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Modeling the Pulp Oil Extraction with Water on Post-harvest Losses from the Safou Crop (*Dacryodes edulis*) in the Congo Basin. Main Factor Effects and Factors Interactions

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Abstract The oil from the dried pulp from post-harvest losses from the safou crop (Dacryodes edulis) was extracted with hot water (50/90°C) and magnetic stirring (0/1000 rpm). Over a variation range of 8 to 38 %, the average value of the extraction yield obtained is 21.14%, with an experimental control yield of 25.14%, i.e. a difference of minus 15%. The effects of the factors studied are positive for the "extraction yield" response: extraction temperature (+9.558); extraction time (+2.916) and stirring speed (+2.387). The interactions of order 2 are negligible (X1X2, X1X3) or even zero (X2X3).

Keywords: *modeling, extraction, experimental design, Dacryodes edulis, Congo-Brazzaville*

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1. Introduction

The safou tree, emblematic tree of Central African landscapes, is an economically major crop in the sub-region [1,2,3,4,5] [6,7,8,9,10,11]. Safou, the fruit of the safou tree, is very fragile. It softens in less than a week and becomes unfit for consumption as edible fruit [12,13,14]. Traditionally it is kept dried or smoked [15]. In recent decades it has begun to be valued by extracting oil from the dried pulp. Drying and oil extraction are the key operations in the production of oil from safou pulp that should be modeled in order to optimize their yield [16,17,18,19,20]. The issue of oil production from safou pulp was timidly approached, at least for Cameroon [21].

2. Material and Methods

2.1. Drying of the Plant Material

The naturally softened safou pulp, one week after its harvest, was dried in open air to constant mass.

2.2. Extraction of Safou Pulp Oil with Water

The oil from the safou pulp was extracted by the local artisanal method. The dried, finely ground pulp (mass m1 (db)) placed in an aluminum container was hot extracted with water under stirring. The supernatant oil was collected using a syringe. Let m_2 be the mass of the oil obtained, the extraction yield is given by:

$$Y(\%) = (m_2 / m_1)100 \qquad (1)$$

2.3. Design of Experiments Method

The modeling was carried out using the design of experiments method as described previously [12,18]. We used a two-level full factorial design involving three factors and a control point 2^3 (Table 1, Table 2).

Table 1. Levels of the 3 factors studied

Factors	X_1:Extraction time (min)	X_2: stirring speed (trs/min)	X_3: Heating temperature (°C)
Level 2 (+1)	120	1000	90
Level 1 (- 1)	30	0	50
Control (0)	75	500	70

Table 2. Matrix of Design of experiments du plan

Run	X_1	X_2	X_3
1	- 1	- 1	- 1
2	+1	- 1	- 1
3	- 1	+1	- 1
4	+1	+1	- 1
5	- 1	- 1	+1
6	+1	- 1	+1
7	- 1	+1	+1
8	+1	+1	+1
9	0	0	0

3. Results and Discussion

Table 3 presents the design of experiments and the extraction yield response of the extraction of safou pulp oil by water.

Table 3. Design of experiments and the extraction yield response

Runs	X_1 (min)	X_2 (tr/min)	X_3 (° C)	Y (%)
1	30	0	50	8,47
2	120	0	50	10,48
3	30	1000	50	11,93
4	120	1000	50	16,62
5	30	0	90	24,76
6	120	0	90	32,48
7	30	1000	90	28,92
8	120	1000	90	37,83
9 (control)	75	500	70	25.14

3.1. Extraction Yield Response

The NemrodW software generated the following mathematical model:

$Yt(\%) = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3$

with b0, the mean of the response Y which serves as the control point of the model; b_i the coefficients of the factors effects X_i and b_{ij} the coefficients of the interactions between factors X_{ij}. If the factors (X_i) are reduced and centered (xi) with $xi = (X_i\text{-}X_0)/\Delta X$ [22].

$Yt(\%) = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3$

The coefficients have simple meanings: b_0 = response mean, bi = main factor effect and bij= interaction of factor effects.

The extraction of the safou pulp oil with water leads to the following model:

$$Yt\ (\%) = 21.4355 + 2.9155\ x_1 + 2.3875\ x_2 + 9.5590\ x_3 + 2.9155\ x_1x_2 + 2.9155x_1x_3 + 2.3875x_2x_3 \quad (2)$$

The average extraction yield Y_0 generated by the design is equal to 21.44%; this value is very close to that of the experimental control point (run 9), which corresponds to a yield at the center of the design of 25.14%, i.e. a difference of less than 15%. Thus, validating the model.

Figure 1 brings together the main factors effects and second order interaction effects during oil extraction from safou pulp with water.

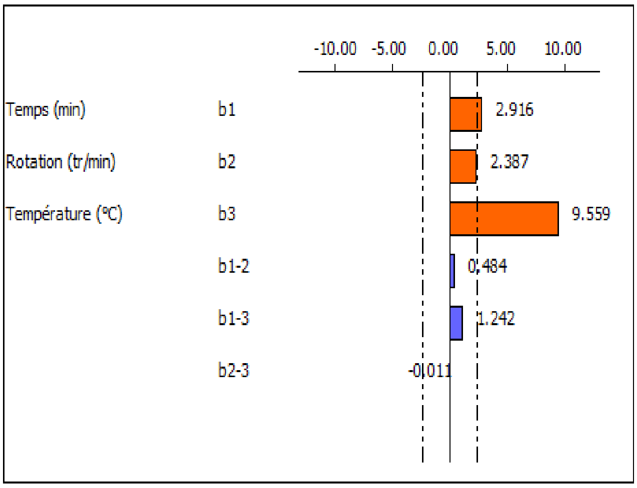

Figure 1. Coefficients b_i of the factors effects and coefficients b_{ij} of the interaction effects between factors during oil extraction from safou pulp with water

3.2. Main Factors Effects

All main factor effects are positive and the extraction temperature effect is the most important (+ 9.559). In the study domain considered here, any increase in the value of one of these factors improves the extraction yield and the most significant increase in yield is observed for the increase in the extraction temperature. The coefficients relating to these effects were determined with a good level of significance (Table 4).

Table 4. Statistics of coefficients of factor effects and interactions during the water extraction of safou oil

	Coefficient	F. Inflation	SD	t. exp	Signif. %
b0	21.4355	1.00	0.1860	115.24	0.552**
b 1	2.9155	1.00	0.1860	15.67	4.06*
b 2	2.3875	1.00	0.1860	12.84	4.95*
b 3	9.5590	1.00	0.1860	51.39	1.24
b 1-2	0.4835	1.00	0.1860	2.60	23.4
b 1-3	1.2420	1.00	0.1860	6.68	9.5
b 2-3	-0.0110	1.00	0.1860	-0.06	96.2

3.3. Factors Interactions Effects

Figure 2 shows that the values of the coefficients of the order 2 interactions effects between factors were very low (b_{12} = 0.484 and b_{13}= 1.242), or even nulles (b_{23})

A more detailed examination of these interactions deal to finer trends of their evolution (Figure 2)

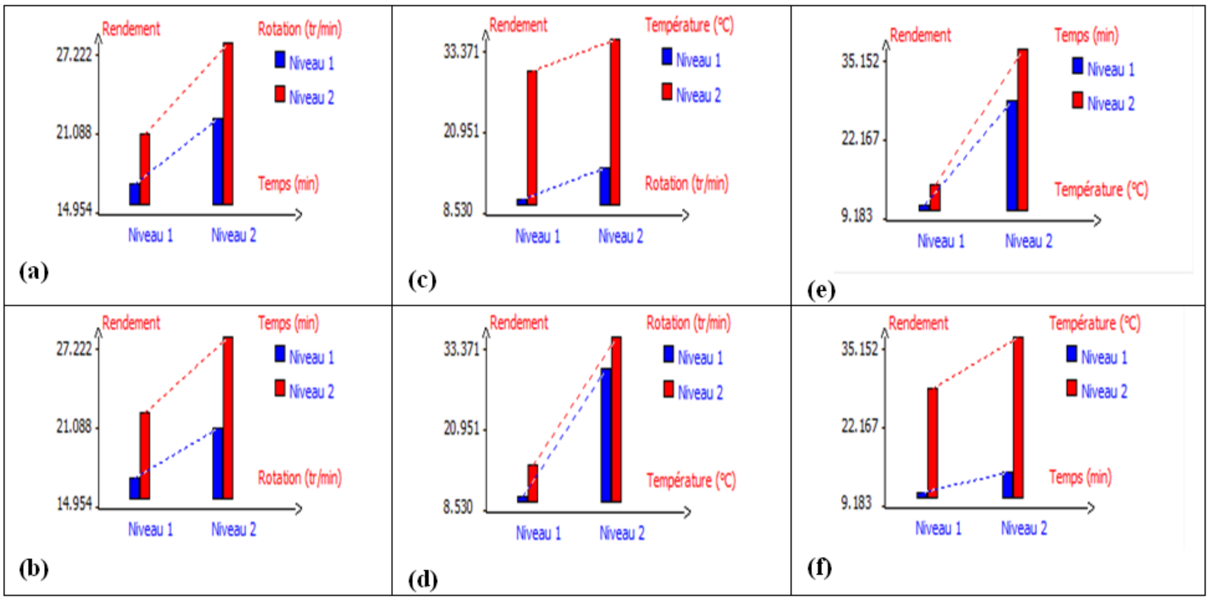

Figure 2. Schemas of main factor effects and second-order interaction effects between factors of oil extraction from safou pulp

For example, carefully observation of diagram 2f shows that:

Changing the extraction time from level 1 (30 min) to level 2 (180 min) when the mixture is heated to level 1 (50°C, dotted blue line) increases significantly the yield of extraction.

Carrying out the same operation under level 2 of heating (90°C, dotted red line) produces the same effect but with much higher yield values.

The representative curves of the quasi-parallel effects reflects an absence of interactions between the time and temperature factors of extraction.

Such a reading, extended to the 6 diagrams in Figure 2, further reveals the course of the process.

Finally, Figure 2 attests to important main factors effects: high value of the slopes of the dotted lines (blue and red); very weak second-order interaction effects: quasi-parallel red and blue dotted lines on the 6 diagrams (Figures 2a to Figure 2f).

Moreover, the correlation between the experimental values and the yield values generated by the model is almost perfect: R^2 = 0.9997 (Figure 3). This constitutes the ultimate validation of the mathematical model adopted.

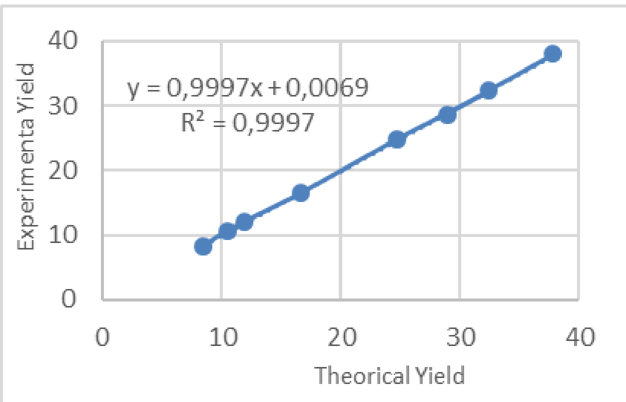

Figure 3. Validation of the model by the experiment

4. Conclusion

Safou is a major crop in Central and West Africa which unfortunately records more than 50 % of post-harvest losses.

The oil is extracted from the dried pulp of softened safou (post-harvest losses) with an average yield of 24.14% over a variation range of 8-37%. In the experimental domain considered, the extraction temperature is the most important factor, followed in order by the extraction time and the stirring speed. The interactions of order 2 are negligible.

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