

Research Article

# Using Kinetics Results of Esterification with Citric Acid to Determine the Nature of the Porosity Structure of the Different Parts of the *Nymphaea nouchali*

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## Abstract

In this study, the *Nymphaea nouchali* aquatic plant was subdivided into 12 parts. To extract the bioactive organic molecules, present in these different parts of the *Nymphaea nouchali* aquatic plant, the esterification method with citric acid was used. The aim of this study was to determine the nature of the porous structure of each part, either microporous structure or mesoporous and macroporous structure, from the results of their kinetic constants during esterification with citric acid, their water content and their density. In this way, kinetic monitoring was carried out for each part of the plant, enabling the different kinetic constants of each esterification to be determined. In addition, the water content and density of each part of the *Nymphaea nouchali* aquatic plant were determined. This water content of each part of the *Nymphaea nouchali* can already give an idea of the nature of their pore structure. But by comparing the water content with the kinetic constants of each part, in particular, the partial order with respect to citric acid and the partial order with respect to organic molecules and the initial and long-term conversion, it is now possible to define the nature of their porous structure. But with a third comparison of the kinetic data and water content with the density of each part of the *Nymphaea nouchali*, the nature of the porous structure of each part becomes increasingly clear and precise. The maximum fatty acid extraction yield is assigned to the part with a mesoporous-macroporous structure. However, it had been noted that the microporous structure parts also show high fatty acid extraction yields, and by determining the extraction yields per gram of sample, it is clear that those of the microporous structure parts are very high. These results confirm that, by virtue of their filiform nature and small molecular widths, these fatty acid molecules manage to locate themselves preferentially in the microporous structure parts.

## Keywords

*Nymphaea nouchali*, Esterification with Citric Acid, Density, Water Content, Porosity, Microporous, Mesoporous-macroporous

## 1. Introduction

The first part of this manuscript presents the different kinetic results of esterification with citric acid of different parts

of *Nymphaea nouchali*. The water content and density of each part of *Nymphaea nouchali* studied had been determined by

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standard laboratory methods. The second part of this manuscript presents the relationships between the kinetic results of esterification with citric acid of each part of *Nymphaea nouchali*, their water content and the nature of their pore structure. Next, a correlation was noted between the odor intensity of citric acid esters from each part and their porous structure. The last part deals with the confirmation of the natures of the porous structures in relation to the kinetic constants of each part, particularly, the partial order with respect to citric acid and the partial order with respect to the organic molecules and the initial as well as long-term conversion. In addition, the fatty acid mass concentrations of each part of *Nymphaea nouchali* were determined using the soxhlet method, confirming the nature of their porous structure.

The materials used during the experiments carried out for this manuscript are: a reflux set-up with 250ml flask, a straight refrigerator and a flask heater for esterification with citric acid, graduated cylinder, 250ml beaker, burette, heli-anthin indicator, NaOH-0.05N, soxhlet, evaporator, citric acid,





*Nymphaea nouchali*, precision balance.






## 2. Esterification with Citric Acid of the Different Parts of *Nymphaea nouchali*

Esterification with citric acid is a method for extracting bioactive organic molecules from a plant by an esterification reaction between the citric acid's carboxylic acid and alcohol functions and the plants' bioactive molecules [1-10].

Here, the different parts of the plant *Nymphaea nouchali* (Table 1) [11-14] were esterified with citric acid. The experimental conditions of each esterification are presented in Table 1, while knowing that for each esterification a monitoring of the progress of the reaction had been carried out as a function of time by assaying at each chosen time the citric acid content of a sample. From these results were deduced the citric acid conversion [1, 2, 9, 10].

**Table 1.** Determination of the different parts of the *Nymphaea nouchali* study in this manuscript.

PARTS	PHOTOS
P1 - white roots submerged in water	
P2 – Receptacle submerged in water	
P3-1 - leaf-bearing stem only	
P3-2 - leaf-bearing stem and flower	

PARTS	PHOTOS
P4 - Leaf	
P9– Receptacle of the flower	
P6 – leaf white/green flowers	
P7-1 – Fresh Pistil and stamen	
P7-2 – non fresh / dry stamens and pistil	-
P8 - Petals	
P5-1 – unripe receptacle P9	-
P5-2 - ripe receptacle P9	-

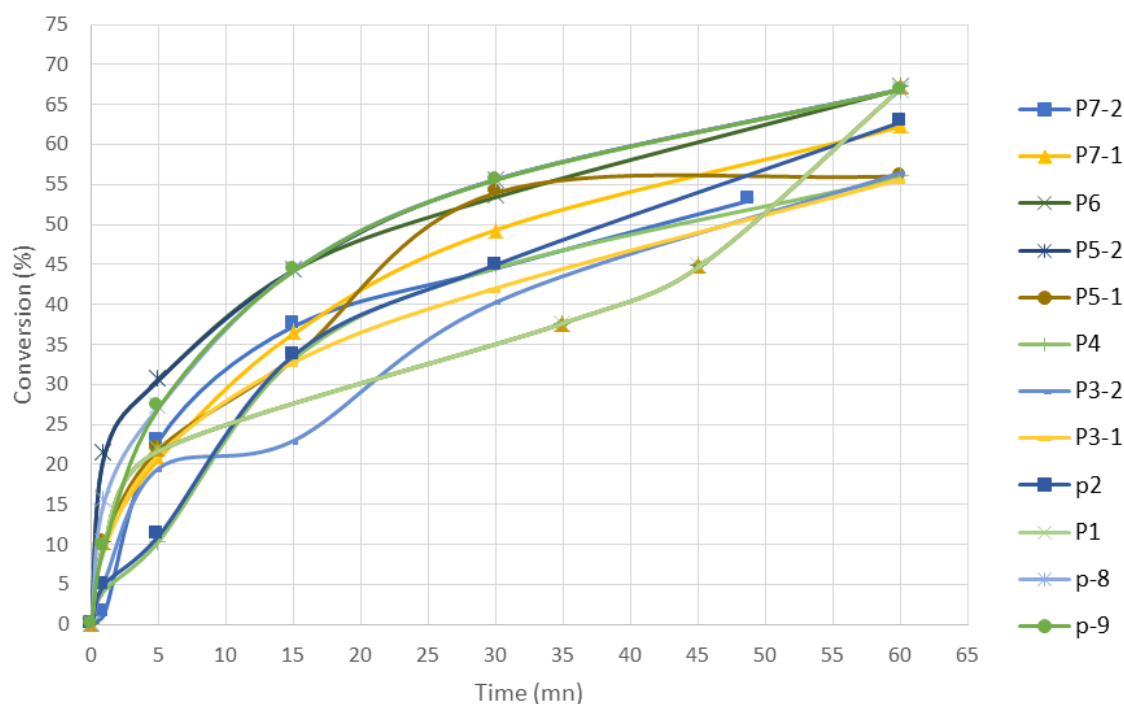
**Table 2.** Experimental conditions and conversion to citric acid over time for the different parts of *Nymphaea nouchali*.

Sample	Reaction time [mn]	Parts of the plant <i>Nymphaea nouchali</i>	Citric acid weight - g	Wet sample weight – g	Distillated water volume - ml	Citric acid conversion - %
Sample1		P1	0.6378	0.4890	200	
	1'					10.04
	5'					21.68
	35'					37.66

Sample	Reaction time [mn]	Parts of the plant <i>Nymphaea nouchali</i>	Citric acid weight - g	Wet sample weight – g	Distillated water volume - ml	Citric acid conversion - %
Sample2	45'	P8	0.6362	0.4904	200	44.62
	60'					66.94
	1'					15.48
	5'					27.11
	15'					44.21
	30'					55.60
Sample3	60'	P3-2	0.6446	0.4936	200	66.87
	1'					5.45
	5'					19.51
	15'					22.96
	30'					40.27
	60'					56.44
Sample4	1'	P9	0.6354	0.4895	200	9.73
	5'					27.02
	15'					44.14
	30'					55.54
	60'					66.82
Sample5	1'	P3-1	0.6336	0.4868	200	9.47
	5'					21.18
	15'					32.78
	30'					42.04
	60'					55.64
Sample6	1'	P7-2	0.5090	0.4062	200	1.40
	5'					22.91
	15'					37.25
	30'					44.50
	49'					53.06
Sample7	1'	P6	0.6366	0.4892	200	21.16
	5'					30.52
	15'					44.25
	30'					53.41
	60'					66.89

Sample	Reaction time [mn]	Parts of the plant <i>Nymphaea nouchali</i>	Citric acid weight - g	Wet sample weight – g	Distillated water volume - ml	Citric acid conversion - %
Sample8		P5-1	0.6390	0.4918	200	
	1'					10.24
	5'					21.85
	15'					33.35
	30'					53.95
	60'					56.06
Sample9		P7-1	0.5574	0.4305	200	
	1'					9.96
	5'					20.65
	15'					36.33
	30'					49.32
	60'					62.18
Sample10		P4	0.6367	0.4890	200	
	1'					4.28
	5'					10.36
	15'					33.11
	30'					44.54
	60'					55.86
Sample11		P5-2	0.6366	0.4904	200	
	1'					21.16
	5'					30.52
	15'					44.25
	30'					55.62
	60'					66.89
Sample12		P2	0.6416	0.4940	200	
	1'					5.01
	5'					11.05
	15'					33.62
	30'					44.96
	60'					62.76

The following [Figure 1](#) shows the evolution of citric acid conversion as a function of time for each esterification of the different parts of *Nymphaea nouchali*.



**Figure 1.** Evolution over time of citric acid conversion during esterification with citric acid of different parts of *Nymphaea nouchali*.

Figure 1 shows that:

- 1) The initial conversion of citric acid during esterification of parts P8 and P5-2 is exceptionally higher than that of the other parts.
- 2) The initial conversion of citric acid during esterification of parts P7-2, P2, P9, P5-1, and P3-2 are the least significant.
- 3) The initial conversion of citric acid during esterification of the remaining parts P1, P3-1, P4, P6, P7-1 are all in the middle of these two previous groups.
- 4) At a much longer time, the citric acid conversion during esterification of P7-2, P2 and P9, initially low, reaches that of the middle, while that of P3-2 remains constantly low.
- 5) For the other parts, at a much longer time, their conversions retain their lead from the initial instants in relation to the other parts of *Nymphaea nouchali*.

### 3. Relationship Between Kinetic Results of *Nymphaea nouchali* Parts and Their Water Content

#### 3.1. Overall Statistical Interpretations of the Kinetic Constants in Relation to the Water Content of the Various Parts of *Nymphaea nouchali*

**Table 3.** Summary table of kinetic parameters and water content.

Parts	initial weight (g)	Final weight (g)	Water content [%]	Speed constant k	" $\alpha$ " partial order for citric acid	" $\beta$ " partial order for organic molecules	Global order
p1	1.7895	0.0625	96.51	1.57E-05	6.13E-01	-9.53E-01	-3.40E-01
P8	0.2137	0.0202	90.55	3.49E+01	1.83E+00	1.70E-01	2.01E+00
P3-2	0.8857	0.0844	90.47	1.16E-02	7.66E-01	-6.41E-02	7.02E-01
P9	0.5040	0.0514	89.80	3.49E+01	1.74E+00	2.68E-01	2.01E+00
P3-1	0.7360	0.0837	88.63	8.78E+03	1.84E+00	1.03E+00	2.87E+00

Parts	initial weight (g)	Final weight (g)	Water content [%]	Speed constant k	" $\alpha$ " partial order for citric acid	" $\beta$ " partial order for organic molecules	Global order
P7-2	0.1406	0.0201	85.70	3.92E+00	1.08E+00	5.34E-01	1.61E+00
P6	0.5730	0.0823	85.64	4.40E+01	1.87E+00	1.34E-01	2.00E+00
P5-1	0.3059	0.0441	85.58	6.21E-06	3.32E-01	-9.22E-01	-5.90E-01
P7-1	0.1130	0.0178	84.25	7.20E+04	2.59E+00	6.54E-01	3.24E+00
P4	0.5682	0.1445	74.57	2.53E+00	1.32E+00	2.74E-01	1.59E+00
P5-2	0.8440	0.2823	66.55	7.32E+04	2.74E+00	5.03E-01	3.24E+00
P2	0.6012	0.2660	55.76	2.54E+00	1.35E+00	2.46E-01	1.59E+00
			82.83362979				

Micro: microporous structure (<2nm).

Mesomacro: mesoporous [2nm-50nm] and/or macroporous structure (>50nm).

It is noticed that;

A1- The average water content of the whole plant is 82.83%. Nine (9) parts of the plant have a water content higher than 82.83% (average), i. e. 75% of the parts studied, and only 25% have a water content lower than this average.

A2 - The high-water content implies that the part is essentially composed of water that had evaporated during the drying process. As a result, the structure of this part is made up of medium to large pores, i. e. mesopores and macropores. This is the case for parts with above-average water content: P1 - P8 - P3-2 - P9 - P3-1 - P7-2 - P6 - P5-1 - P7-1.

A3 - The low water content implies that either the part is essentially composed of water, which evaporates only slightly during drying, or the part certainly has a low water content. In both cases, it is possible to envisage that the structure of this part is composed of porosity with small openings and/or in the form of longitudinal channels. This is the case for parts with below-average water content: P4 - P5-2 - P2.

A4 - Looking at the partial order with respect to citric acid, half (50%) of the plant parts had a partial order greater than 1.5 and 83.33% of this half have a water content above average, i. e. according to the A2 statement, the structure of these parts is made up of mesopores and macropores. The very high partial order with respect to citric acid means that citric acid molecules react readily in these parts. Recall that according to the values given by the Chemschetch chemistry software [15], the size of a citric acid molecule is  $7.06\text{\AA}$  (O13 - O3)  $\times$   $5.463\text{\AA}$  (H16 - H19) with a maximum diagonal of  $7.81\text{\AA}$  (H21 - H16). So, at the very least, the size of the porous structure in these parts is greater than  $8\text{\AA}$ . This is the case for parts: P8 - P9 - P3-1 - P6 - P7-1. Only part P5-2 has a partial order greater than 1.5 and a below-average water content,

which could mean that the structure of this part P5-2 is either essentially made up of mesopores and macropores and a few micropores, or that the water content of this part is low. Referring to the nature of this P5-2 part, which is the large core-grain receptacle of the plant, which is very friable and waterlogged and could therefore be easily removed from this structure, then it has rather a porous structure formed essentially of mesopores and macropores with micropores that may be longitudinal, given the location of this P5-2 part and its function as a receptacle - a transitional position between the genitalia and the stem - and their supports.

As a result, the parts whose partial orders with respect to citric acid are less than 1 contain microporous structures whose quantities are inversely proportional to their water content. This is the case for parts P1 - P3-2 - P5-1, where their partial orders even in relation to organic molecules are negative, confirming the non-negligible existence of micropores in their structures.

A5 - Looking at the partial orders with respect to organic molecules, the majority of their values (91.67%) are less than 1, confirming the existence of micropores and/or mesopores in the structures of the parts seen in assertion A4. Only part P3-1 has a partial order with respect to organic molecules greater than 1, indicating that this part is essentially made up of mesopores and macropores favorable to the formation of large citric acid ester molecules. This P3-1 part is the stem that connects the P2 part, the core of the plant immersed in water, and the leaf of the plant, the P4 part.

A6 - Exploiting the partial orders allows us to confirm the previous assertions for each part and to classify them according to their nature and overall quantity as shown in Table 4, as follows.



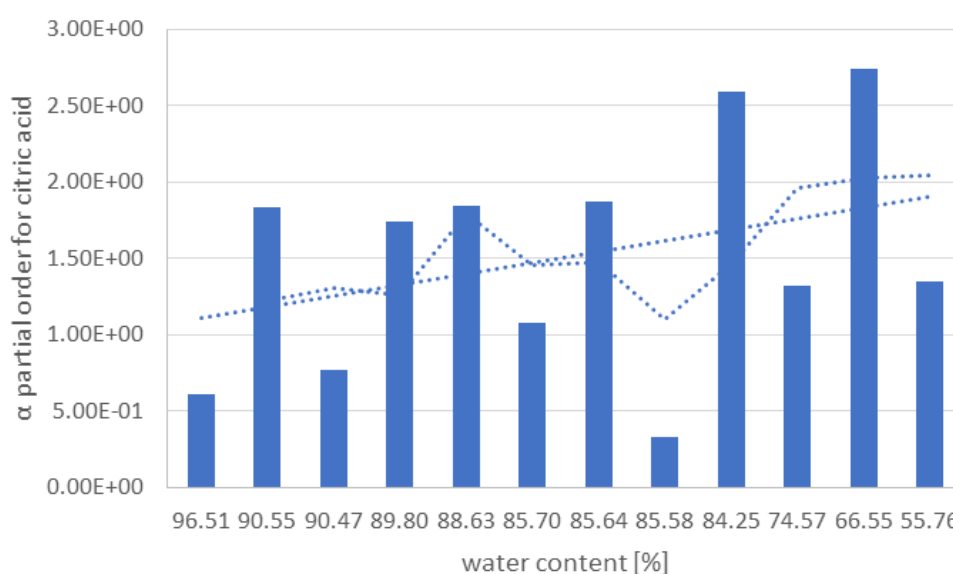
**Table 4.** Proposal for assessing the nature of the porosity of the structures of the various parts of *Nymphaea nouchali*.

Parts	Initial weight (g)	Final weight (g)	Water Content [%]	Speed constant k	" $\alpha$ " partial order for citric acid	" $\beta$ " partial order for organic molecules	Global ordre	Porosity structure
p1	1.7895	0.0625	96.51	1.57E-05	6.13E-01	-9.53E-01	-3.40E-01	micro > mesomacro
P8	0.2137	0.0202	90.55	3.49E+01	1.83E+00	1.70E-01	2.01E+00	micro < mesomacro
P3-2	0.8857	0.0844	90.47	1.16E-02	7.66E-01	-6.41E-02	7.02E-01	micro > mesomacro
P9	0.5040	0.0514	89.80	3.49E+01	1.74E+00	2.68E-01	2.01E+00	micro < mesomacro
P3-1	0.7360	0.0837	88.63	8.78E+03	1.84E+00	1.03E+00	2.87E+00	mesomacro
P7-2	0.1406	0.0201	85.70	3.92E+00	1.08E+00	5.34E-01	1.61E+00	micro < mesomacro
P6	0.5730	0.0823	85.64	4.40E+01	1.87E+00	1.34E-01	2.00E+00	micro < mesomacro
P5-1	0.3059	0.0441	85.58	6.21E-06	3.32E-01	-9.22E-01	-5.90E-01	micro > mesomacro
P7-1	0.1130	0.0178	84.25	7.20E+04	2.59E+00	6.54E-01	3.24E+00	micro < mesomacro
P4	0.5682	0.1445	74.57	2.53E+00	1.32E+00	2.74E-01	1.59E+00	micro < mesomacro
P5-2	0.8440	0.2823	66.55	7.32E+04	2.74E+00	5.03E-01	3.24E+00	microL< esomacro
P2	0.6012	0.2660	55.76	2.54E+00	1.35E+00	2.46E-01	1.59E+00	micro+< esomacro

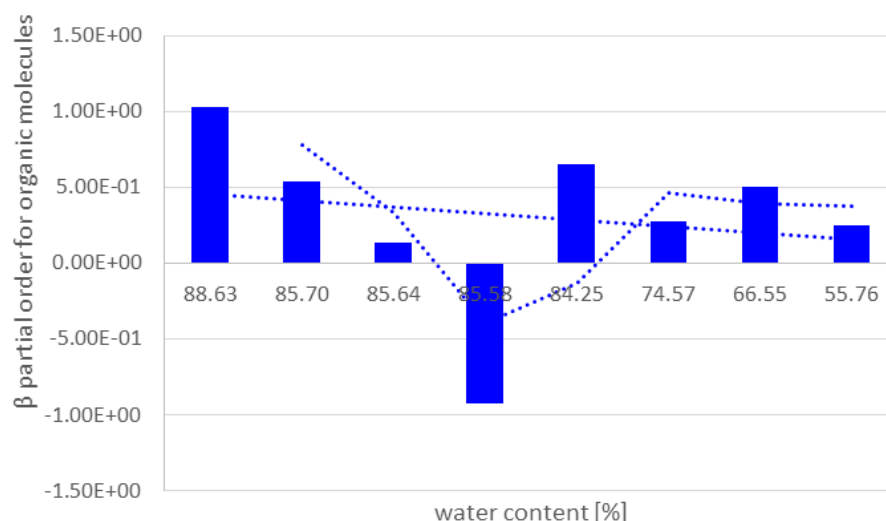
### 3.2. Graphical Interpretation of the Evolution of the *Nymphaea nouchali*'s Parts Kinetic Constants with Their Water Content

It is worth noting that the partial order with respect to citric acid (alpha- $\alpha$ ) (figure 2) of the different parts of *Nymphaea*

*nouchali* generally increases with decreasing water content, a result which confirms that the different parts of *Nymphaea nouchali* have structures not only with mesoporous and macroporous porosities in which citric acid molecules can react freely and efficiently, but also micropores whose quantity increase inversely with water content (cf. Table 4).

**Figure 2.** Evolution of the partial order relative to citric acid (alpha) of the different parts of *Nymphaea nouchali* with their water content.

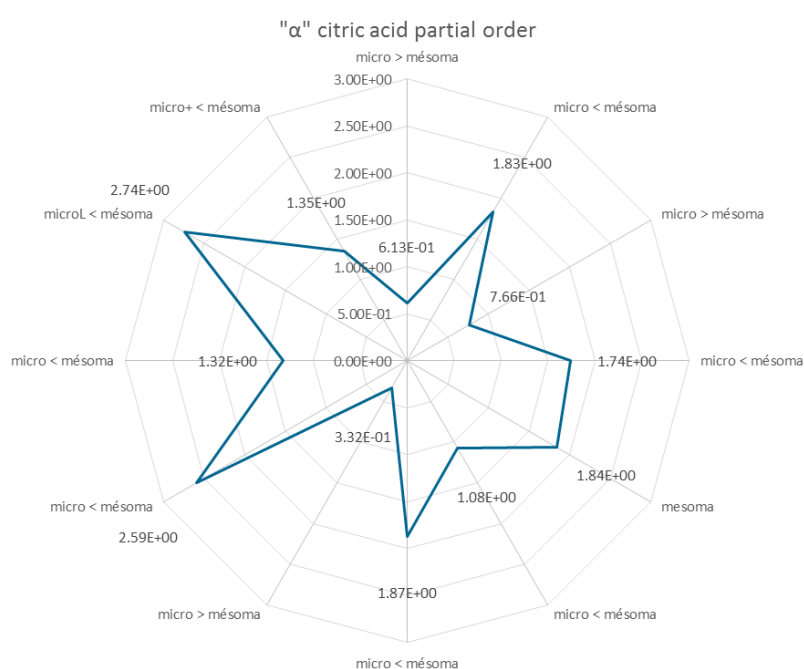




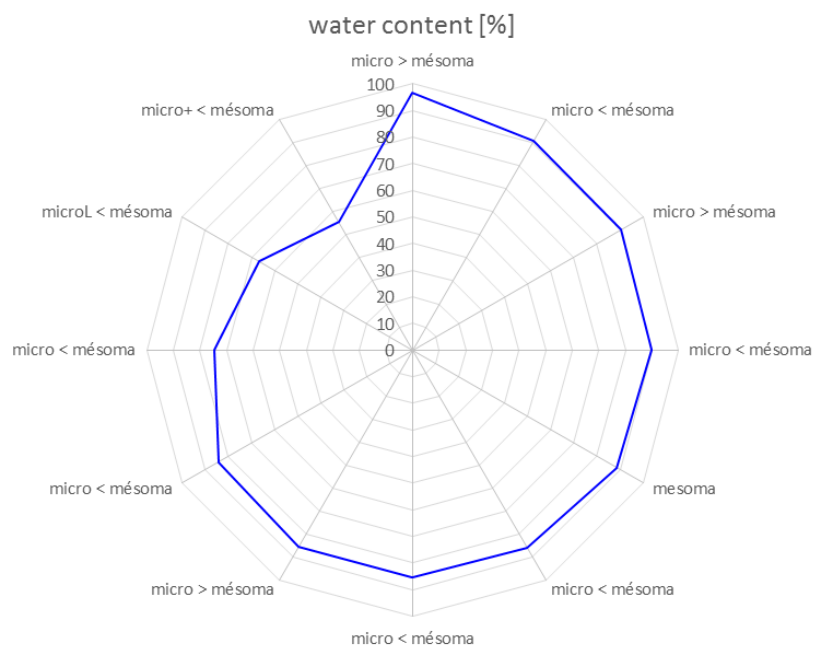
**Figure 3.** Evolution of the partial order of organic molecules (beta) of the different parts of *Nymphaea nouchali* with their water content.

Figure 3 shows that, in general, the partial order of the organic molecules (beta- $\beta$ ) in the various parts of *Nymphaea nouchali* decreases with water content. This result confirms that when the nature (quantity and/or quality) of the micropores in the structures of the various parts is inversely proportional to their water content, then when the water content is low, the micropores are non-negligible and may have longitudinal channel shapes (microL - Table 4), and when the water content is high, the mesopores and macropores are non-negligible; however, any final assessment of the nature (quantity and/or quality) of mesopores and macropores, as well as micropores, must be controlled by the value of the corresponding kinetic constants (figure 4, figure 5 and figure 6). Indeed, when the kinetic constant is great, the

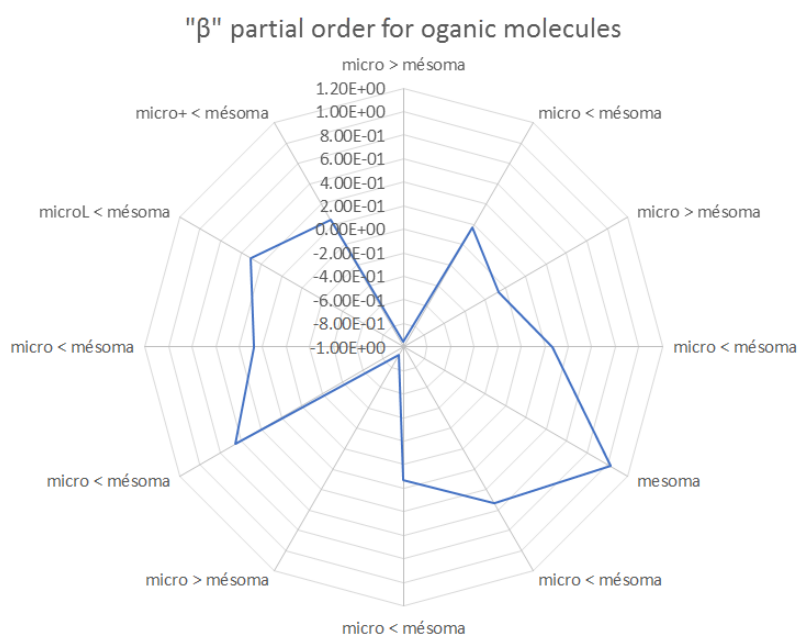
porosity structure of the plant should be sufficient for the size of the molecule corresponding to this constant. Thus, “the water content is not sufficient to determine the nature of the porosity of a part of a plant, it is necessary to know the values of its kinetic constants”. The exceptional negative value of 85.58 for water content is that of the P5-1 part of statements A2 and A4, which is none other than the large, ripe kernel-grain receptacle of the plant, which is very friable and waterlogged, and could therefore be easily removed from this structure, so it has more of a porous structure made up essentially of mesopores and macropores with micropores that may be longitudinal, given the location of this P5-2 part and its function as a receptacle - a transitional position between the genitalia organ and the stem - and their supports.



**Figure 4.** Proposed structure porosity as a function of partial order with respect to citric acid.



**Figure 5.** Proposed structure porosity as a function of water content.



**Figure 6.** Proposed structure porosity as a function of partial order with respect to reacting organic molecules.

#### 4. Relationship Between the *Nymphaea nouchali* Parts' Porosity Structures with Their Citric Acid Esters Odors

The aim of this paragraph is to try and establish a relationship between the nature of the porosity of the structures of

the different parts of *Nymphaea nouchali*, deduced from the kinetic constants of their esterification with citric acid, and the odor of their corresponding citric acid ester solutions. To achieve this, it was necessary to give quantifiable scores to these odors of the different parts, the values of which are given in the following Table 5.

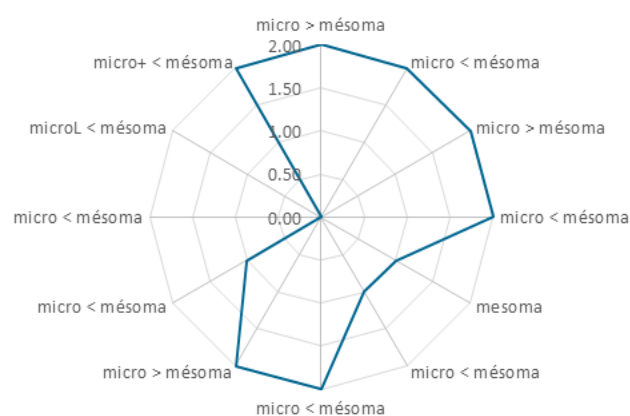
**Table 5.** Notation of odors and colors of different citric acid ester solutions from different parts of the *Nymphaea nouchali* plant.

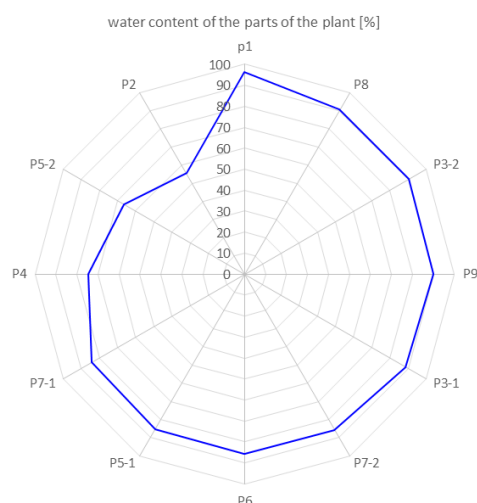
Parts	Odor characteristics	Odor intensity quantifications		Water content [%]	Speed constant k	" $\alpha$ " partial order for citric acid	" $\beta$ " partial order for organic molecules	Global orger	Porosity structure
p1	water hyacinth	++	2	96.51	1.57E-05	6.13E-01	-9.53E-01	-3.40E-01	micro > m ésoma
P8	strong heart note	++	2	90.55	3.49E+01	1.83E+00	1.70E-01	2.01E+00	micro < m ésoma
P3-2	water hyacinth	++	2	90.47	1.16E-02	7.66E-01	-6.41E-02	7.02E-01	micro > m ésoma
P9	shrimp	++	2	89.80	3.49E+01	1.74E+00	2.68E-01	2.01E+00	micro < m ésoma
P3-1	Strong odor	+	1	88.63	8.78E+03	1.84E+00	1.03E+00	2.87E+00	mesoma
P7-2	Strong odor	+	1	85.70	3.92E+00	1.08E+00	5.34E-01	1.61E+00	micro < m ésoma
P6	water hyacinth	++	2	85.64	4.40E+01	1.87E+00	1.34E-01	2.00E+00	micro < m ésoma
P5-1	strong heart note	++	2	85.58	6.21E-06	3.32E-01	-9.22E-01	-5.90E-01	micro > m ésoma
P7-1	tamarrin	+	1	84.25	7.20E+04	2.59E+00	6.54E-01	3.24E+00	micro < m ésoma
P4	odorless	-	0	74.57	2.53E+00	1.32E+00	2.74E-01	1.59E+00	micro < m ésoma
P5-2	odorless	-	0	66.55	7.32E+04	2.74E+00	5.03E-01	3.24E+00	microL < m ésoma
P2	Strong odor	++	2	55.76	2.54E+00	1.35E+00	2.46E-01	1.59E+00	micro+ < m ésoma

By plotting a figure showing the relationship between odor notes and the nature of the porosity of the structures of the different parts of *Nymphaea nouchali*, deduced from the kinetic constants of their esterifications with citric acid (Figure 7), it can be seen that the existence of micropores in the porosity of the structures results in remarkable odor notes, whereas the significant presence of mesopores and macropores tends to significantly reduce these odor notes to zero. In other words, the micropores in the structures effectively retain odors and gradually dissipate them, unlike the mesopores and macropores, which retain none. Thus, it is possible to deduce that the size of the molecules responsible for the strong odor notes of these citric acid ester solutions from the plant *Nymphaea nouchali* is of the order of microns. Thus, the nature of the porosity of a plant's structures, deduced from the results of the kinetic constants of its esterification with citric acid coupled with its odor notes, makes it possible to determine the value of this ester solution in the manufacture of a perfume.

In the case of *Nymphaea nouchali*, referring to the graphs in Figures 7 and 8 below, the citric acid ester solutions of the parts that could be valorized first in a perfume note according to their odors are those of parts P1 - P2 - P3-2 and P5-1. This does not exclude the possibility of upgrading other parts

depending on the marketing and economic strategy to be implemented, bearing in mind that the odor lifespan of other parts not mentioned is normally shorter than that of the parts mentioned above.

**odor note and porosity structure relation****Figure 7.** Graph showing the relationship between odor notes and structure porosity.



**Figure 8.** Graph showing the relationship between water content and plant parts *Nymphaea nouchali*.

## 5. Relationship Between the *Nymphaea nouchali*'s Parts Porosity Structures with Their Conversions

The following Table 6 shows the evolution of the nature of the porosities in the structures of the *Nymphaea nouchali* parts and the evolution of their initial conversion and their conversion at a much longer time (greater than 15 minutes). This suggests that initial conversion is high for mesopores and macropores. On the other hand, initial conversion is predominantly low for micropores, but becomes more significant over the long term for those with significant mesopores and macropores. However, this conversion remains low over the long term for structures with non-negligible micropores, except for those with average initial conversion (Table 6).

**Table 6.** Evolution of the conversion with the nature of the porosities of the structures of the parts of *Nymphaea nouchali*.

	Porosity structure	Initial conversion	conversion at final time reaction
P1	micro > m ésoma	medium	high
P8	micro < m ésoma	high	high
P3-2	micro > m ésoma	low	low
P9	micro < m ésoma	low	high
P3-1	mesoma	medium	high
P7-2	micro < m ésoma	low	high
P6	micro < m ésoma	high	high
P5-1	micro > m ésoma	low	low
P7-1	micro < m ésoma	medium	medium
P4	micro < m ésoma	high	low
P5-2	microL < m ésoma	high	high
P2	micro+ < m ésoma	high	high

## 6. Relationship Between Kinetic Results for *Nymphaea nouchali* Parts and Their Densities

**Table 7.** The bulk densities of the various parts of *Nymphaea nouchali*.

Parts	Density	Density*100
p1	0.4116	41.16
P8	0.6095	60.95
P3-2	0.4823	48.25

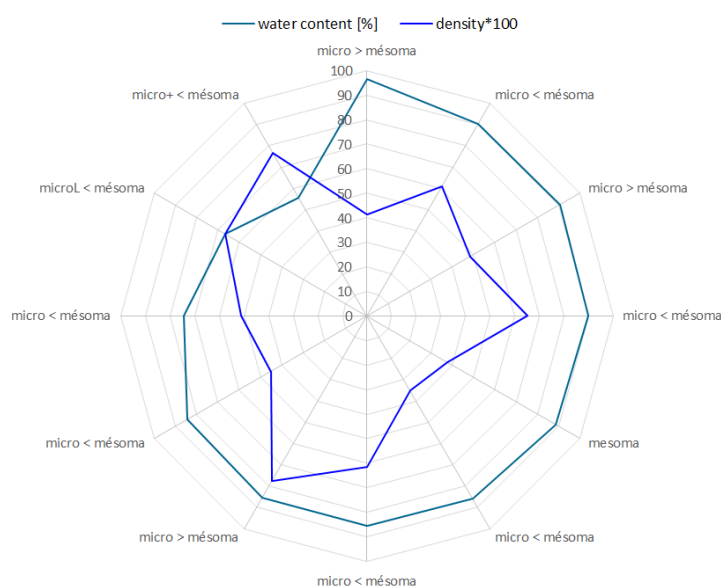
Parts	Density	Density*100
P9	0.6536	65.36
P3-1	0.3778	37.78
P7-2	0.3487	34.87
P6	0.6148	61.48
P5-1	0.7767	77.67
P7-1	0.4526	45.26
P4	0.5118	51.18
P5-2	0.666	66.6
P2	0.7656	76.56

Firstly, when the bulk density or density of a part sample expressed in g/ml is the mass of that part sample occupying a 1ml volume. When this density is large this means that the mass of the sample that occupies this 1ml volume is large whereas when this density is small the mass of the sample that occupies this same 1ml volume is small so it is possible to deduce that this second sample is more porous than the first sample.

Thus,  $\rho_1 \geq \rho_2 \leftrightarrow \text{porous volume sample}_1 \leq \text{porous volume sample}_2$

The average density of the different parts is equal to 0.5559 g/ml, the parts with densities higher than this average (of which they all have a density higher than 0.6 g/ml are colored red and are composed of less total pore volume than the rest of the parts.

By cross-referencing these density results for the various *Nymphaea nouchali* parts with their water content and the nature of their pore structures, we can deduce the quantity of the latter from their densities, as shown in the following Figure 9:



**Figure 9.** Cross-referencing the nature of the pore structures of the various parts with their density and water content.

**Table 8.** Summary of the nature of the porous structures deduced from the kinetic study with density.

P1	its density is low, so its pore volume is very large and composed mainly of micropores
P8	its density is medium, so its pore volume is large and composed mainly of mesopores and macropores

<b>P1</b>	<b>its density is low, so its pore volume is very large and composed mainly of micropores</b>
P3-2	its density is low, so its pore volume is very large and composed mainly of micropores
P9	its density is high, so its pore volume is smaller and composed mainly of mesopores and macropores
P3-1	its density is very low, so its pore volume is very large and composed essentially of mesopores and macropores
P7-2	its density is very low and its pore volume is very large, composed mainly of micropores
P6	its density is medium, so its pore volume is large and composed mainly of micropores
P5-1	its density is very high, so its pore volume is smaller and composed mainly of micropores
P7-1	its density is low, so its pore volume is very large and composed essentially of mesopores and macropores
P4	its density is low, so its pore volume is very large and composed essentially of mesopores and macropores
P5-2	its density is very high, so its pore volume is smaller and composed mainly of mesopores and macropores
P2	its density is very high, so its pore volume is smaller and composed mainly of mesopores and macropores, with significant micropores.

Thus, Table 8 above describes the nature of the porosities of the different parts of *Nymphaea nouchali*.

There is no obvious relationship between water content and the nature of the porous structures of the parts. It is only found that generally when water content and density are all important, so that density\*100 and water content values are close, then the part contains non-negligible micropores.

A simple quantification/notation (Table 9) of the nature of

the various physico-chemical characteristics of the parts of *Nymphaea nouchali* and cross-referencing of the values allows us to deduce that:

1. When density is high, the most likely porous structure of the part is mesoporous-macroporous.
2. When water content is high, the most likely pore structure of the part is microporous.

**Table 9.** Summary table of notes on the nature of the various physico-chemical characteristics of parts of *Nymphaea nouchali*.

	density	Pore volume	structure	Water content
P1	1	3	micropores	2
P8	2	2	m é soma	2
P3-2	1	3	micropores	2
P9	3	1	m é soma	2
P3-1	0	3	m é soma	2
P7-2	0	3	micropores	2
P6	2	2	micropores	2
P5-1	4	1	micropores	2
P7-1	1	3	m é soma	2
P4	1	3	m é soma	1
P5-2	4	1	m é somamicro	1
P2	4	1	m é somamicro	1
	Less than 1		microinfl	
	50.00%		50.00%	
	More than 1		m é soma	micropores
	50.00%		44.44%	56%

**Table 9.** Nature given to the note of the various physico-chemical characteristics of the parts of *Nymphaea nouchali*.

	density	Pore volume	structure	Water content
P1	low	Very important	micropores	important
P8	medium	important	m é soma	important
P3-2	low	very important	micropores	important
P9	great	less important	m é soma	important
P3-1	Very low	very important	m é soma	important
P7-2	Very low	very important	micropores	important
P6	medium	important	micropores	important
P5-1	Very great	Less important	micropores	important
	density	Pore volume	Structure	Water content
P7-1	low	very important	m é soma	important
P4	low	veryimportant	m é soma	low
P5-2	Very great	less important	m é somamicro	low
P2	Very great	less important	m é somamicro	low
	Very low = 0	less important = 1		low = 1
	low = 1	important = 2		important = 2
	medium = 2	very important = 3		
	great = 3			
	Very great = 4			

## 7. Nature of the Various Physico-Chemical Characteristics of the Parts of *Nymphaea nouchali*

The fatty acids of the various dried and ground parts of *Nymphaea nouchali* had been extracted by soxhlet. Both the extraction time and the number of siphoning operations were sufficient to drain the fatty acids from the various samples. Extraction results are shown in [Table 10](#) below.

**Table 10.** Soxhlet Fatty acid extraction results.

	density	Pore volume	structure	Water content	Extraction yield (%)	Weight concentration of fatty acids [mg/g]	Sample initial weight (g)	Yield per initial weight (%/g)	proposal for fatty acid analysis groups
P1	1	3	micropores	2	6.81	68.10	0.5125	13.29	group3
P8	2	2	m é soma	2	20.71	207.10	0.7243	28.59	group1
P3-2	1	3	micropores	2	5.72	57.24	0.9522	6.01	group4
P9	3	1	m é soma	2	4.03	40.27	0.7325	5.50	group4
P3-1	0	3	m é soma	2	5.86	58.58	0.7101	8.25	group5
P7-2	0	3	micropores	2	10.89	108.86	0.598	18.20	group2
P6	2	2	micropores	2	10.85	108.46	0.8298	13.07	group4



	density	Pore volume	structure	Water content	Extraction yield (%)	Weight concentration of fatty acids [mg/g]	Sample initial weight (g)	Yield per initial weight (%/g)	proposal for fatty acid analysis groups
P5-1	4	1	micropores	2	11.30	112.96	0.7985	14.15	group7
P7-1	1	3	mésoma	2	8.82	88.16	0.8893	9.91	group2
P4	1	3	mésoma	1	6.36	63.60	1.1352	5.60	group6
P5-2	4	1	mésomamicro	1	7.47	74.73	1.1147	6.70	group7
P2	4	1	mésomamicro	1	5.43	54.25	0.8405	6.45	group5
								11.31	

It is note that:

- 1) the values recorded are higher in micropore structures than in mesopore and macropore structures.
- 2) values are higher in parts with higher water content.
- 3) yield per initial mass is lower in parts with mesopore and macropore structures.
- 4) above-average yield per initial mass in parts with micropore structures.
- 5) The P8 part with macroporous structure has the highest yield per initial mass.

In establishing an indicator “yield per initial mass - %/g (Rabeharitsara, et al., 2024) which was important not only for assessing extraction quality but also the nature of the fatty acids in a part, a relationship was found between the nature of the structures and the magnitude of this indicator. Indeed, when this indicator is higher, the porosity of the structure is micropore.

The maximum fatty acid extraction yield is assigned to the part with a mesoporous-macroporous structure. However, it had been noted that parts with a microporous structure also show high fatty acid extraction yields, and by determining extraction yields per gram of sample, it is clear that those of parts with a microporous structure are very high. These results confirm that, by virtue of their filiform nature and small molecular widths, these fatty acid molecules manage to locate themselves preferentially in the microporous structure parts.

6- From these indicators and according to the nature of the part and the aim of the analysis, it's possible to gain efficiency through analysis by grouping the chromatography analysis of different parts. On the Table 10 is given a proposition of this grouping analysis.

## 8. Conclusion

The results of this study led to the conclusion that it is possible to determine the nature of the porous structures of a plant, in this case *Nymphaea nouchali*, by comparing the kinetic results of their esterification with citric acid, the evolution of their conversion to citric acid at initial and long-term

instants with their water content and density. Two types of pore structure had been identified on the different parts of *Nymphaea nouchali*, a microporous structure for parts P1, P3-2, P7-2, P6, P5-1, a mesoporous and macroporous structure for parts P8, P9, P3-1, P7-1 and P4 and a structure that was both microporous and mesoporous and macroporous for parts P5-2 and P2. The comparison of the porous structures of the parts with their fatty acid mass concentration and their fatty acid mass concentration per gram of extraction sample led to the conclusion that, due to their filiform natures at low molecular widths, these fatty acid molecules manage to locate themselves preferentially in the parts with microporous structures. The study of the correlation between odor intensity and the nature of the porous structures led to the conclusion that the greater the odor intensity, the more microporous the structure of the parts. In short, the kinetic results of esterification with citric acid of a plant or plant part confronted with its water content and density enabled the nature of its porous structure to be determined. On the other hand, these results indicate also that the nature of the porous structures of plant influenced the reaction speed, the reaction which occurred there preferentially and certainly its product reactions. Indeed, it was noted that in this the esterification reaction between the citric acid and the small width molecules fatty acids of *Nymphaea nouchali* occurred preferentially on microporous structure.

## Abbreviations

mésoma	Mesoporous with Macroporous
Micro	Microporous
mésomamicro	Mesoporous with Macroporous with Microporous
microL	Longitudinal Microporous
Micro+	More Microporous

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## Conflicts of Interest

The authors declare no conflicts of interest.

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