

Full Length Research Paper

Encapsulation by complex coacervation of total flavonoids and total phenols of methanol extract of *Anacardium occidentale* L. (Anacardeaceae) obtained by microwave assisted extraction

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The study was carried out to produce a microcapsule powder of total flavonoids and total total phenols of methanol extract of the cashew, using a complex coacervation encapsulation method. In the search for optimal conditions for encapsulation, a three level factorial design was set up, while taking into account factors like time and proportions in Arabic gum and gelatin. The kinetic of encapsulation follows a kinetic of 2nd order which gives polynomial equations of the second degree. The conditions found are respectively 45 min, 30% Arabic gum and 70% gelatin, for an encapsulation yield is 84.37%; the encapsulation rate is 77.9% for the total flavonoids and 76.5% for the total phenols. The powder obtained has a doubled concentration in total flavonoids and total phenols than the raw bark powder.

Key words: Encapsulation, complex coacervation, total flavonoids, total phenols, *Anacardium occidentale*.

INTRODUCTION

Humans have always used the products of their environment, especially plants for their medical needs. Plants have several therapeutic properties and their uses for the treatment of diseases in living beings are very old and have always been done empirically (Jeansheng and Cheng, 2018). These plants represent a primary source of medicines and have continued to provide humanity with new remedies to date. Now, research is showing more and more that the active ingredients in herbal

medicines are often linked to secondary metabolites. Thus, the African and Malagasy Council for Higher Education (CAMES) program has empowered the Central Africa Network to carry out research activities on medicinal plants used in the treatment of complicated diseases, with a view to producing improved traditional medicines (Ngolo et al., 2018). In the perspective of researching molecules endowed with properties against these diseases, this study was oriented on one of the

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plants with proven pharmacological activities. It is *Anacardium occidentale* (Anacardiaceae).

A. occidentale is an 8-10 m tall tree, native to tropical America and introduced to all tropical countries. Phytochemical studies conducted on the plant reveal the presence of tannins, flavonoids (Annalisa et al., 2017), saponins (Dharamveer et al., 2013) and alkaloids (Alfa et al., 2017). Resorcinolic acid, ascorbic acid, carotenoids (α -carotene, β -carotene and β -cryptoxanthin), vitamin C and phenols are also identified in cashew apples (Farid et al., 2014). The work of Madjitouloum et al. (2018b) isolated two flavonoids: quercetin-3-O--D-glucopyranoside and Kempferol-3-O--D-glucopyranoside. The decoction and infusion of the leaves and bark of the trunk are used in pharmacopoeia to treat several diseases namely: High blood pressure, gastrointestinal ailments, ulcers, and sore throat (Jeansheng and Cheng, 2018). In this practice, the effectiveness and quantity of the active ingredient in the solution is not controlled hence the need to extract it.

The performance of extracts in terms of biological activities is linked to extraction techniques. Speaking of extraction methods, apart from the so-called conventional extraction methods such as decoction, infusion, maceration, mechanical agitation and soxhlet, innovative methods of extraction, fractionation and identification of natural products of plant origin have been implemented in order to participate in technological advances faster, more efficient while reducing the quantities of solvent, energy and consumption of samples. Among these innovative extraction methods, microwave assisted extraction has also been implemented. This is also aiming to improve these traditional techniques that are long, tedious, and require large amounts of organic solvents harmful to our environment and health (Madjitoloum et al., 2018a). This technique can be influenced by the parameters such as power, time, solvent polarity, and liquid/solid ratio; its effects can be independent or interactive (Jing et al., 2016). Then, it is necessary to define the best extraction conditions in terms of biological activities and yield. Faced with these difficulties, the use of substances of plant origin is increasingly considered as an alternative or complementary means for poor populations (Raoufou and Kouami, 2013).

In addition to this concern, there is the procedure of formulating a powder by complex coacervation of the active extracts of *A. occidentale*. It should be noted that the quality and the rate of encapsulation of this powder depend on factors such as the time of mixing and the proportions of adjuvants such as gum arabic and gelatin. Encapsulation which is an inclusion technique to confine a substance in a polymeric matrix covered by one or more semi-permeable membranes, whereby the encapsulated compound becomes more stable than the one from which it was isolated. It becomes necessary to solve the shortcomings found in the adsorption technique (Deepak and Sheweta, 2020). In order to minimize the negative aspects, several techniques have been

developed to implement different formulations to suit different applications. Nowadays, powder formulation has become one of the most attractive methods for immobilization and protection of active ingredients (Yuksel et al., 2018). To achieve this powder formulation, two main techniques have been developed following the example of adsorption and coacervation encapsulation (Yuksel et al., 2018). Coacervation can be simple or complex: Simple coacervation involves only a single polymer with the addition of strongly hydrophilic agents into the colloidal solution and complex coacervation, two or more polymers are used (Lv et al., 2012). The choice of complex coacervation is the easy release of the active ingredient into the solution.

Our objective is to protect the methanolic extract of *A. occidentale* trunk bark obtained under the optimal conditions of microwave-assisted extraction from adverse effects, minimizing the interactions between the active ingredient and the polymers of the formulation by complex coacervation (Mohammadinejad et al., 2016; Vázquez-González et al., 2021). To grasp this technique, a study on the kinetics and encapsulation parameters needed to be carried out followed by investigating the most influential levels of factors in complex coacervation.

MATERIALS AND METHODS

Plant material

Active ingredient

The active ingredient, called the active principle, in the formula is the methanol extract from the bark of the plant's trunk. This extract is obtained under optimal conditions of microwave assisted extraction at the time of 83 s, at the power of 620 W, at the solvent-matter ratio of 30 mL/g and at 63% water-methanol for which the values total phenols and total flavonoids, are respectively 655.90 mg EGA / 100 g DM and 82.94 mg EQ / 100 g DM of bark (Madjitoloum et al., 2018a). After filtration, the filtrate is concentrated using a rotary evaporator and dried in the jars, then crushed, pulverized and stored for further study.

Auxiliaries

The auxiliaries are adjuvants which have secondary and tertiary functions of the formula. These are gum Arabic and gelatin. Gum Arabic is a highly branched hydrocolloid and a polysaccharide polymer. Its solution has a density of negative charges compared to the acid function (Oumarou et al., 2010). Protein polymer gelatin is used as an encapsulation material thanks to its amphiphilic properties, its ability to interact with different types of molecules, its high molecular weight and the flexibility of its molecular chains. It has a density of positive charges in solution with respect to its amine functions to form ammonium ions (Marta et al., 2020).

Preparation of coacervates

The method used for the preparation of microcapsules is that of Sarunyoo et al. (2018) which has been adapted. The colloidal

Table 1. Matrix of the factorial plan at three levels (27 experiments).

Factor	Factor levels			Responses		
				TF	TP	Tu
Coded values	X	-1	0	+1		
	X ₁					
Real values	X ₂					
	X ₃					

With X1: gum Arabic; X2: gelatin and X3: mixing time; TP: total phenols; TF: total flavonoids and Tu: turbididly.

$$X = \frac{x_i - x_0}{\Delta x_i} \quad \text{Hence} \quad x_i = X * \Delta x_i + x_0$$

This transformation operation use was adapted from Pillet et al. (2011).

Source: Author

solution is prepared by mixing the solutions of the two polymers with Moulinex to properly emulsify the solution: the gum arabic solution (2% m/v) with that of gelatin (8% m/v) at 40°C. The active principle (0.2 g) is introduced into the colloidal solution (1 mL) and the addition of CH₃CO₂H at 50% v/v is made to adjust the pH of the mixture to pH = 4.5 while stirring for 30 min. Then the addition of CH₂O (37% w/v) 4 mL per 100 mL in the mixture allows crosslinking. Finally, the whole is incubated at 4°C for 30 min. Two phases were observed and after screening the coacervates are recovered and subjected to lyophilization to produce the powder of the microcapsules. The freeze-dryer (Scientz-10ND vacuum Freezer dryer) freezes the coacervate solution at -20°C for 4 h before producing the powder in 48 h.

Quantitative study of flavonoids and total phenols

For quantitative analysis, phytochemical quantification of total flavonoids and total phenols was carried out according to the protocol of Jothi et al. (2013) adapted by Madjitouloum et al. (2018a).

Study of the encapsulation parameters

Effect of time on encapsulation

Time is a parameter which influences the encapsulation of active extracts by complex coacervation. The mixing was carried out for a period of 0 to 120 min in steps of 15 min, the other parameters being constant. The models studied for modeling are as follows.

The kinetic model of order 2: Its equation is of the form:

$c(t) = \frac{t}{k_1 + k_2 * t}$ with c (t) the concentration of the extract at time t, t times the extraction in seconds then k₁ and k₂ the speed constants (Tsatsop et al., 2016). The speed constant k₁ makes it possible to have the speed of the extraction B₀ at the initial instant, that is to say at the instant when the solvent comes into contact with the dry matter: $B_0 = \frac{1}{k_1}$ and the constant of speed k₂ allows to have the quantity of extract at equilibrium:

$$c_0 = \frac{1}{k_2}$$

Gauss model: It obeys the equation: $Y = ae^{-\left(\frac{t-t_0}{4+k}\right)^2}$ where Y is the rate of encapsulation, a is the maximum value of the encapsulation rate, t is the time studied in the encapsulation, and t₀ is the time corresponding to the maximum value of the

encapsulation rate and k is the kinetic constant reflecting the influence of the factor studied on the mixture (Zhang et al., 2013). Note that this last model was the one best suited for modeling the encapsulation taking into account all of our different factors in the context of this work.

Influence of the proportion of gum arabic on the encapsulation

The proportion of the gum arabic solution varies from 0 to 100% in 25% steps and the time remains constant (45 min).

Influence of the proportion of gelatin on the encapsulation

We also varied the proportion of the gelatin solution from 0 to 100% in 25% steps, keeping the time constant (45 min).

Encapsulation optimization

At the end of the tests, the experimental field for each of the three factors (time (min), proportion of the gum arabic solution (%) and proportion of the gelatin solution (%)) was chosen. A three-level factorial design is used to find the levels of the most influential factors in complex coacervation (Table 1).

Proposal of a model

The proposed model has the advantage of properly representing the experimental responses studied in the experimental field of interest and making it possible to obtain an estimate of the value of the studied responses of acceptable quality. The model is as follows:

$$Y_i = a_0 + a_1X_1 + a_2X_2 + a_3X_3 + a_{12}X_1X_2 + a_{13}X_1X_3 + a_{23}X_2X_3 + a_{11}X_1^2 + a_{22}X_2^2 + a_{33}X_3^2 + \epsilon$$

where Y_i are the expected responses, a₀ the constant, a₁, a₂, a₃ the linear coefficients, a₁₁, a₂₂, a₃₃ the square coefficients, a₁₂, a₁₃, a₂₃ the interaction coefficients, X₁, X₂, X₃; X₁X₂, X₁X₃, X₂X₃ et X₁², X₂², X₃² are the levels of the independent variables, and finally being the error.

Validation of models

The performance of the model was measured by comparing the

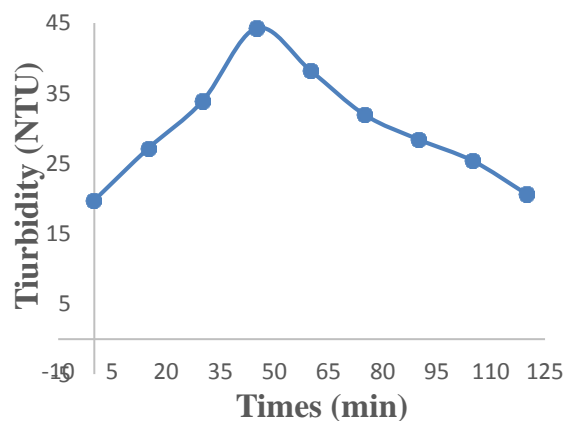
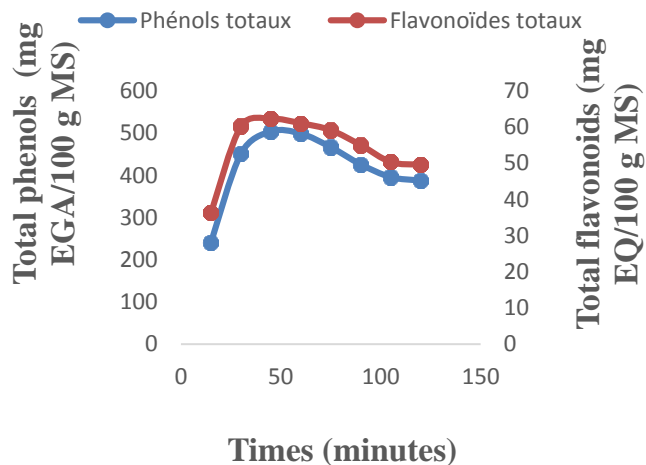


Figure 1. Encapsulation kinetics.
Source: Author



x values of the predicted responses with those observed. In addition to the linear regression coefficient (R^2), other mathematical procedures and tools were used; the Absolute Analysis of Average Deviation (AADM), the bias factor (Bf) and the Accuracy factors Af_1 (Catherine, 2015) and Af_2 (Baranyi et al., 1999) were determined using the following expressions:

$$AADM = \frac{\sum_{i=1}^p \left(\frac{Y_{iexp} - Y_{ical}}{Y_{iexp}} \right)}{p}$$

with Y_{iexp} the experimental response and Y_{ical} the response calculated from the model for an experiment i ; p being the total number of experiments. $Bf = 10^B$; Bias B is given by the relation:

$$B = \frac{1}{n} \sum \log \left(\frac{Y_{théo}}{Y_{Obs}} \right).$$

$Af_1 = 10^{A_1}$, with A_1 and A_2 the accuracy which is determined according to the following relationships:

$$A_1 = \frac{1}{n} \sum_{i=1}^n \left| \log \left(\frac{Y_{théo}}{Y_{Obs}} \right) \right|.$$

Thus, a model is considered perfect if the bias factor and the accuracy factors are equal to the unit, and the AADM equal to zero:

$$Bf = Af_1 = Af_2 = 1 \text{ et } AADM = 0$$

The graphical representations of the response surfaces of the postulated models were made using the STATGRAPHICS Centurion XV software.

Evaluation of the behaviour of the microcapsule powder

At the end of the encapsulation, a quantitative study of the powder obtained is made. The active ingredient present in microcapsules is characterized by several quantities.

Yield

The most common size of the powders obtained by coacervation is the encapsulation yield which is calculated according to the following formula:

$$\tau = \frac{m_P}{m_{GA} + m_G + m_{PA}} \times 100$$

Where m_P is the mass of the powder, m_{GA} is the mass of the gum arabic, m_G is the mass of the gelatin and m_{PA} is the mass of the active ingredient. It is also the yield of the formulation.

Encapsulation rate

The optimized encapsulation rate of the extract is the content of total phenols or total flavonoids encapsulated on the content of total phenols or total flavonoids introduced expressed as a percentage (%) according to the formula:

$$\tau = \frac{Q_{encapsulées}}{Q_{introduites}} \times 100.$$

RESULTS AND DISCUSSION

Study of the influence of factors on coacervation encapsulation

Effect of time on coacervation encapsulation

The influence of time on complex coacervation is shown in Figure 1. The first part of the curves corresponds to an increasing curve from time $t = 0$ min to time $t = 45$ min where the optimum is reached at 44.28 NTU of the turbidity of the mixture and the degree of encapsulation of the total phenols and flavonoids respectively at 503.88 mg EGA/100 g P and 62.32 mg EQ/100 g P with a concavity turned upwards at $t = 30$ min. In this phase, the

Table 2. Coefficients of kinetic models.

Responses	K ₁	K ₂	Pseudo kinetics of 2 nd order			Gauss model		
			B ₀	q _e	R ²	a	k	R ²
Tu	0.05	0.02	19.76	44.38	0.96	44.28	27.7	0.90
TF	0.004	0.002	240.7	503.88	0.97	503.88	106.4	0.93
TP	0.03	0.02	36.22	62.32	0.95	62.32	73.9	0.91

Source: Author

methanol extract of the bark from the trunk of the cashew is being encapsulated by polymers (gum arabic and gelatin). The second part corresponds to a decreasing curve at the end of $t = 45$ min to $t = 120$ min with an upward concavity at $t = 75$ min with a reduction in turbidity up to 20.62 NTU and the rate of encapsulation total phenols and flavonoids at 395.82 mg EGA/100 g P and 49.56 mg EQ/100 g P respectively. This phase corresponds to destruction of the microcapsules. The explanation that one could bring to these results is that at $t = 45$ min, the equilibrium of encapsulation of the active substance of the matrix and the polymers is reached, this is the isoelectric point. Beyond the point, the mixture mixing apparatus breaks the bonds between the polymers and there is degradation of the microcapsules which dissolve in the mixture. The study terminals chosen are [30; 60 min].

Kinetic modeling of encapsulation by coacervation

Two kinetic models allowed us to describe the rate of encapsulation:

1. Gauss model:

$$Y = a_0 \exp\left[-\left(\frac{t-t_0}{4*k}\right)^2\right]$$

Y is the quantity encapsulated at time t and a_0 is the quantity encapsulated at time t_0 .

2. Pseudo kinetics of 2nd order (Tsatsop et al., 2016):

$$\frac{dq_e}{dt} = k(q_e - qt)^2 \quad \text{then} \quad q_t = \frac{t}{k_1 + k_2 * t} \quad \text{with} \quad B_0 = \frac{1}{k_1}$$

la initial rate of encapsulation, and $q_e = \frac{1}{k_2}$ the maximum amount encapsulated.

We notice that the pseudo kinetics of 2nd order adjust better because the curves contain an increasing part up to a maximum and an almost constant part for flavonoids and total phenols. As for the Gauss model the curve decreases sharply after their maximum for turbidity. This was justified by the values of the constants in Table 2.

Pseudo kinetics of 2nd order has well described the encapsulation with respect to its R^2 which are superior to

those of the Gauss model. However, these two models are valid. So in kinetics of 2nd order, the first phase corresponds to the rapid approximation of molecules (k_1) to coacervation and the second corresponds to the slow approximation (k_2) to crosslinking. The adjustment curves of the Gauss models and kinetics order 2 (Figures 2 and 3) show that the rate of encapsulation and the turbidity of the mixture depend on the mixing time.

Effect of gum arabic solution on coacervation encapsulation

Figure 4 shows the turbidity of the mixture, total phenols and flavonoids as a function of the proportion of the gum arabic solution. The mixture is made with a variation of the proportions of the gum arabic solution and the time, are constants.

For the effect of gum arabic, we find that the curves reach their maximum at around 30% which is the equilibrium point then they decrease. The phenomenon of decrease is that the more the gum arabic is increased, the more the density of negative charges increases and the bonds between the polymers break from where there is degradation of the microcapsules: this is dilution. The limits set for the experiment are [20; 40%].

Effect of gelatin solution on coacervation encapsulation

One of the parameters studied during encapsulation is the effect of the proportion of the gelatin solution. This is done in different proportions and the time is kept constant. Figure 5 illustrates the evolution of the turbidity of the mixture and that of the encapsulated total phenols and flavonoids.

Increasing the amount of gelatin increases the turbidity of the mixture and the content of total phenols and total flavonoids. This could be explained by the gradient of encapsulation of the microcapsules between the polymer and the gelatin matrix which is high when the percentage used is large. The application bounds for the experiment plan adopted are [50; 70%]. Thus, the summary of the preliminary tests is presented in Table 3.

The specifications which will allow us to define a compromise zone are defined with turbidity greater than

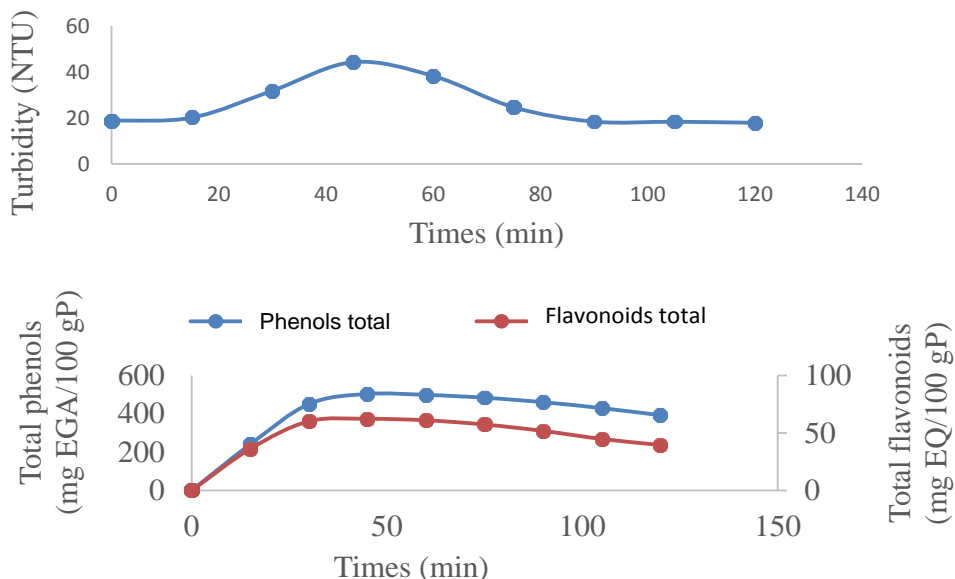


Figure 2. Gauss model.
Source: Author

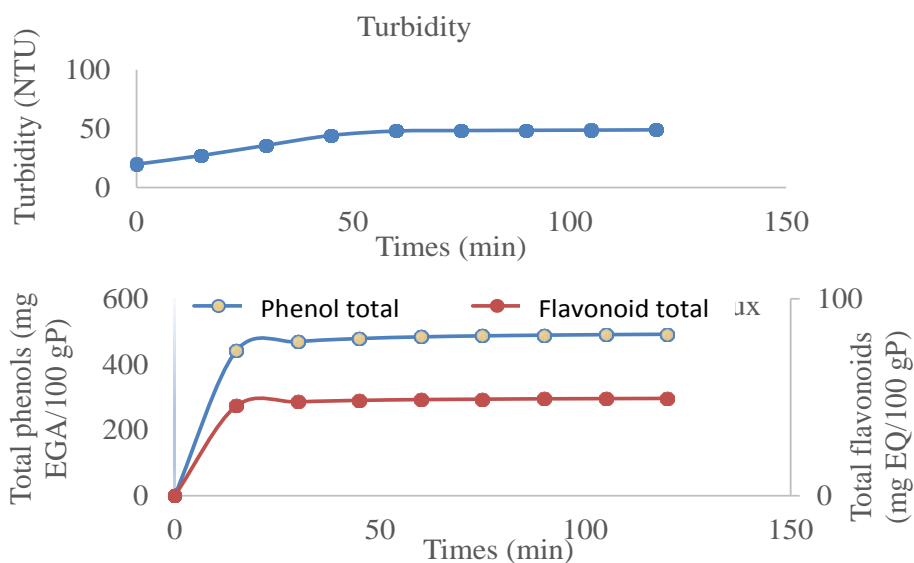


Figure 3. Kinetics model of second order.
Source: Author

or equal to the value of 44.28 NTU; the content of total phenols greater than or equal to 503.88 mg EGA/100 g P and the total flavonoid content greater than or equal to 62.32 mg EQ/100 g P.

The experiment plan

At the end of the experiment plan, the statistical analysis allowed us to have the validation indicators of the models

designed in Table 4.

For a model to be validated, R^2 must be adjusted $\geq 80\%$; Bias factor and accuracy factor ϵ [0.75 and 1.25]; and $0 \leq AADM \leq 0.3$. We have three models which are turbidity model (Y_T), total phenol model (Y_{TP}) and total flavonoid model (Y_{TF}). All three models are valid because their validation indicators are in the standards. The equations of these models are as follows:

$$Y_T \text{ (NTU)} = -74.4 + 0.9X_1 + 0.4X_2 + 4.2X_3 - 0.004X_1X_2 +$$

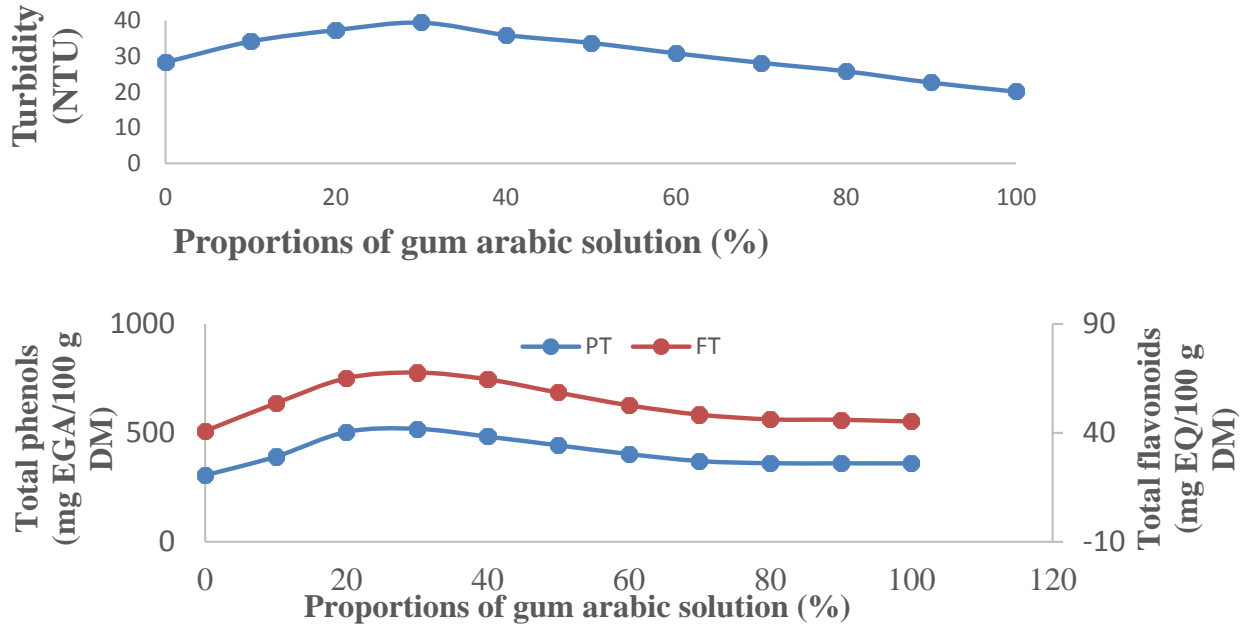


Figure 4. Effect of gum arabic solution on the mixture.
Source: Author

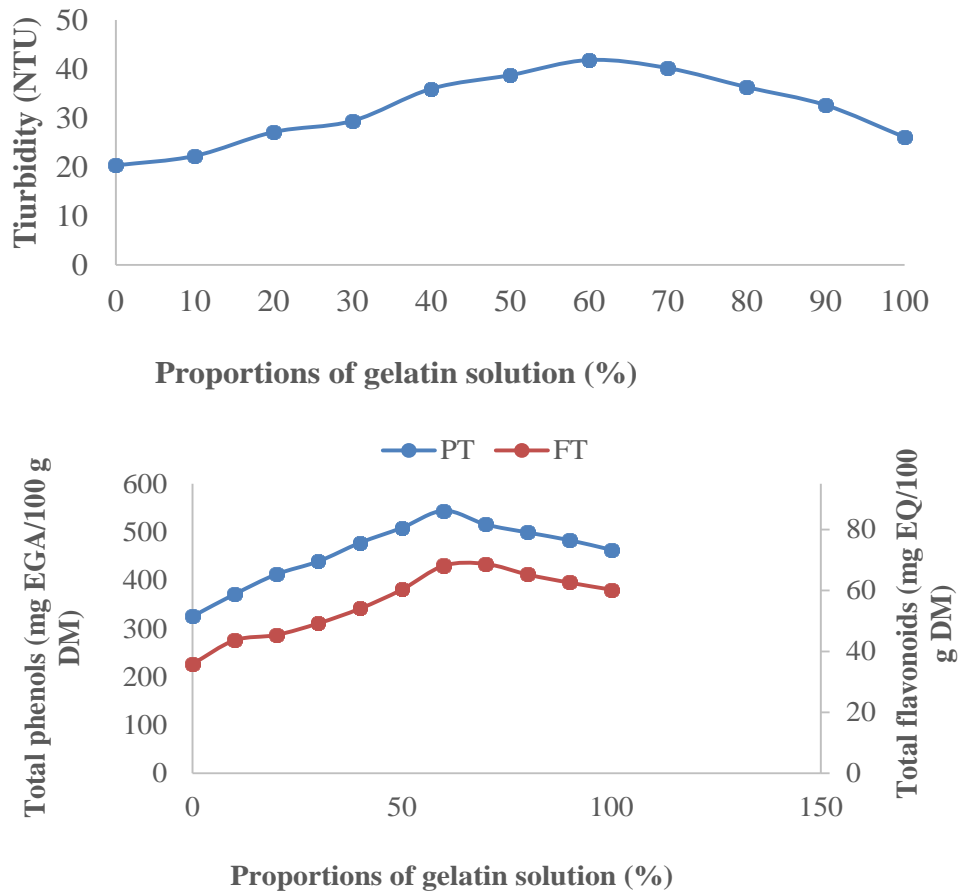


Figure 5. Effect of the gelatin solution on the mixture.
Source: Author

Table 3. Values of the low and high levels for the four factors chosen.

Factors	Low level	Center	High level
Times (s)	30	45	60
Gum arabic (%)	20	30	40
Gelatine (%)	50	60	70

Source: Author

Table 4. Validation of models.

Validation indicator	Model Y_T	Model Y_{TP}	Model Y_{TF}
R^2	99.52	99.63	98.14
Adjusted R^2	99.27	99.43	97.15
AADM	0.01	0.02	0.01
Bias factor	0.894	0.747	0.804
Accuracy factor	1.136	1.003	1.074

Source: Author

$$0.004X_1X_3 - 0.01X_2X_3 - 0.01X_1^2 + 0.003X_2^2 - 0.04X_3^2$$

$$Y_{TP} \text{ (mg EAG/100 gP)} = -763.5 + 11.7X_1 + 2.4X_2 + 46.6X_3 - 0.03X_1X_2 - 0.004X_1X_3 - 0.1X_2X_3 - 0.2X_1^2 + 0.04X_2^2 - 0.46X_3^2$$

$$Y_{TF} \text{ (mg EQ/100 gP)} = -166.6 + 0.5X_1 + 2.4X_2 + 6.9X_3 - 0.002X_1X_2 + 0.01X_1X_3 - 0.03X_2X_3 - 0.02X_1^2 - 0.01X_2^2 - 0.1X_3^2$$

The factor coefficients are shown in Table 5. All the factors X_1 , X_2 and X_3 have a positive and significant influence on the encapsulation. While all interactions and quadratic effects have insignificant influence. Figure 6 presents the contribution of the factors of the models. It confirms that the direct effects contribute to the encapsulation and especially X_3 which contributes strongly, but its quadratic effect contributes negatively. This confirms that the longer the agitation takes place, the more the microcapsules are not broken by the shocks of the agitation.

Encapsulation optimization

The results of the optimization of the encapsulation by complex coacervation are reported in Table 6. The optimum values of responses such as turbidity, total phenols and total flavonoids were measured in two trials and then compared to the values calculated by the equations of the models found. Let's remember that the higher the values of turbidity, total phenols and total flavonoids, the greater the encapsulation yield and these are the best responses. At each optimal condition, for the responses, experimental tests were carried out and the results obtained are recorded in Table 6. The experimental results are almost similar to the calculated results, which is why the design of these experiments is

validated.

In addition, a multi-response optimization was performed. Indeed, the mixture is obtained from the multi-response optimization of the microcapsules. The combination of the different factors is shown in Table 7. Under these conditions, we represent the combination of factors for optimizing the encapsulation of microcapsules by coacervation of the models of turbidity, total phenols and total flavonoids in Table 7.

Evaluation of the powder obtained

Formula yield obtained

The mixture is made according to the experimental plan, by adding in 2 L of distilled water, 40 g of gum arabic, 160 g of gelatin and 40 g of the active Principe (methanol extract from the bark of the trunk of the cashew). After lyophilization, we obtained 202.48 g of powder from the microcapsules. The yield is calculated according to the following formula:

$$\tau = \frac{m_P}{m_{GA} + m_G + m_{PA}} \times 100$$

m_P = mass of the powder, m_{GA} = mass of the gum arabic, m_G = mass of the gelatin and m_{PA} = mass of the active Principe.

So we have:

$$\tau = \frac{202,48}{40+160+40} \times 100 = 84,37\%$$

The optimized extract encapsulation rate is the quantity of active compounds encapsulated over the quantity of

Table 5. Coefficients of the factors of the models.

Factor	$Y_{\text{Turbidity}}$	$Y_{\text{Total phenols}}$	$Y_{\text{Total flavonoids}}$
X_1	0.9	11.7	0.5
X_2	0.4	2.4	2.4
X_3	4.2	46.6	6.9
X_1X_2	-0.004	-0.03	-0.002
X_1X_3	0.004	-0.004	0.01
X_2X_3	-0.01	-0.1	-0.03
X_1^2	-0.01	-0.2	-0.02
X_2^2	0.003	0.04	-0.01
X_3^2	-0.04	-0.05	-0.1

X_1 : Gum arabic; X_2 : gelatin and X_3 : mixing time.
Source: Author

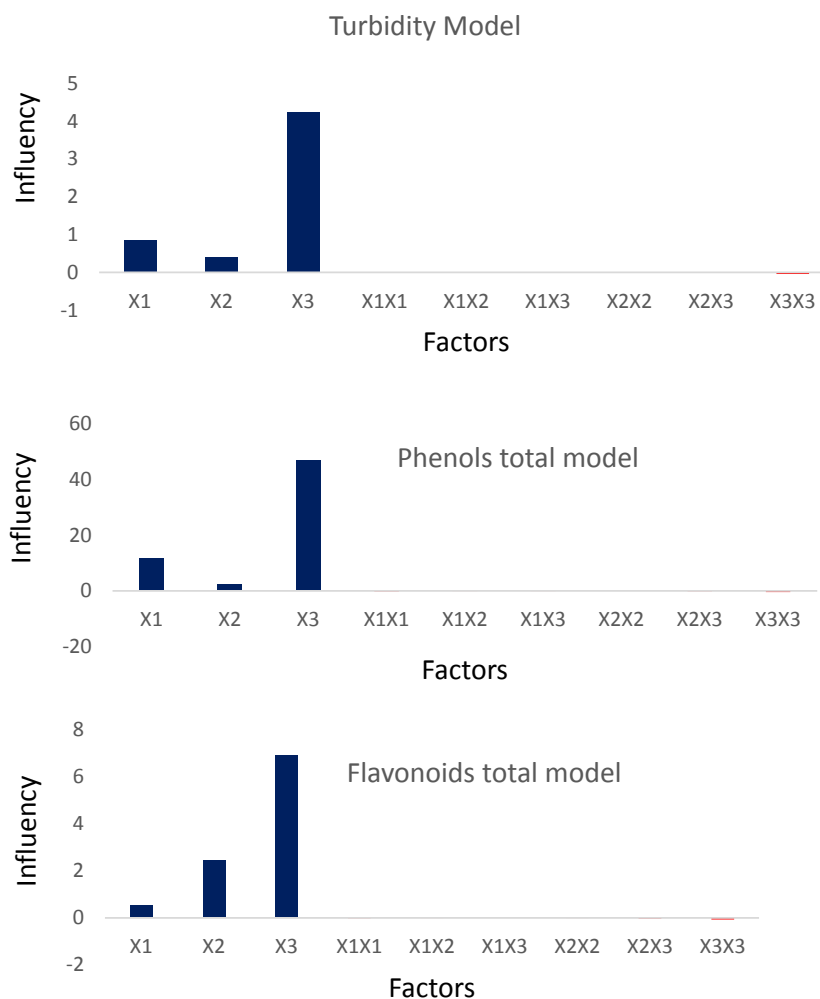


Figure 6. Contribution of model factors.
Source Author

active compounds introduced, all multiplied by 100, that is the content of total phenols and total flavonoids

encapsulated on the content of total phenols and total flavonoids introduced expressed as a percentage (%)

Table 6. Optimization results of the encapsulation by complex.

Factor actual values		Y _{Turbidity} (NTU)			Y _{PT} (mg EGA/100 g P)			Y _{FT} (mg EQ/100 g P)		
		Calculated	Test 1	Test 2	Calculated	Test 1	Test 2	Calculated	Test 1	Test 2
X ₁ (%)	30									
X ₂ (%)	70	42.61	42.84	43.15	492.94	503.88	506.13	62.32	61.50	64.93
X ₃ (min)	45									

X₁: proportion of the gum arabic solution; X₂: proportion of the gelatin solution; X₃: mixing time; Y_{Turbidity}: turbidity response; Y_{PT}: response of total phenols and Y_{FT}: response of total flavonoids.

Source: Author

Table 7. Combination of factors for multi-response optimization of microcapsule encapsulation models.

Factor	Level		Turbidity optimum		PT Optimum		FT Optimum	
	Low	High	Coded value	Real value	Coded value	Real value	Coded value	Real value
X ₁ (%)	20	40	0.999878	39.999	0.59284	35.9284	-0.99999	20.0001
X ₂ (%)	60	80	-0.98351	60.1649	-1.0	60	0.49506	74.9506
X ₃ (min)	30	60	1.0	60	1.0	60	1.0	60

X₁: proportion of the gum arabic solution; X₂: proportion of the gelatin solution and X₃: mixing time. So for the implementation of our formula, we will take the following conditions: 40% of the gum arabic solution, 60% of the gelatin solution and the mixing time is 60 min.

Source: Author

Table 8. Comparison of the quantity of the encapsulated principle with that in the bark.

Extraction technique	Bark powder	Microcapsule powder obtained
Yield (%)	39.71	84.37
TF (mg EQ/100 g P)	262.11	505.01
TP (mg EGA/100 g P)	32.23	63.22

Source: Author

according to the formula:

$$\tau = \frac{Q_{\text{encapsulées}}}{Q_{\text{introduite}}} \times 100.$$

Then

$$\tau_{FT} = \frac{TF_{\text{encapsulée}}}{TF_{\text{introduite}}} \times 100 = \frac{49,25}{63,22} \times 100 = 77,90\%,$$

and

$$\tau_{PT} = \frac{TP_{\text{encapsulée}}}{TP_{\text{introduite}}} \times 100 = \frac{386,38}{505,01} \times 100 = 76.51\%.$$

These values are acceptable because the complex coacervation method encapsulates between 70 and 90%. It is the best chemical method of encapsulation. These results corroborate those of Annalisa et al. (2017).

So the amount of the active ingredient in the powder obtained and the bark powder of the plant used in this study can be compared. Table 8 gives the results of the comparison.

The results show that the powder obtained contains

twice as much of the active principle as the powder of the bark of the trunk of the cashew. So the study microcapsule powder is rich and can be valued.

Conclusion

This study has shown and confirmed previous studies which attest that the rate of encapsulation of the active compounds depends on the proportion of gum arabic, the proportion of gelatin and also on the mixing time. The kinetics of encapsulation follows kinetics of order 2 which gives polynomial equations of the second degree. The best conditions for encapsulation by complex coacervation are as follows: 40% of the gum arabic solution, 60% of the gelatin solution and the mixing time is 60 min. They give the values of total phenols and total flavonoids of 689.82 mg EAG / 100 g DM and 88.64 mg EQ/100 g DM, respectively. The evaluation of the powder gives us a yield of the powder formulation of 84.37% and the encapsulation rate of 77.9% for the total flavonoids

and 76.5% for the total phenols. Finally, the powder obtained is twice as rich in active principle as the plant material used.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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