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Optimization of *Elaeïs guineensis* Palm Sap Extraction Process using Doehlert Method for Extraction Time Reduction and Palm Heart Preservation

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Abstract: ***This study was led in order to evaluate the influence of some factors on sap extraction process from oil palm trees, for reduction of extraction time (DE) and preservation of palm heart (CPE) quantity at the end of aforesaid extraction. To do this, controllable and influential factors were sought first. Then, an experiment design based on the Doehlert method was applied for the optimization of the study factors. As results, controllable and influencing factors in the sap extraction process such as daily incision numbers (NI), incision surface (SI) and thickness of polyurethane sponge (EM) were retained. Experimentation has shown that to reduce sap extraction time and preserve more quantity of palm heart at the end of sap extraction from oil palm tree, a maximum of three daily incisions must be done in the palm heart. Then, the thickness of the polyurethane sponge and the incision surface must be kept at their optimum levels. Under these conditions, about two thirds of the initial weight of the palm heart can be preserved at the end of sap extraction time estimated to about three weeks.***

Keywords: *Elaeïs guineensis*, Doehlert experimental design, Optimization, Oil palm tree, Palm heart, Sap extraction process

1. Introduction

African oil palm (*Elaeïs guineensis* Jacq.) is originating from the Gulf of Guinea [1]. This plant belongs to the branching of Angiosperms, the subphylum of Monocotyledons and the family of *Arecaceae* (formerly called *Palmaceae*). The family *Arecaceae* includes 183 genera and over 2400 species. These plant species can be grouped into five main types of palms: nut palms, peach palms, coconut palms, date palms, and oil palms [2]. The *Elaeïs* genus that is the subject of this study includes the commonly encountered species *Elaeïs guineensis* (Jacq) and *Elaeïs oleifera*, representing respectively african and american oil palms [1]. The oil palm *Elaeïs guineensis* is the most widespread species in west Africa because of its economic and genetic selection interests.

The oil palm sector ranks fourth in the ivorian economy and employs more than one million people in the southern part of the forest zone. With 400,000 t of crude palm oil produced per year, Côte d'Ivoire ranks fifth in the world after Malaysia, Indonesia, Nigeria and Colombia. The country is the leading african exporter and the second largest african producer behind Nigeria [3].

With manifold aims and a source of traditional and modern technologies, man can obtain invaluable wealth from oil palm: food, drink, medicine, household and building materials, art objects, fuels, livestock and agricultural products, cosmetics, etc. [4]. Thus, the slaughter of old oil palm trees seedlings for the sap extraction (improperly called palm wine) and for an ethylic alcohol distillation is a source of exploitation of the oil palm tree. The income per hectare (140 palm trees) is 210,000 FCFA, or nearly two years of net income (non-labour) of a palm grove in production [5]. In 2000, the exploitation of one hectare of oil palm trees plantation for sap extraction yielded to the planter between 350,000 and 420,000 FCFA, at 2,500 or 3,000 FCFA per tree [6]. Hence the interest of such exploitation in the value added to the oil palm. However, sap extraction requires regular incisions in the heart of the palm tree for about two months [7]. This action induces in a drastic reduction of the palm heart weight at the end of sap extraction.

However, among the products derived from oil palm tree and used in human nutrition, we find the palm heart from young plants. It is extracted from several species and genera of palm trees. Ecuador is the world's largest exporter, followed by Costa Rica and Brazil [8]. Palm hearts are generally richer in water (80 % - 93 %), it contains crude proteins (10.7±0.66 - 13.12±0.69 %), crude fiber (21.98±0.02 - 34.9±0.1 %), ash (6.91±0.07 - 8.28±0.51 %), carbohydrates (39.85±0.06 - 46.42±0.11 %) and energy (270.45±0.04 - 330.65±0.01 kcal / 100 g) and contains 17 amino acids. All essential amino acids are present in the heart of palms. It is also an excellent source of vitamin C and a potential source of vitamins A, B1, B2, B3, B6 and K. Minerals such as calcium, iron, potassium, sodium, phosphorus and zinc are found in moderate amounts in the heart of palms [9]–[12].

With regard to the nutritional value of palm heart, this study aimed to reduce sap extraction time for more preservation of palm heart quantity at the end of sap extraction from oil palm trees. Specifically, search for controllable and influential factors in oil palm sap extraction process and make use of response surface method for their optimization.

2. Material and methods

2.1 Biological material

Elaeïs guineensis Jacq oil palm trees aged 20-years-old were our biological material. The oil palm had a stipe height ranging from 9.5±1.25 to 10.34±1.55 m and a diameter of 51.77 ± 2.45 cm. It was obtained locally from a commercial plantation in the region of Mé (Alépé / Côte d'Ivoire). The study was conducted during the long dry season of the country (from 1st December to 30th February), during which, the palm heart rot is limited.

2.2 Polyurethane sponge

The sponge used in this study is based on polyurethane. Its main technical interests are: low thermal conductivity, high specific modules, high water absorption capacity, low density and thermal insulation [13]. Polyurethane sponge was also easy to access and lower cost over the markets.

Figure 1: Polyurethane sponge

2.3 Oil palm tree sap extraction process

In this study, the artisanal method of extraction of sap adopted by the farmers was followed while making some modifications. Thus, after the selection of the 16 oil palm trees (2a), they were totally uprooted without injury the stipe (2b). Then, the felled palms were left to rest for a period of 7 days, thus plunging the palm trees into a state of water stress and leading to the descent into the stipe a good deal of the sap accumulated into the leaves [7]. The crown of leaves was then trimmed to the base of the petioles of the last developing leaves that protected the heart of oil palm tree (2c). At this stage, a cavity was opened in it from the upper face to its lower contact face with the last leaves. A bleeding surface was then released over the periphery of the palm heart. The bottom of the cavity was drilled with a stainless steel rod and a 1 cm diameter PVC pipe was inserted into the hole. This pipe was the channel through which the sap flowed by gravity. This made it possible to collect the sap into a container placed below the cavity. This system served as a funnel and allowed the flow of sap to the recollection can. Subsequently, a polyurethane sponge was attached to the bleeding surface of a lot of oil palm trees (2d) and the cavity was covered with a heavy petiole cut accordingly (2e). The heart of oil palm trees were subsequently bled daily one to five times and at regular intervals. The bleeding was renewed by an incision of about 1 mm from the bleeding surface until the stoppage of the sap flow from the stipe. Once sap extraction was complete, the remaining palm heart was then isolated (2f) and weighed.

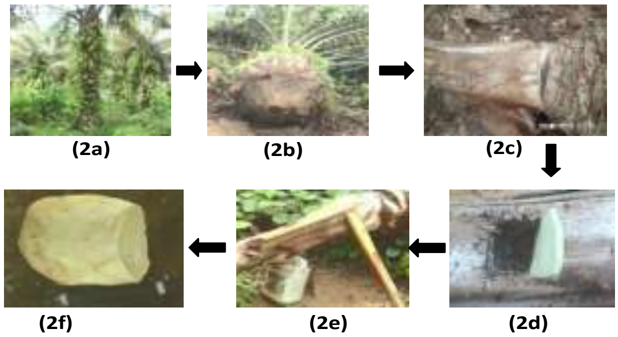

Figure 2: Sap extraction process (2a – 2e) and sap post-extraction palm heart (2f)

2.4 Study of the influence of the extraction parameters on the sap flow rate from oil palm trees

In this experiment, the factors targeted were the thickness of the polyurethane sponge used (0 cm, 0.75 cm and 1.5 cm), the number of daily incisions in the palm heart (1 and 2) and the surface of these incisions (362.07 and 498.78 cm²). During sap extraction, two factors were fixed and the third was varied. For 24 hours, the sap volume of each palm concerned was measured in 2 hours increments with graduated beaker. In the case of highlighting the influence of the incision surface, the experiment took place between 7.00 Am and 13.00 Am of the day corresponding to the hours of strong sap flow.

2.5 Doehlert's experience design

The Doehlert's method was chosen to study the influence of the number of the incision (NI), the incision surface (SI) and the thickness of the polyurethane sponge (EM) on the mass of the sap post-extraction palm heart (CPE) and extraction time (DE). The choice of the matrix, Doehlert's uniform network, was motivated by its ability to assign different levels to each independent variable (variable 1: 5 levels, variable 2: 7 levels, variable 3: 3 levels) thus favouring the use of conditions likely to achieve optimum results. The number of experiments (N) to be realized was determined by the number of factors (k) [14]. The formula of calculation was the following one:

$$N = K^2 + K + 1 \quad (1)$$

The matrix thus constituted led to the realization of 13 distinct tests by combination of the three factors levels retained for this experimentation. In the centre of the study's field, the experiment was repeated three times (experiences 14, 15 and 16 were the repeated one) to determine the experimental error by analysis of variance.

The selection of the factors to be studied was motivated by the preliminary results of the experiments (part 2.4). These solicited factors already gave satisfactory results. These three factors have been defined respectively as the variables X1, X2 and X3. The levels of the factors selected for optimization of sap extraction process are presented in Table 1. The range of variation was set between 1 and 5 for the incision number (NI) factor, between 0 cm and 1.5 cm for polyurethane sponge thickness factor (EM) and that of incision surface (SI) fixed between 362.07 and 478.78 cm².

Table 1: Factors and study field

Independent variables	*Levels*	*Experimental values*
Number of Incision X1	5	1, 2, 3, 4, 5
Sponge thickness X2	7	0, 0.25, 0.5, 0.75, 1, 1.25, 1.5
Incision surface X3	3	362.07, 430.43, 498.78

2.6 Weight of the sap post-extraction palm heart and the duration of sap extraction from oil palm

Sap extraction was stopped at each palm when the daily sap volume was less than or equal to 100 mL. It was as soon as this volume almost, that the traditional extractors of palm wine put end of sap extraction from oil palm tree. Then, at the end of the sap extraction, the palm heart left was isolated and weighed using balance (ACCULAB VIC-412).

3. Results and discussion

3.1 Factors Influencing Sap Extraction From Oil Palm

Figures 3 & 4 provide information on the influence of the number of incisions made in the palm heart and the thickness of the polyurethane sponge on the flow rate of the sap, during 24 hours of sap extraction. The analysis of variance carried out showed a significant difference ($p \leq 0.05$) concerning the sap flow velocity at all of oil palm trees under extraction conditions. On the figure 3, only one incision was made and the polyurethane sponge thickness varied from 0 to 1.5 cm. At the end of the 24 hours of extraction, the difference was statistically significant ($p \leq 0.05$) about the volumes of sap harvested. Sap volumes were lower in the absence of polyurethane sponge and higher when sponge was used. Then, a maximum volume was observed when using the polyurethane sponge at 1.5 cm thickness. Moreover, after 12 hours of sap flow, it velocity drops significantly at the oil palm trees in the absence of sponge compared to those with a sponge.

Concerning the figure 4, two incisions were done in the palm heart during the 24 hours of sap extraction. The first incision was done at the beginning of the extraction and the second took place 12 hours later. Just after the first incision, an increase in the volume of sap collected was observed at all of the oil palm trees under extraction conditions. These volumes were more important when polyurethane sponges were used in sap extraction process. Beyond the peaks observed after 6 hours of sap extraction, sap flow velocity decreased gradually until the next incision. The second incision induced a renewed of sap flow velocity. But, this velocity dropped 2 hours later on in the absence of polyurethane sponge. Then, using polyurethane sponge, the revival of sap flow velocity remains constant from 4 to 6 hours after the second incision before decreasing progressively.

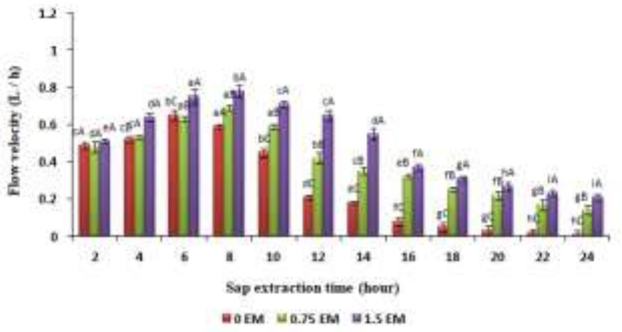

Figure 3: Influence of polyurethane sponge thickness (EM) on oil palm sap flow velocity

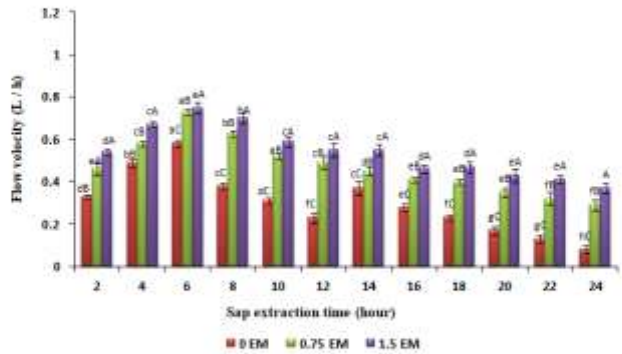

Figure 4: Influence of incision numbers and polyurethane sponge thickness (EM) on oil palm sap flow velocity

This study shows that a single incision in the palm heart (sap flow opening) leads to an increase in the sap volume collected in all palms. A peak of these volumes was observed six hours later. It remains more important at the oil palm trees treated with a polyurethane sponge at 1.5 cm of thickness than those did not have a polyurethane sponge. Beyond the peaks, the sap flow velocity decreased sharply at the palm trees not treated with polyurethane sponge. But, at the oil palm trees with polyurethane sponge, the flow velocity was stable about four hours before decreasing gradually and slowly. The practice of a second incision led to a regain of sap flow velocity at all of the oil palm trees submitted to sap extraction.

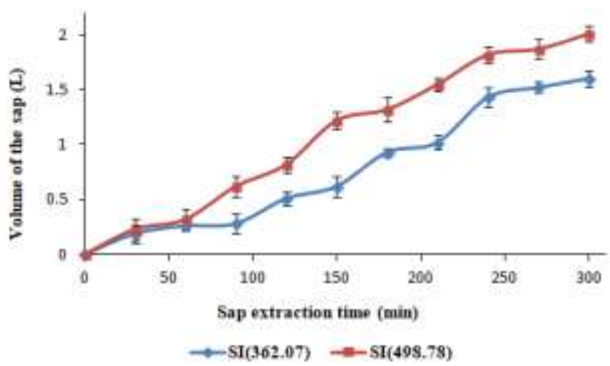

Figure 5: Influence of the incision surface on oil palm-sap flow velocity

If this flow velocity was kept constant for nearly six hours at the palm trees treated with polyurethane sponge, however, it fell four hours later at the oil palms trees that did not had polyurethane sponge. We could notice that incision was the operation which clear clogged orifice in palm heart during the sap extraction.

This observation has already been made by [15], who has stated that during the sap flow, microorganisms such as bacteria and yeasts accumulated into the tissues of the bleeding surface. This deposition of microorganisms would result in the gradual decrease of the sap flow velocity. Also, [16], [17], [18] and [19] have demonstrated that, as a result of injury stress, plants established a healing mechanism involving the oxidative activities of polyphenoloxidases (PPOs) and peroxidases (PODs).). This mechanism led to the synthesis of polymers such as lignin involved in the strengthening of pectocellulosic walls. In this study, the incision thus allowed each time to rid the scar area obstructed by the deposition of polymers and thus favoured a flowing of palm sap. In addition to the incision, the use of polyurethane sponge helped to keep the flow of sap constant for some time. According to [13], polyurethane sponge had a high water absorption capacity and acted as a thermal insulator. In view of the characteristics of the polyurethane sponge, once in contact with the bleeding surface of the palm heart, it would absorb the sap on the surface and once soaked, it would let the sap flow by gravity. Also, once impregnated, the sponge would become a barrier between the bleeding surface and the outside environment. It was undoubtedly this barrier formed from the polyurethane sponge which depleting the bleeding surface of dioxygen and reduced the oxidative activity of PPOs and POD and the lignification phenomenon evoked by [20]. In addition, among the factors that can influence sap production, the incision area can be indexed. In this study, the larger the incision area, the greater the volume of sap produced by the palm tree. This variability of sap volume resulting from an increase in incision surface would be due to the number of sap-conducting bundles that increase in number as the incision surface was enlarged.

3.2 Experimental design for sap extraction time reduction and palm heart preservation

The extraction time and the weight of sap post-extraction palm heart obtained by combining the three factors of extraction are given in Table 2.

Table 2: Doehlert matrix showing factors and duration of sap extraction and weight of sap post-extraction palm heart

Essay	*Factors*			*Responses*	
	NI	*EM (cm)*	*SI (cm²)*	*CPE (kg)*	*DE (days)*
1	5	0.75	430.43	2.34	35
2	1	0.75	430.43	3.4	52
3	4	1.5	430.43	7.65	26
4	2	0	430.43	1.98	59
5	4	0	430.43	2.87	45
6	2	1.5	430.43	9.88	30
7	4	1	498.78	7.17	28
8	2	0.5	362.07	3.63	51
9	4	0.5	362.07	4.71	40
10	3	1.25	362.07	9.22	28
11	2	1	498.78	7.82	32
12	3	0.25	498.78	5.49	41
13	3	0.75	430.43	6.55	31
14	3	0.75	430.43	5.88	34
15	3	0.75	430.43	6.27	33
16	3	0.75	430.43	6.82	30

Tables 3 and 4 highlight coefficients of three linear terms (NI, SI and EM), three quadratic terms (NI^2, SI^2 and EM^2) and three interaction terms (NIxSI, NIxEM and EMxSI).

Terms with positive and significant coefficients ($p < 0.05$) had an effect in favour of the response. In the case of negative and significant coefficients ($p < 0.05$), their effect depreciated the expected responses. Seen in this light, it was the sponge thickness factor, with a positive coefficient (EM: 3.764) which favoured more obtaining of sap post-extraction palm heart weight compared to surface of incision (SI: 0.596). The number of incisions, through its negative quadratic effect (NI2: -0.379), indicated that there was a critical value that caused a significant drop of the weight of sap post-extraction palm heart (Table 3). In addition, the reduction of oil palm sap extraction time is favoured by the three factors studied, all of which have negative coefficients (Table 4). The sponge thickness factor having a higher absolute coefficient had a greater effect on the reduction of sap extraction time.

Table 3: Regression analysis for quantification of sap post-extraction palm heart

Noun	*Coeff*	*SD*	*t. exp.*	*p (%)*
Constant	6.550	0.160	41.06	< 0.01 ***
NI	-0.379	0.160	-2.37	5.5
EM	3.764	0.160	23.59	< 0.01 ***
SI	0.596	0.160	3.74	0.966 **
NI²	-3.680	0.276	-13.32	< 0.01 ***
EM²	-0.047	0.276	-0.17	87.1
SI²	0.617	0.260	2.37	5.6
NIxEM	-1.801	0.368	-4.89	0.274 **
NIxSI	-0.422	0.412	-1.03	34.5
EMxSI	-0.868	0.412	-2.11	7.9
$R^2 = 0.993$			R^2adjusted = 0.982	

*: $p \leq 5\%$; **: $p \leq 1\%$; ***: $p \leq 0.1\%$ (in the NemrodW software)
NI = number of incisions; SI = surface of the incision;
EM = Thickness of the polyurethane sponge;
CPE = quantity of sap post-extraction palm heart

Table 4: Regression analysis for the determination of sap extraction time

Noun	*Coeff*	*SD*	*t. exp.*	*p (%)*
Constant	34	0.510	66.66	< 0.01 ***
NI	-8.375	0.510	-16.42	< 0.01 ***
EM	-14.506	0.510	-28.44	< 0.01 ***
SI	-3.674	0.510	-7.20	0.0362 ***
NI²	9.500	0.883	10.75	< 0.01 ***
EM²	4.834	0.883	5.47	0.156 **
SI²	0.416	0.833	0.50	63.5
NIxEM	5.774	1.178	4.90	0.271 **
NIxSI	2.245	1.317	1.70	13.9
EMxSI	2.946	1.317	2.24	6.7
$R^2 = 0.995$			R^2adjusted = 0.989	

*: $p \leq 5\%$; **: $p \leq 1\%$; ***: $p \leq 0.1\%$ (in the NemrodW software) NI = Number of incisions; SI = Surface of the incision; EM = Thickness of the polyurethane sponge; DE = Quantity of sap post-extraction heart

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Variance analysis is based on Fisher's statistical test (F-test) (Tables 5 & 6). The regression displayed a significance probability of F1 (P < 0.1 %). This indicated that the equation didn't indeed establish a relationship between factor variation and response. In the case of lack of fit, the probability of F2 was not significance (P > 0.05). This showed that the residuals related to the model were of the same order of magnitude as the natural error, the model was thus fair and faithful. With regard to the coefficients of determinations (0.90 < R^2 < 1) and the adjusted coefficients of determinations (0.90 < R^2adjusted < 1), the descriptive quality of the models was very satisfactory.

Table 5: Validation of the model which quantify sap post-extraction palm heart by analysis of the variance

Sources of variation	*df*	*SS*	*MS*	*F -Report*	*P-value*
Regression	9	85.28	9.48	51.91	< 0.01 ***
Residual	6	1.10	0.18		
Lack of fit	3	0.61	0.20	1.26	42.70
Validity	3	0.49	0.16		
Total	15	86.38			

SS = Sum of squares; df = degree of freedom; MS = mean of squares; p = probability

Table 6: Validation of the model which evaluated sap extraction time by Analysis of the variance

Sources of variation	*df*	*SS*	*MS*	*F -Report*	*P-value*
Regression	9	1.70E+03	1.89E+02	87.419	<0.01 ***
Residual	6	1.30E+01	2.17E+00		
Lack of fit	3	8.24E+00	2.75E+00	1.735	33.1
Validity	3	4.75E+00	1.58E+00		
Total	15	1.72E+03			

SS = Sum of squares; df = degree of freedom; MS = mean of squares; p = probability

The iso-response curves (Figures 6) reflect the evolution of factors two by two by setting the level of one of the three at the centre of the field of study. It could be seen that the proportion of the sap post extraction palm heart is influenced by the number of incisions made in the heart of oil palm trees and the thickness of polyurethane sponge applied. Thus, increasing of the polyurethane sponge thickness led to better preservation of sap post-extraction palm heart weight. It was the same when increasing the number of incisions, except that beyond an incision threshold, the weight sap post-extraction palm heart was greatly reduced. The surface of the incision is a factor that has little influence on the expected results. However, it was the largest incision surface that maximized the weight of sap post-extraction palm heart.

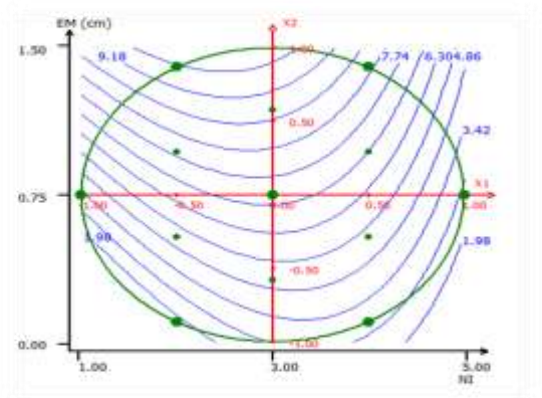

Figure 6a: Effect of daily incision numbers (NI) and polyurethane sponge thickness (EM) on post-extraction palm heart (CPE) quantity (incision surface kept at 430.43 cm²)

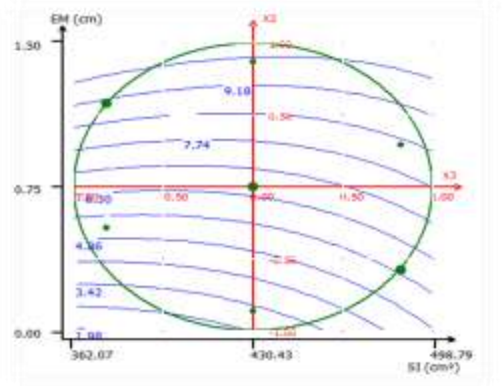

Figure 6b: Effect of polyurethane sponge thickness (EM) and incision surface (SI) on sap post-extraction palm heart (CPE) quantity (daily incision numbers kept at 3)

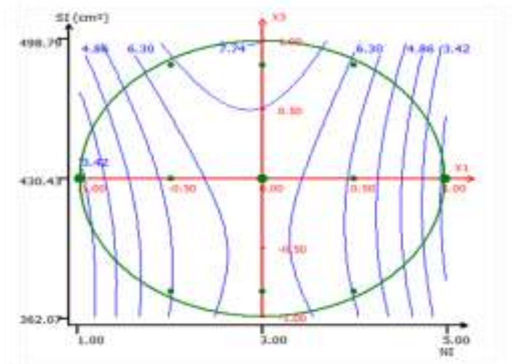

Figure 6c: Effect of incision surface (SI) and daily incision numbers (NI) on sap-post-extraction palm heart (CPE) quantity (thickness of polyurethane sponge kept at 0.75 cm)

The evolution of the environmental factors for the optimization of the extraction time of the palm sap is translated by the iso-response curves (Figures 7). Reducing the sap extraction time of the palm tree is favoured by increasing the thickness of the sponge and the surface of the incision while limiting the number of the incision to three. Thus, to minimize sap extraction time, the thickness of the sponge and the surface of the incision should be increased at their height level and the number of incisions reduced to three.

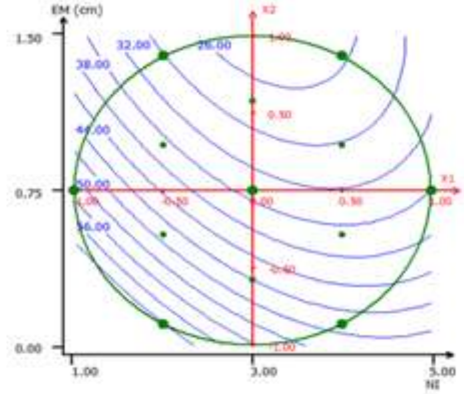

Figure 7a: Effect of daily incision numbers (NI) and polyurethane sponge thickness (EM) on sap extraction time (DE) (incision surface kept at 430.43 cm²)

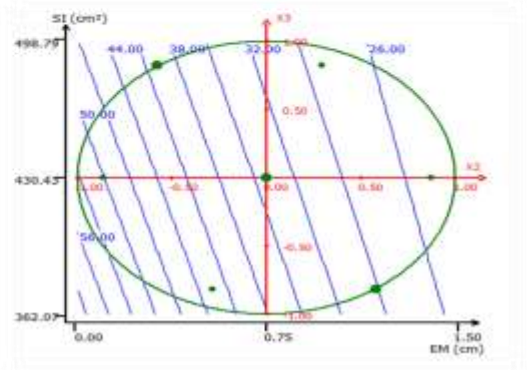

Figure 7b: Effect of the polyurethane sponge thickness (EM) and the incision surface (SI) on the sap extraction time (DE) (daily number of incisions kept at 3)

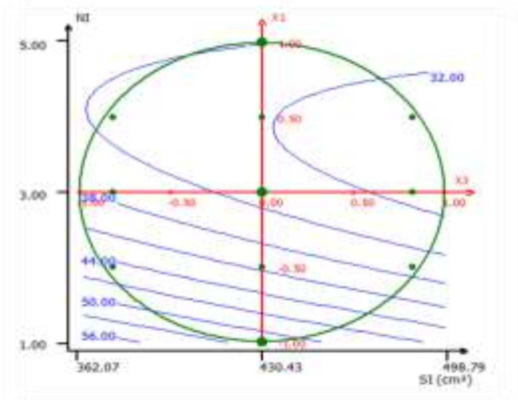

Figure 7c: Effect of incision surface (SI) and daily incision numbers (NI) on sap extraction time (DE) (polyurethane sponge thickness kept at 0.75 cm)

The effect of daily incision numbers, incision surface and the use of polyurethane sponge with variable thickness on sap extraction process being proven, the response surface method was used to optimize these extraction parameters. For [21], this method permitted to determine an approximation relation between the input variables (incision numbers, incision surface and polyurethane sponge thickness) and the output responses that are the weight of sap post-extraction palm heart (CPE) and the duration of sap extraction (DE). This relation has been translated as a second degree polynomial. This polynomial allowed optimization of the parameters of sap extraction process in order to reach desirable responses. The analysis of the variance showed that among tested effects, linear (EM and SI), quadratic (NI^2) and interaction (NIxEM) were the ones that have been significant on sap post extraction palm heart quantity (table 3). The significant ($p < 0.05$) regression coefficients of the two linear effects (EM and SI) were positive. This showed that the use of polyurethane sponge and the widening of incision surface allowed a quantitative preservation of palm heart at the end of sap extraction. However, the effect of polyurethane sponge is the most important. Moreover, the negative value of quadratic coefficient ($NI^2 = -3.68$) reflects the existence of daily incision critical number [22] which allowed a maximum preservation of palm heart at the end of sap extraction. In table 4, linear effects (NI, EM and SI) were significant ($p < 0.05$). In addition, these effects have negative coefficient values. It would mean that polyurethane sponge thickness, number of daily incisions and incision surface reduced sap extraction duration, with most important effect of polyurethane sponge thickness.

Moreover, in order to illustrate the linear, quadratic and interactive effects on each output variable, the isoresponses curves were obtained by keeping a constant variable at the central level and by varying the two others within the experimental limits. It was varied from 1 to 5 for the incision number, from 362.07 to 498.78 cm² for the surface of incisions and from 0 to 1.5 cm for the thickness of the polyurethane sponge. Figure 5 shows that the weight of sap post-extraction palm heart (CPE) reaches maximum values when the incision has been performed three (3) times daily and by increasing the incision surface and the thickness of the polyurethane sponge to their maximum value. Thus, to perform a short time of sap extraction, optimal conditions require to keep the number of daily incision at three (3), the incision surface at 498.78 cm² and the polyurethane sponge thickness at 1.5 cm. From the foregoing, the predictive values obtained from the models were 10.073 kg and 23.234 days respectively for the weight of sap post-extraction palm heart (CPE) and the duration of sap extraction (DE). The predict responses were well below to the results of [7] who estimated at 54 days, time of sap extraction from oil palm trees aged 26-years-old. However, the extraction duration predicted in this experiment was closed to the first 18 days that this author defined as being the period of intense sap flow from the oil palm trees.

4. Conclusion

Sap extraction from oil palm trees was influenced by the number of daily incisions, the surface of the incision and noticeably by the high polyurethane sponge thickness. The experimental design using the response surface methodology allowed the simultaneous evaluation of the influence of these three factors on the extraction time and the quantity of the sap post-extraction palm heart. Thus, duration of about three weeks was predicted for sap extraction when optimal condition of sap extraction process were fixed at 3 incisions daily, 1.5 cm thickness of the polyurethane sponge and 498.78 cm² of incision surface. At this same optimal condition, palm heart quantity predicted at the end of sap extraction was about 10 kg. The palm heart thus preserved at the end of sap extraction could be used in food and feed.

5. Acknowledgment

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