2002). Indeed, throughout Africa, the different parts of the baobab tree such as the roots, trunk, bark, leaves, pulp and seeds are used for therapeutic purposes (Ifeyinwa, Ajibola, & Johnpaul, 2021). In the traditional African pharmacopoeia, the baobab is used in the preparation of many remedies, particularly for digestive problems, but also inflammatory ones (Sibibe & Williams, 2002). *Adansonia Digitata* also has an antimicrobial, antiviral and anti-trypanosome activity (Kaboré *et al.* 2011). Moreover, in Morocco, a study conducted in the Laâyoune region revealed following an ethnobotanical investigation, the abundant use of the leaves and pulp of *Adansonia Digitata* as a remedy against stomach aches and diarrhea (El yahyaoui *et al.*, 2015).

On the other hand, antibiotic resistance caused by massive and sometimes inappropriate prescription of these agents has led to the selection of multi-resistant strains (Cassir, Di Marco, Poujol, & Lagier, 2012). Added to this is the high cost of drugs (Fokunang *et al.* 2011), a health system struggling to cope with demand and adverse effects of conventional therapy (Gakuya *et al.* 2020). These various parameters push us to direct research towards the discovery of new sources of drugs based on medicinal plants producing natural compounds used as antimicrobial agents in folk medicine. Indeed, medicinal plants can be an interesting source of new antibiotic compounds, which could possibly help tackling the problem of resistance to antibiotics (Shah, Cross, & Palombo, 2004).

It is in this context that this study focuses on this impressive medicinal plant; *Adansonia Digitata*, often used in the traditional treatment of various infectious diseases. Its objective is to evaluate both the nutritional value of its different edible parts, namely the fruit pulp, seeds and leaves of *Adansonia Digitata* as well as the antibacterial activity of their methanol and dichloromethane extracts. A comparison of this activity with the effect of some synthetic antibiotics is also carried out in order to highlight possible natural antibiotic agents. The modeling of the causal relationships is also performed using multivariate logistic regression.

## Material and methods

### *Plant material and sample preparation*

The baobab (*Adansonia Digitata*) is a tree belonging to the *Malvaceae* family. It is a leafy, massive and majestic tree present in its natural state almost everywhere in tropical continental Africa. Although this tree is absent on Moroccan territory, but its edible parts, namely the leaves, the pulp of the fruit and the seeds, are introduced by Mauritanian traders and sold everywhere in the Moroccan Sahara by traditional healers in the form of well-ground powders obtained after drying and grinding them. They are used in traditional pharmacopoeia against stomach aches, diarrhea and inflammatory problems (Kaboré *et al.* 2011).

This is a cross-sectional experimental study conducted over a period from January 2018 to June of the same year. To characterize *Adansonia Digitata* in fatty acids and evaluate its antibacterial effect, we exploited the powders of the edible parts of this plant marketed by

traditional practitioners and herbalists. Several samples of pulp, leaves and seeds were purchased in local markets from herbalists and associations located in the city of Laayoune, southern Morocco. The samples of the pulp of the fruit of *Adansonia Digitata* are in the form of a fine, uniform, white and floury powder, having acidulous and slightly sweet taste. The powder of the leaves is of green color, very fine, uniform and very viscous in contact with water. On the other hand, the powder obtained from the seeds is brown and relatively granular compared to the other powders collected. Thus, the different samples collected are mixed and stored at the Laboratory of Natural Resources and Sustainable Development, Faculty of Science Ibn Tofail in Kenitra (Morocco) at room temperature in glass jars avoiding exposure to light until the biochemical and microbial analysis.

#### *Characterization of biochemical composition*

The determination of the moisture content is carried out according to the norm [NF V05-105 \(1974\)](#). In addition, the [AOAC 985.29 \(2005\)](#) and [AOAC 991.35 \(1995\)](#) methods are used for the characterization of the different samples in fiber and fat content, respectively. The protein content is obtained using the norm [NF V18-100 \(1977\)](#) and the content of total sugars is determined by the Gabriel Bertrand method cited in the work of [Bourdon and Gielfrich \(1972\)](#). The energy value is evaluated according to the guidelines of the Official Journal of the European Union ([Official Journal of the European Union, 2011](#)). It is calculated from the protein, sugar and fat contents according to the following formula:

$$E = 4 \times P + 4 \times S + 9 \times F$$

where E: Energy content in Kcal/100 g; P: Protein content; S: Sugar content; F: Fat content.

#### *Characterization of fatty acids by gas chromatography (GC)*

This method specifies the analysis of fatty acids by GC according to standard 5509 ([ISO 5509:2000](#)). The chromatographic conditions used are as follows:

- (1) The temperature of the injector: 220 °C;
- (2) The temperature of the flame ionization detector (FID) is 220 °C;
- (3) The capillary column used is of the BP\*70 type, the length of which is 60 m, the internal diameter is 0.32 mm and the film is 0.25 µm;
- (4) The injection volume is 1 µl and
- (5) Gas flow: H<sub>2</sub> (40 ml/min), air (400 ml/min).

The results are expressed according to standards corresponding to the methyl esters sought. The percentage of fatty acids is given by the following ratio:

$$\% \text{FA} = \left( \frac{S_i}{\sum S_i} \right) \times 100$$

where  $S_i$  is the surface of the fatty acid;  $\sum S_i$  is the sum of the surface areas of the various fatty acids.

#### *Extraction*

The extraction method used is that of successive exhaustion. It is a solid-liquid cold extraction, using two solvents with different polarities and boiling temperatures: dichloromethane and methanol.

Practically, 15 g of each powder of the different edible parts of *Adansonia Digitata* are macerated in 100 ml of dichloromethane for 24 h at room temperature and in the dark. The filtrate obtained was then evaporated to dryness using the rotavapor and boiling temperature of 40 °C. The extracts thus obtained were adjusted to 2 ml each as final volume.

The dry marc obtained after filtration is macerated in 100 ml of methanol for 24 h at room temperature and in the dark. After filtration, it is evaporated to dryness using a rotavapor and at a boiling point of 65 °C. The methanolic extracts thus obtained were adjusted to 2 ml each as the final volume.

The yield of the extracts was calculated according to the following formula (Fellah *et al.* 2008):

$$Y (\%) = \frac{M_{ext}}{M_{samp}} \times 100$$

where Y is the yield in %; M<sub>ext</sub> is the mass of the extract after evaporation of the solvent in mg; M<sub>samp</sub> is the dry mass of the plant sample in mg.

#### *Antibacterial effect*

The bacterial strains used are *Escherichia coli* ATCC25922, *Enterococcus faecalis* ATCC29212, *Staphylococcus aureus* ATCC29213 and *Pseudomonas aeruginosa* ATCC27853. The revivification of the strains is carried out by the streaking method on nutrient agar, with incubation at 37 °C for 18–24 h in order to obtain a young culture.

The inoculum was prepared from the preculture. A few colonies are removed by the loop and then introduced into test tubes containing sterile physiological water. After good homogenization of the bacterial suspension, a reading of its optical density (OD) was carried out at 625 nm. The opacity of the solution should be equivalent to 0.5 McFarland or an OD between 0.08 and 0.1. This OD corresponds to 10<sup>8</sup> bacteria/ml. The suspension is diluted to 1/100th to have a final concentration of 10<sup>6</sup> CFU/ml, as indicated by the Antibioqram Committee of the French Society of Microbiology (Société Française de Microbiologie, 2001).

The sensitivity of bacteria to the extracts is assessed using the disk diffusion technique on a solid medium according to the National Committee for Clinical Laboratory Standards method (NCCLS, 1997). The culture medium used is Mueller Hinton (MH) which, after solidification, is inoculated on the surface with the inoculum of the microbial strains to be tested, using sterile spreaders in order to spread the suspensions. Discs of 9 mm diameter of Whatman N° 4 paper, impregnated with 60 µl of the various extracts as well as a disc soaked in methanol serving as a negative control are dried and then placed on the inoculated agars at an equal distance from each other. The boxes were then placed in a cool place (4 °C) before being incubated at 37 °C for 24 h. An extract is considered active when measuring a zone of inhibition around the disc with a diameter greater than 9 mm and inside which no microbial growth is observed.

#### *Antibiogram test*

In order to compare the antibacterial effect of our extracts with that of a synthetic compound, several antibiotics were tested; Ceftazidime, Piperacillin, Ceftriaxone, Ticarcillin, Tetracycline, Vancomycin, Imipenem, Penicillin and Erythromycin, using the disk diffusion method on agar medium according to the Antibioqram Committee of the French Society of Microbiology (CASFM) standard (Société Française de Microbiologie, 2015). The inoculation of the bacterial suspensions was carried out by flooding 1.5 ml in boxes containing the MH agar medium, the excess is eliminated and the box is placed in the oven for

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10–15 min at 37 °C for drying. The antibiogram discs were placed in the boxes which were then incubated at 37 °C for 24 h.

#### *Determination of minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC)*

For the determination of the minimum inhibitory concentration (MIC), the method of dilution in liquid medium was used. All the inoculated dilutions are incubated for 24 h at 37 °C, and the results are read visually according to the turbidity (Kpemissi, 2007). The nutrient agar poured into petri dishes is inoculated in streaks with 100 µl of the contents of the tubes having a concentration  $\geq$  MIC in the previous dilution series. Minimum bactericidal concentration (MBC) is determined after incubation for 24 h at 37 °C. It is the smallest concentration that completely inhibits growth (Ranjita & Sanjeeb, 2012). In addition, the MBC/MIC ratio of each extract is calculated in order to assess its antibacterial power. When the MBC/MIC ratio of a given substance is less than or equal to 4, this substance is considered bactericidal, while it is said to be bacteriostatic if this ratio is greater than 4 (Traoré, Ouattara, Yéo, Dombia, & Coulibaly, 2012).

#### *Statistical analysis*

Data are expressed as percentages for categorical variables in the descriptive analysis. The other continuous variables are expressed as mean  $\pm$  standard deviation (inhibition, MIC and MBC). Student's *t* test was adopted to compare two groups of solvents. However, the parametric ANOVA test and multiple comparisons of means by Tuckey's test were used to estimate the significance of differences between the parameters examined (Tukey, 1949). These parametric tests were applied due to a normal distribution of the indicators related to the inhibition of bacterial growth analyzed according to the results of the Shapiro–Wilk test (Shapiro & Francia, 1972) and the equality of variance determined using the Fisher–Snedecor test.

The dataset was analyzed using the heatmap. Consisting of two sets of variables (the effect of plant extracts and synthetic antibiotics on the one hand and bacteria tested in vitro culture media on the other hand), they are expressed as z-scores to facilitate comparability within the set (Kolde & Kolde, 2015).

A binary logistic regression was performed to determine if the extracts of *Adansonia Digitata* (leaves and pulp) and synthetic antibiotics, compared to the seed extract (reference category), predicted an inhibition threshold greater than or equal to 9 mm or not. Second, a comparison of bacterial resistance (*Enterococcus faecalis* ATCC29212, *Staphylococcus aureus* ATCC29213 and *Pseudomonas aeruginosa* ATCC27853) to *Escherichia coli* ATCC25922 (reference category) was also performed. Thus, associations between the independent variables (plant extracts; synthetic antibiotics; bacterial type) with bacterial inhibition efficacy ( $\geq 9$  mm) were evaluated by applying univariate binary logistic regression analysis. Multivariate binary logistic regression analysis was also used. In our model, we defined at the dichotomous outcome variable level, bacterial inhibition efficiency greater than or equal to 9 mm versus other inhibitions less than 9 mm (reference category). The results of the univariate and multivariate logistic regression were presented in terms of the corresponding OR and 95% confidence interval (CI).

All statistical analyses were performed with R software (<https://www.r-project.org/>) using the packages “ggplot2” (wickhan 2016), “GGally”, “RColorBrewer”, “ggpairs” (Kassambara, 2017), “factoextra” (Kassambara & Mundt, 2017), “pheatmap” (Kolde & Kolde, 2015), “dplyr”, “devtools”, “ggpubr”, “multcomp” and “car” (Kassambara, 2019). All p-values presented were two-sided, and  $p < 0.05$  was considered statistically significant.

**Results***Biochemical characterization*

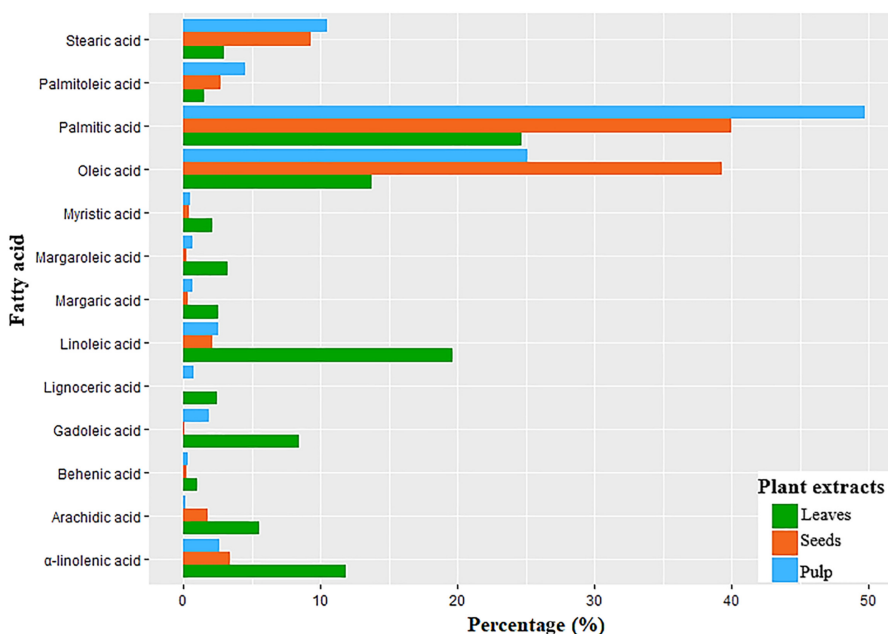
The biochemical characteristics of the edible parts of *Adansonia Digitata* are presented in Table 1. It showed that the percentage of moisture is approximately the same (8.5–8.6%) for all the organs studied. The same is noted for the percentage of protein which did not exceed about 3%. The highest fat content (20.3%) was obtained for *Adansonia Digitata* seeds. On the other hand, the other samples showed values that varied between 0.6 and 1.4% for pulp and leaves, respectively. The results of the fiber content showed variable proportions ranging from 3.6% for the seeds and 6.2% for the fruit pulp. Regarding the total sugar content, the percentages obtained were 82.4, 75.3 and 66.5% for the fruit pulp, leaves and seeds, respectively.

The energy value corresponding to the caloric intake of each sample was calculated from the obtained values of total sugars, proteins and fats. The energy value of seeds is by far the highest. However, the lowest caloric intake was recorded for the leaves.

The analysis results of the different parts of *Adansonia Digitata* by GC are reported in Figure 1. It shows a predominant presence of palmitic acid (24.72%), followed by linoleic acid (19.69%), oleic acid (13.78%),  $\alpha$ -linolenic acid (11.89%) and other fatty acids for the leaves of

**Table 1.**  
Biochemical characteristics of the different edible parts of *Adansonia Digitata*

Percentages	Pulp fruit	Leaf	Seed
Humidity (%)	8.5	8.6	8.5
Protein (%)	3.11	0.12	1.39
Fat (%)	0.6	1.4	20.3
Fiber (%)	6.2	4.2	3.6
Total sugars (%)	82.4	75.3	66.5
Energy value (kcal/100 g)	347.3	313.9	454.6



**Figure 1.**  
Bar plot of fatty acid percentage according to edible part extracts (leaves, seeds, pulp) of *Adansonia Digitata*

*Adansonia Digitata*. The pulp of the same plant abounds mainly in palmitic acid with a percentage of 49.70%, followed by oleic acid (25.16%) and the other acids. These same fatty acids are noted at the level of the seed with a percentage of 39.98% for palmitic acid and 39.28% for oleic acid.

*Extraction yield*

The results of the comparative yield show that methanol is found to be a better extraction solvent in the case of leaves and fruit pulp. The extraction of *Adansonia Digitata* by methanol gave results of 17.18% for the fruit pulp and 12.93% for the leaves against 0.31% and 1.11% for the same parts by dichloromethane. Only the seeds showed an opposite result, namely 6.67% by methanol and 17.29% by dichloromethane.

*Descriptive analysis of antibacterial activity*

The results of the antibacterial activity tests are shown in Table 2. It appears that each of the parts studied has a well-defined activity on at least one of the bacteria tested. Indeed, the pulp methanolic extract is active against *Escherichia coli* ATCC25922 with an inhibition diameter of  $11.5 \pm 1.9$  mm and against *Enterococcus faecalis* ATCC29212 ( $10.3 \pm 1.5$  mm), as well as *Staphylococcus aureus* ATCC29213 and *Pseudomonas aeruginosa* ATCC27853 with inhibition diameters of  $11.3 \pm 1.4$  mm and  $9.3 \pm 0.5$  mm, respectively. The leaf extract showed antibacterial activity against the same bacteria cited for the pulp with a slight difference in the diameters of inhibition. The seed inhibited the growth of *Staphylococcus aureus* ATCC29213 only ( $12 \pm 1.2$ ).

On the other hand, the pulp dichloromethane extract was active against *Escherichia coli* ATCC 25922 with a diameter of  $0.9 \pm 0.1$  mm. Concerning *Staphylococcus aureus* ATCC 29213, it was inhibited by the dichloromethane extracts of *Adansonia Digitata* pulp and seeds with diameters of  $10.3 \pm 1.5$  and  $9.8 \pm 0.9$  mm respectively.

Part of plant	Pulp		Leaf		Seed	
	MeOH extracts	DCM extracts	MeOH extracts	DCM extracts	MeOH extracts	DCM extracts
<i>Enterococcus faecalis</i> ATCC29212 (Gram+)	$10.3 \pm 1.5$	–	$14.8 \pm 1.7$	–	–	–
<i>Staphylococcus aureus</i> ATCC29213 (Gram+)	$11.3 \pm 1.4$	$10.3 \pm 1.5$	$17.2 \pm 2.2$	–	$12 \pm 1.2$	$9.8 \pm 0.9$
<i>Escherichia coli</i> ATCC25922 (Gram–)	$11.5 \pm 1.9$	$9 \pm 1$	$15.3 \pm 1.3$	–	–	–
<i>Pseudomonas aeruginosa</i> ATCC27853 (Gram–)	$9.3 \pm 0.5$	–	$17.3 \pm 0.4$	–	–	–

**Note(s):** MeOH extract: methanol extract; DCM extract: dichloromethane extract

**Table 2.** Inhibition diameters of the methanolic and dichloromethane extracts of the different parts of *Adansonia Digitata*

Bacterial strains	<i>Escherichia coli</i> ATCC25922			<i>Pseudomonas aeruginosa</i> ATCC27853			<i>Staphylococcus aureus</i> ATCC29213			<i>Enterococcus faecalis</i> ATCC29212		
	MIC	MBC	MBC/MIC	MIC	MBC	MBC/MIC	MIC	MBC	MBC/MIC	MIC	MBC	MBC/MIC
Pulp	0.16	0.33	2.03	0.16	0.33	2.03	0.17	0.33	2	0.07	0.16	2.46
Leaf	0.07	0.16	2.46	0.03	0.16	4.92	0.03	0.1688	5	0.07	0.325	5
Seed	–	–	–	–	–	–	0.05	0.105	2	–	–	–

**Table 3.** Minimum inhibitory concentration (MIC) (g/ml), Minimum bactericidal concentration (MBC) (g/ml) and MBC/MIC values

*Minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC)*

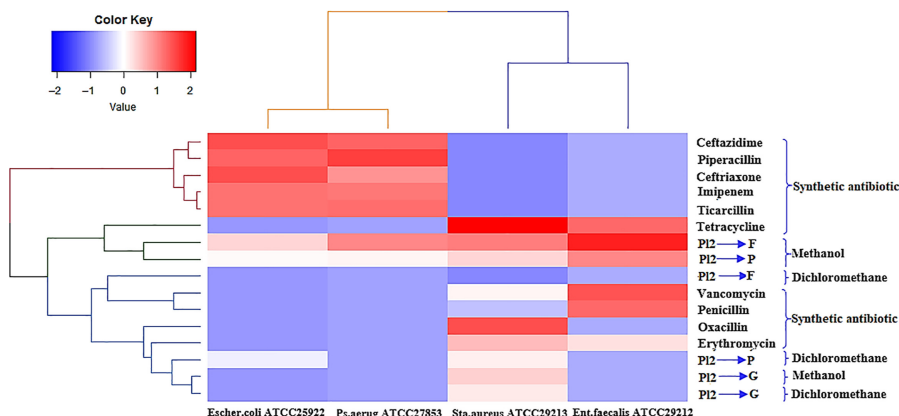
In view of the results recorded in Table 3, the minimum concentrations fluctuate between 0.03 g/ml for the leaves of *Adansonia Digitata* and 0.17 g/ml for the pulp. The MBCs obtained for the extracts fluctuate between 0.105 g/ml; value recorded for the seed extract and 0.33 g/ml recorded for the pulp. The methanolic extract of the pulp of *Adansonia Digitata* showed a bactericidal effect on the majority of the bacteria tested, namely *Escherichia coli*, *Pseudomonas aeruginosa*, *Staphylococcus aureus* and *Enterococcus faecalis*. The seed extract also exerted this effect but only on *Staphylococcus aureus*. On the other hand, the bacteriostatic effect was noticed for the leaf extract against *Pseudomonas aeruginosa*, *Staphylococcus aureus* and *Enterococcus faecalis*.

*Analysis of the expression of bacterial inhibition of plant extracts and antibiotics*

The results obtained in the Heatmap in Figure 2 represent the average inhibition values in (mm) of the different edible parts of *Adansonia Digitata* (leaves, pulp and seeds) extracted with two solvents (methanol and dichloromethane) and those of the synthetic antibiotics.

The methanolic extract of the leaves showed the highest average expression in terms of bacterial inhibition against *Enterococcus faecalis* ATCC29212 compared to all the other extracts as well as all the synthetic antibiotics tested. In the same case, the effect of the methanol-extracted pulp is slightly lower than that of the leaf extract but as significant as the antibiotics. Regarding *Staphylococcus aureus* ATCC29213, an inhibitory effect of the methanolic extract of the leaves was also reported, but lower than that of tetracycline and oxacillin. Similarly, the same extract showed a slightly elevated effect against *Pseudomonas aeruginosa* ATCC27853. On the other hand, the inhibition exerted regarding *Escherichia coli* ATCC25922 was less significant.

The comparison of bacterial growth inhibition by extracts, namely methanolic and dichloromethane, obtained from *Adansonia Digitata* as well as synthetic antibiotics are represented in Figure 3.



**Figure 2.**

The hierarchical clustering visualized by a heatmap where the data values are transformed to color scale based on Ward's method

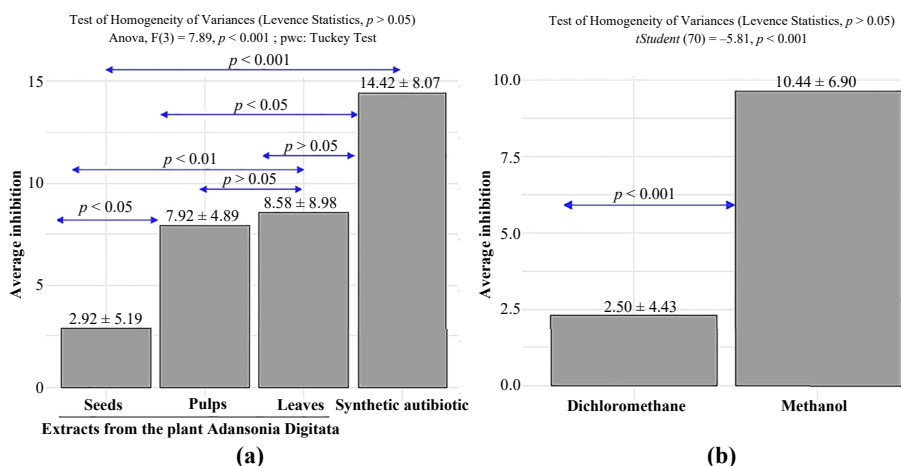
**Note(s):** The color scale indicates the expression values; the red color indicates the highest average values and blue color indicates the lowest average values. The Heatmap was generated via the R software (R: The R Project for Statistical Computing (r-project.org))

P12: *Adansonia Digitata*; F: Leaves; P: pulp; G: seeds; Escher.coli: *Escherichia coli* ATCC 25922; Ps.aerug: *Pseudomonas aeruginosa* ATCC27853; Sta.aureus: *Staphylococcus aureus* ATCC29213; Ent.faecalis: *Enterococcus faecalis* ATCC29212

The parts of plant extracted by methanol were found to be significantly more effective in inhibition of bacteria compared to dichloromethane ( $p < 0.001$ ). The multiple comparison of the mean bacterial growth inhibition exerted by *Adansonia Digitata* extracts and that exerted by synthetic antibiotics showed that the effect of the latter was significantly greater than that of the pulp and seed extracts ( $p < 0.05$ ), while the effects of synthetic antibiotics and leaf extracts were found to be significantly similar ( $p > 0.05$ ). On the other hand, leaf extracts showed significantly significant inhibition when compared to seed extracts ( $p < 0.01$ ), and no significant difference was found when compared to pulp extracts. In contrast, the difference between the inhibitory effect of seed and pulp extracts was significantly high in favor of the pulp extract ( $p < 0.05$ ).

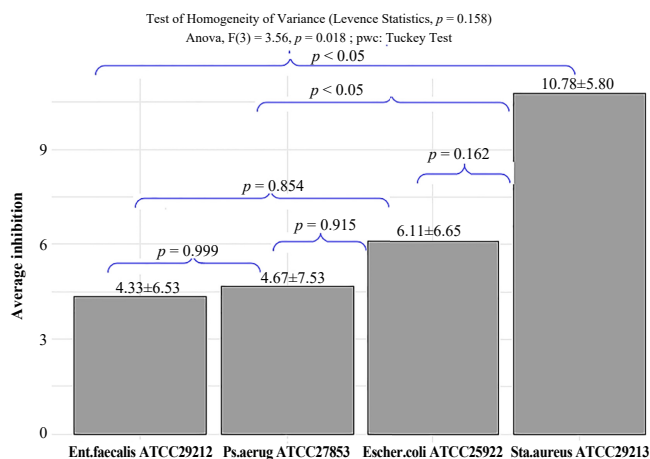
An average comparison of inhibition values between the four types of bacteria studied is represented in Figure 4.

It revealed that *Staphylococcus aureus* ATCC29213 was significantly less resistant than *Pseudomonas aeruginosa* ATCC27853 ( $p < 0.05$ ) and *Enterococcus faecalis* ATCC29212 ( $p < 0.05$ ) but significantly similar to *Escherichia coli* ATCC25922 ( $p > 0.05$ ). In contrast,



**Figure 3.**  
(a) Analysis of variance of groups for three extracts (seeds, pulps, leaves) and synthetic antibiotics among bacteria inhibition. (b) Inhibition by the solvent used as measured by *t* student method with a level of 5%

Note(s):  $\alpha = 0.05$



**Figure 4.**  
Analysis of variance between four types of bacteria according to inhibition level

**Table 4.**

Results of multivariate logistic regression analysis for inhibition greater than 9 mm for *Adansonia Digitata* extracts/synthetic antibiotic and bacteria by type

Covariates	Crude analysis <sup>c</sup> OR (95% CI) <sup>b</sup> -value	Adjusted analysis <sup>a</sup> OR (95% CI) <sup>b</sup> -value
<i>Extracts from Adansonia digitata/synthetic antibiotics</i>		
Seeds	Reference	Reference
Pulps	2.33 (0.50–10.69) <sup>NS</sup>	2.41 (0.51–11.40)
Leaves	7.00 (1.64–29.85) <sup>**</sup>	7.76 (1.74–34.61) <sup>***</sup>
Synthetic antibiotic	7.00 (1.11–44.05) <sup>*</sup>	7.76 (1.16–51.72) <sup>*</sup>
<i>Bacteria type</i>		
<i>Escherichia coli</i> ATCC25922	Reference	Reference
<i>Enterococcus faecalis</i> ATCC29212	0.46 (0.11–1.93) <sup>NS</sup>	0.41 (0.091–1.92) <sup>NS</sup>
<i>Pseudomonas aeruginosa</i> ATCC27853	0.61 (0.15–2.42) <sup>NS</sup>	0.57 (0.13–2.49) <sup>NS</sup>
<i>Staphylococcus aureus</i> ATCC29213	1.51 (0.42–5.42) <sup>NS</sup>	1.63 (0.41–6.50) <sup>NS</sup>
Leaves adjusted for <i>Enterococcus faecalis</i> ATCC29212		3.25 (0.41–25.50) <sup>NS</sup>
Leaves adjusted for <i>Pseudomonas aeruginosa</i> ATCC27853		4.48 (0.58–34.43) <sup>NS</sup>
Leaves adjusted for <i>Staphylococcus aureus</i> ATCC29213		1.68 (1.55–103.32) <sup>*</sup>
Synthetic antibiotic adjusted for <i>Enterococcus faecalis</i> ATCC29212		3.25 (0.30–34.72) <sup>NS</sup>
Synthetic antibiotic adjusted for <i>Pseudomonas aeruginosa</i> ATCC27853		4.48 (0.42–47.02) <sup>NS</sup>
Synthetic antibiotic adjusted for <i>Staphylococcus aureus</i> ATCC29213		12.68 (1.14–140.0) <sup>*</sup>
<b>Note(s):</b> <sup>*</sup> <i>p</i> < 0.05; <sup>**</sup> <i>p</i> < 0.01; <sup>NS</sup> ; No significant; <sup>Dv</sup> ; dependent variable; <sup>c</sup> OR: crude odds ratio; <sup>a</sup> OR: adjusted odds ratio; CI: confidence interval; Crude analysis: univariate analysis; Adjusted analysis: multivariate analysis		

no significant difference was found for *Pseudomonas aeruginosa* ATCC27853, *Escherichia coli* ATCC25922 and *Enterococcus faecalis* ATCC29212 (*p* > 0.05).

#### Logistic regression modeling

Based on the multivariate logistic regression results (Table 4), it was found that bacterial inhibition greater than or equal to 9 mm was more likely to be predicted (almost eightfold compared to seeds) by leaf extracts ( $OR_a$ : 7.76; 95% CI: 1.74–34.61; *p* < 0.01), synthetic antibiotics ( $OR_a$ : 7.76; 95% CI: 1.16–51.72; *p* < 0.05), leaf extracts are adjusted for *Staphylococcus aureus* ATCC29213 ( $OR_a$ : 1.68; 95% CI: 1.55–103.32; *p* < 0.05) and synthetic antibiotics adjusted for *Staphylococcus aureus* ATCC29213 ( $OR_a$ : 12.68; 95% CI: 1.14–140.02; *p* < 0.05).

## Discussion

### Characterization of biochemical composition

The biochemical characterization concerning the percentages of moisture, proteins, total sugars, fibers and fatty acids is carried out to enhance this plant and highlight its energy value and its nutritional and curative benefits.

The results obtained for the moisture content of the different parts of *Adansonia Digitata* in our study, indicated an excellent storage quality. The work of B.Kouamé *et al.* (Kouamé, Assanvo, & Kouamé, 2018) reported that the moisture content of the pulp varies from 7.2 to 16.24% with an average of 11.40%, which is consistent with our work and those conducted by the team of M.Cisse (Cisse *et al.* 2009). Given its low moisture content, the total sugar content was found to be high. This was confirmed by the studies of A.Diop *et al.* (Diop, Sakho, Dornier, Cisse, & Reynes, 2006) specifying that as for most fruits, carbohydrates represent more than 70% of dry matter for the pulp of *Adansonia Digitata* and are composed of half of soluble sugars. Caluwé, Halamová and Van Damme (2010) report that the dry pulp of the baobab fruit has a slightly acidic taste, refreshing and very nutritious, with particularly high values of carbohydrates (fructose, sucrose and glucose). They also confirm that the leaves contain (expressed in dry weight) 60–70% carbohydrates.

According to our results, the richest part in fiber is the pulp, which is confirmed by the work of A. Diop *et al.* (Diop *et al.* 2006) who report that the pulp of the baobab is relatively rich in fiber and that the leaves can contain up to 16%, specifying that the values vary greatly from one author to another.

Moreover, it was noted in our study that the pulp is the poorest part in terms of fat, unlike the seeds. According to Caluwé *et al.* (2010), the leaf contains 4–10% fat, and the seed contains higher amounts. Based on the work of A. Diop *et al.* (Diop *et al.* 2006), this content is generally lower than 2 g/100 g for the pulp, and according to the studies of M. Cisse *et al.* (Cisse *et al.* 2009), this content fluctuated between 0.2 and 0.8%. As a result, the most important energy value is raised for the seeds given their high fat content and therefore in fatty acids.

These same fatty acids, which are major molecules, are currently the subject of particular and increasing attention because they constitute aggravating or protective factors in certain diseases, especially in the case of cardiovascular diseases (Del Gobbo, Imamura, Aslibekyan, & al., 2016). Of natural or industrial origin, they are mainly present in our diet. Therefore, it seemed interesting to be able to quantify them at the level of *Adansonia Digitata* in order to be able to identify the many beneficial physiological effects reported by ethnobotanical investigations.

GC analysis of the different parts of *Adansonia Digitata* shows a majority presence in the leaf of palmitic acid (24.72%), linoleic acid (19.69%), oleic acid (13.78 %) and  $\alpha$ -linolenic acid (11.89%) and many other fatty acids with smaller percentages. GC coupled with mass spectrometry of baobab leaves' analyzes by Suliman and Nour (2017) report the identification of palmitic acid and linoleic acid with 8.95 and 1.70% respectively. Few authors have studied the fatty acid content of baobab leaves, in contrast, most of the reported data essentially concern the essential oil extracted from the seeds. The fatty acids noted in our results for the seed are in particular palmitic acid with a percentage of 39.98%, and oleic acid 39.28%. Furthermore, studies by (Osman, 2004) found that baobab seed oil was composed of approximately 31.7% saturated fatty acids, 37% monounsaturated fatty acids and 31.7% polyunsaturated fatty acids (PUFAs). The main fatty acid was oleic acid (35.8%), followed by linoleic acid (30.7%) and palmitic acid (24.2%). These results were similar to those of oils extracted from the African baobab (Lockett, Calvert, & Grivetti, 2000). At the end of our results, the pulp of the fruit of the same plant abounds mainly in palmitic acid with a percentage of 49.70%, followed by oleic acid (25.16%) and stearic acid (10.48%). The other fatty acids detected are in the minority. Indeed, most of the fatty acids in the pulp do not reach detectable levels and the variability of the values reported by the literature is high, even if the methods used by the researchers for the identification and the quantification are identical (Chadar *et al.* 2009). Glew *et al.* (1997) recorded a total lipid content of 155 mg/g dry weight and stated that a significant amount of linoleic acid is present. Sena *et al.* (1998) also reported that the baobab fruit is a rich source of linoleic acid, 27 mg/g dry weight, while it contains a very low amount of  $\alpha$ -linolenic acid (<1 mg/g).

The fluctuations recorded at the level of the fatty acid composition as well as the variations concerning the quantification compared to other research may be due either to the genetic heritage of the plants or to pedoclimatic factors and to the conditions and times of the harvest or even to the extraction method. In addition, the profile of fatty acids recorded for all the parts tested of the plant studied, proved to be particularly interesting. Several identified compounds are known for their antioxidant effect as well as their biological activities. Palmitic acid, for example, also called hexadecanoic acid, is well known for its antioxidant properties, its antimicrobial activity (Praveen, Kumaravel, & Lalitha, 2010) and its anticancer potential (Wei, Wee, Siong, & Syamsumir, 2011). Linoleic acid, PUFA, also exhibits antimicrobial properties and is one of the key ingredients in antimicrobial food additives and some antibacterial herbs (Chang, Jung-Sung, Tae-Gyu, & Hee-Young, 2005). Oleic acid has been reported to have potential antifungal and antibacterial activity (Manivachgam, Krishnan, & Venugopalan, 2008).

*Antibacterial effect*

The comparison of the effect of the solvent on the inhibition of the growth of bacteria shows that the extraction by methanol is more effective than that by dichloromethane. It is obvious to say that the pharmacological activity depends on the nature of the extraction solvent. Important variations of action can be demonstrated on extracts of plants treated by solvents presenting very polar characters (Bouharb *et al.* 2014). Indeed, the successive phases of extractions that we carried out followed by filtrations with variation of the solvent caused a fractional dissolution. We initially used a liquid with low solvent power, dichloromethane, and then we increased the dissolution capacity by using a relatively more active solvent, methanol, and hence the significantly higher yield of the methanolic extraction. The most commonly used extraction solvents are alcohols (methanol and ethanol) for highly polar compounds. Less polar solvents (dichloromethane (DCM), chloroform, hexane and benzene) are used to extract apolar compounds (waxes, oils, sterols, chlorophyll, etc) which justifies the high yield observed for seeds which according to previous work are rich in sterols and fatty acids (Mahmoudi, Khali, & Mahmoudi, 2013).

This study also shows that all methanolic extracts of the different edible parts of *Adansonia Digitata* are more or less active against the tested bacteria (inhibition greater than or equal to 9 mm). The methanolic extract of the pulp, for example, was active against *Escherichia coli* ATCC25922 ( $11.5 \pm 1.9$  mm), *Enterococcus faecalis* ATCC29212 ( $10.3 \pm 1.5$  mm), *Staphylococcus aureus* ATCC29213 ( $11.3 \pm 1.4$  mm) and *Pseudomonas aeruginosa* ATCC27853 ( $9.3 \pm 0.5$  mm). This result is confirmed by antimicrobial studies of silver nanoparticles biologically synthesized from *Adansonia Digitata* pulp extract, which report that these agents were active against *Escherichia coli* ( $22.0 \pm 0.38$ ), *Staphylococcus aureus* ( $15.9 \pm 1.09$ ) and *Pseudomonas aeruginosa* ( $24.5 \pm 0.72$ ) (Chennareddy, Pulicherla, & Nataru, 2016).

As for the leaves, according to the work of Suliman and Nour (2017), it showed the highest antibacterial activity. The reported inhibition diameters are 15 mm, 14 mm and 13 mm recorded against *Pseudomonas aeruginosa*, *Escherichia coli* and *Salmonella typhi*, respectively. In addition, the results of the research of Diarrassouba *et al.* (2020) report that the methanolic extract of the leaves of this same plant inhibits the proliferation of *Staphylococcus aureus* with a diameter of  $18.67 \pm 2.52$ . The work of Dieye and Saar (2020) shows that the leaves of *Adansonia Digitata* macerated with water are active against *Enterococcus faecalis* 29212 with an inhibition diameter of 18 mm.

The seed extract was the weakest of the extracts according to our results. This methanol extracted part was only active against *Staphylococcus aureus* ATCC29213 ( $12 \pm 1.2$  mm). Indeed, the work of Gahane and Kogje (2013) shows that the aqueous methanolic extract of the seeds has low antibacterial activity against *Escherichia coli* ( $7.02 \pm 0.05$ ). Other works reported that the essential oil of *Adansonia Digitata* seeds has no antibacterial effect on all the bacteria they tested, namely *Bacillus subtilis*, *Staphylococcus aureus*, *Pseudomonas aeruginosa* and *Escherichia coli* (Edogbanya, Dangana, & Apeji, 2015).

All these results are consistent with those obtained in our study, but few works have been confirmed using statistical tools. In fact, using the ANOVA and multiple comparison of Tuckey test, we were able to confirm that the leaf extract was the most effective, followed by the pulp and finally the seed.

Comparing the inhibitory effect of *Adansonia Digitata* extracts and that of synthetic antibiotics, the results showed that the effect of the latter is significantly similar to the effect of the leaf extract and significantly higher than that of the pulp and seed extracts. This may justify certain ethnopharmacological uses (diarrhea, disinfection and wound treatment) (Diarrassouba *et al.* 2020).

As it is known, gram-positive bacteria are more sensitive than gram-negative bacteria towards plant extracts. This resistance could be attributed to the nature of their cell envelope (Diarrassouba *et al.* 2020). Indeed, an average comparison of inhibition values between the

four types of bacteria studied revealed that *Staphylococcus aureus* ATCC29213 (gram-positive) was significantly less resistant than *Enterococcus faecalis* ATCC29212 (gram-positive) and *Pseudomonas aeruginosa* ATCC27853 (gram-negative) but was significantly similar to *Escherichia coli* ATCC25922 (gram-negative).

In the present study, it was also possible to note an interesting antibacterial activity of the methanolic extracts of the leaves and the pulp of the fruit against two gram-negative bacteria, namely *Escherichia coli*, the main cause of acute traveler's diarrhea, or turista (Truchis and Truchis 2007) and *Pseudomonas aeruginosa*, which is the cause of several dermatoses (Morand & Morand, 2017). This important antibacterial activity can be attributed to the phenolic compounds quantified and reported by several works (Ajibohe *et al.* (2020) or to other constituents such as fatty acids, which are present in this plant. This therefore imperatively justifies the considerable uses of *Adansonia Digitata* in the traditional pharmacopoeia against diarrhea (Ramadan, Harraz, & El-Mougy, 1993), infections (Codija *et al.* 2000; Sibibe & Williams, 2002) and dermatoses caused mainly by the tested bacteria.

On multivariate logistic analysis, only the leaf extracts and synthetic antibiotics showed significant efficacy particularly against *Staphylococcus aureus* ATCC29213. According to the work of Chambers & Deleo (2009), *Staphylococcus aureus* is known for its ability to become resistant to antibiotics (Chambers & Deleo, 2009). This illustrates the important characteristic of *Adansonia Digitata* leaves, which could be used to overcome the resistance of this bacteria to antibiotics.

## Conclusion

The analysis of the biochemical composition indicated that the baobab pulp is rich in protein, fiber, total sugars and various fatty acids, while the leaf contains linoleic acid and  $\alpha$ -linolenic acid in addition to its elements. The seeds are full of palmitic and oleic acid. This study also showed that the type of solvent plays an essential role in the extraction of plant drugs, thus enhancing their antibacterial effects. Indeed, all the studied organs of *Adansonia Digitata* produce more or less important antibacterial activity, but the leaf proved to be the most effective, even compared to some synthetic antibiotics. This contribution could explain the important use of this plant in traditional medicine and could therefore offer great possibilities of application in the medical and pharmaceutical field.

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### Corresponding author

Ouafae El Yahyaoui can be contacted at: [ouafae.elyahyaouir@gmail.com](mailto:ouafae.elyahyaouir@gmail.com)

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