OPTIMIZATION OF INSECTS CURRENT SENSITIVITY FOR A BIO ELECTRICAL APPROACH

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Abstract: *The most used means in the struggle against harmful insects are chemical products. They have, nevertheless, led to the deterioration of both the environment and the human health. The use of an electric approach in the field of agriculture is one of the solutions to control harmful flying insects, it is bio and selective. So, the adoption of electrical device consisted of determining beforehand the most efficient value of insect's sensitivity to current passing through their bodies. To know the behavior of the insect vis à vis the current, an experimental study is conducted on live locusts taking into account certain electrical parameters (voltage and frequency). For that, the design of experiments* ***(DOE)*** *method was applied to optimize current sensitivity in accordance to the selected levels for each parameter. The result proved that the insects exhibit stimulations ranging from sensitive reaction to immobilization. The analysis of this method by the jmp's custom designer (software for statistical graphics) not only did it show an almost complete dependence of these parameters on the sensitivity to current but also allowed use to optimize the latter in accordance to the selected levels for each parameter during the study.*

Keywords: *Harmful insects, bioelectrical approach, current sensitivity, design of experiments method.*

1. Introduction

Currently, in the absence of an alternative, chemical insecticides are always applied in insect control. However, though this method has proven its efficiency, it has, nonetheless and in spite of its wise use, contributed not only to the elimination of other non-targeted species but also in the deterioration of both the environment as a whole and human health.

Indeed, this has engendered to the human being the disruption of the nervous system, an alarming increase in cancer diseases and allergies besides other congenital malformations [1].

The intensive and frequent use of these insecticides had, however, a major side effect. Some insects did adapt and get used to these chemical products. They have, thus, become able both to survive and reproduce [2-3]. For this reason, it is of paramount importance to find other means that would allow us to be selective in the eradication of the undesired harmful species without targeting others, no-harmful.

Using an electrical approach in the field of agriculture is one of the solutions to control harmful flying insects [4-5]. It is mobile, non-polluting and can be powered by a photovoltaic system

This technique is considered as part of a systematic plan against household pests and is preferred to the use of chemicals product. It generally allows to ensure almost instant electrocution of insects with a current 9 to10 mA [6].

However, the adoption of an electrical device consisted of determining beforehand the most efficient value of insects 'sensitivity to current passing through their bodies. So, we have to proceed through experimental measurements which consist, in our case, of two main parameters: *voltage and frequency*. This could be helpful in devising another means of struggle that is bio and Selective.

To achieve this aim we suggested an approach that adopts the design of experiments **(DOE)** method. This would define the most influential parameters on the behavior of the insect vis à vis the current. This method consists to increase simultaneously the levels of a number of factors at each experimental run in order to study only certain points of the experimental field which highlight potential interactions that link these factors and optimize the organization of measures. Such results/outcomes are, in fact, unattainable with conventional methods [7-8].

The electrical system relies on:

- ✓ an attractive effect : light
- ✓ a reductive effect : the electric discharge [9-10].

An electrified system placed inside, consisting of parallel rods, one of which is positively charged (anode) and another with a negative charge (cathode). The rods are separated by a certain distance which the insect must be subjected too, they form an electrified big bead fed by means of an electrical circuit.

An external metal meshes fence placed in front of and behind the device to facility the infiltration of insects inside. The mesh size must be equal or more than the insect's configuration that is aimed at (Figure 1).

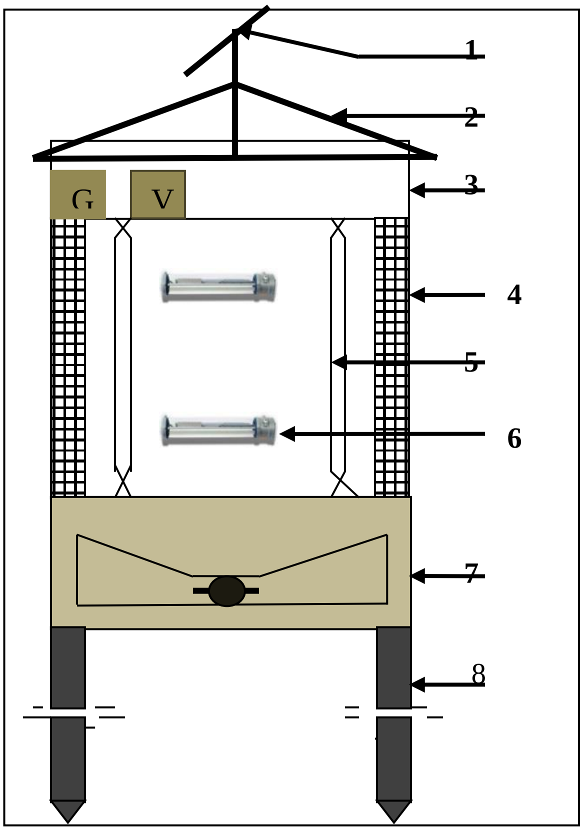


Fig.1. Principle of the system

1: the photovoltaic system; 2: the protection system; 3 : an electrical circuit ; 4 : an external metal; 5: parallel rods connected to a potential difference; 6: two fluorescents lamps to attract insects to the apparatus, one of which is ultraviolet and the other green [11-12]; 7: bac for collecting an electrocuted insects; 8: four supports Which support the apparatus at a certain height.

When the insect gets into the space between the anode and the cathode rods, an electrical discharge is produced and the insect is exterminated. The paralysis may occur as long as the current does not exceed a certain threshold of intensity depending on the power used and the conductivity of the tissue [13] (figure 2).

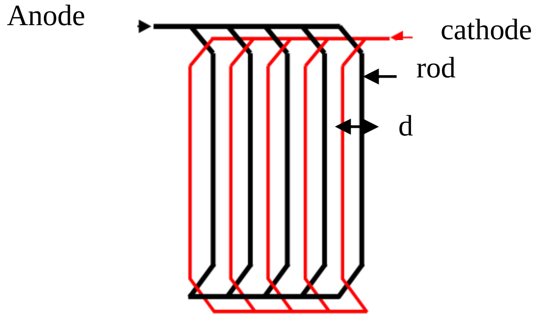


Fig.2. An electrified system

It creates a transition frequency that is involved in the conductivity. It allows the current to cross the plasma of the tissue (figure 3) [15-16].

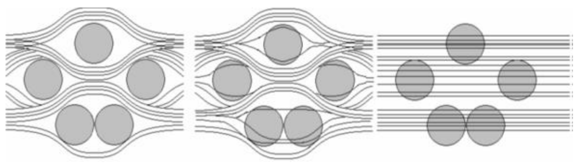


Figure.3. Current path in a cell suspension at different frequencies [14]

The main purpose of this study is to know the behavior of the insect with the current and optimize then the value of the latter.

2. Experimental study

First, the measurements were made in electric discharge laboratory. In order to develop the measurements, we used live locusts (Locusts belong to the Orthoptera order of insects, their extreme density swarm and their voracity threaten our agriculture).

All locusts used in this study had the same weight and size.

2.1. Description of the experimental set

The current measurement was done by planting two electrodes into the tissue of the insect between two points, an electrode was connected to the generator type (PM 5192 PHILIPS; 0.1 mHz- 20 MHz), and the second one to the an ammeter (a measuring device that gives straight forwardly the current value according to the settings). With a generator, we gradually varied the frequency (50 Hz- 900 kHz) and the voltage (1.76 v, 3.5, 5.3 and 7.07V). These are, in fact, values imposed by the generator function. With an *ammeter*, we measured the current passing through the body of the insect (Figure 4).

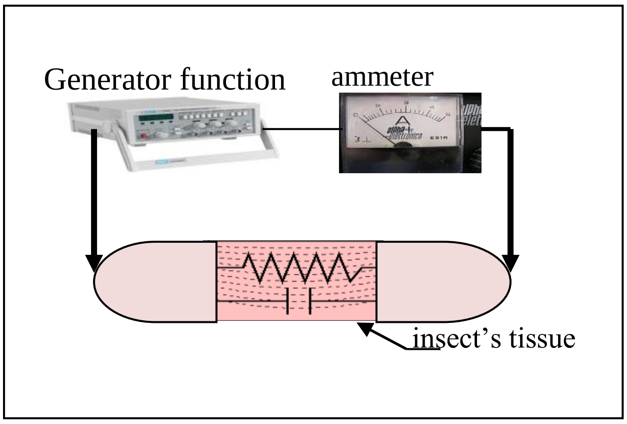


Fig .4.The experimental study

2.2. Preliminary measurements

For the same route taken by the current, the behavioral responses can be varied for different voltage values and frequencies.

No response is observed below 200 KHz for all voltage values used, beyond this value, the insect becomes aware of the flow of electric current through its body. The threshold varies between moderate responses sensations to a severe reaction.

It consists in a reaction of one of its organs (whiskers movement, paw) for a current of the order of 0.9 mA (1.76 V and 500 KHz). Beyond this frequency, The insect trembles for 1.83 mA and 1.95 mA followed directly by the immobilization threshold (table 1).

Table 1
Current value according to voltage and frequency

F [KHz]	current [mA] U[v] 1.76	3.5	5.3	7.07
200	no result	1.38	1.95	3.20
300	no result	1.55	1.96	4.12
400	no result	1.72	1.99	3.15
500	0.91	1.83	2.54	3.84
600	0.92	1.95	2.96	3.96
700	1.04	2.50	3.75	5.14
800	1.54	2.62	3.92	6.20
900	1.56	2.23	4.15	6.40

2.3. Experimental result

2.3.1.The behavior of the insect vis à vis the current

The measurement obtained for 1.76 V shows a sensation threshold in the order of 0.9 mA and a frequency of 500 KHz. Beyond this frequency, the responses start becoming severe followed directly by the immobilization threshold from 1.54 mA and 800 KHz as seen in figure 5.

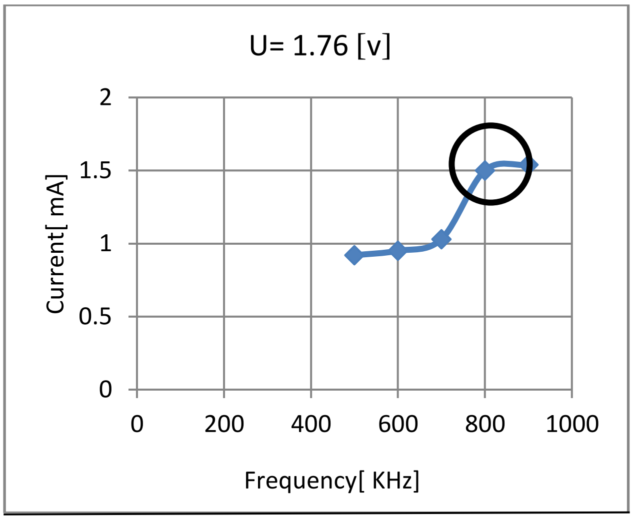


Fig .5. Current threshold for a voltage of 1.76v

The next step, the voltage is increased to 3.5 V, we obtained the sensation threshold for 1.38 mA with a frequency of 200 kHz. From this level, the thresholds will vary to a severe reaction and becomes inactive from 1.95 mA and 600 KHz as seen in figure 6.

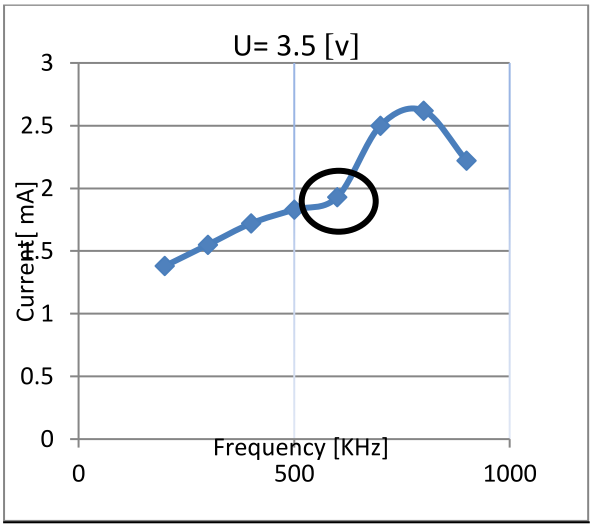


Fig.6.Current threshold for a voltage of 3.5v

It is the same case with following figure when we increase the voltage, the threshold reaches a severe response for a value of 1.95 mA and frequency 200 kHz followed directly by the immobilization threshold from 1.99 mA and a frequency 400KHz as shown in figure 7.

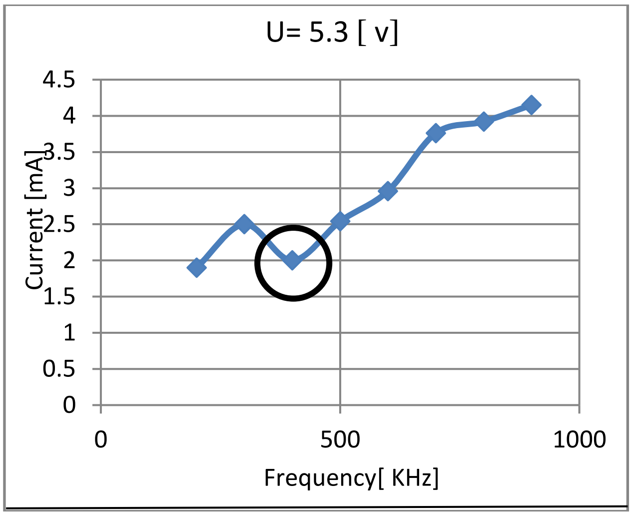


Fig .7.Current threshold for a voltage of 5.3v

On the other hand, the figure 8 shows for 7.07v an immobilization is obtained from 3.2 mA and 200 KHz.

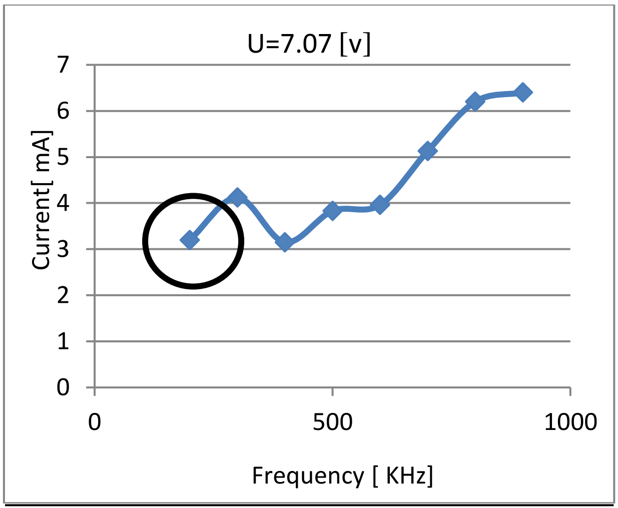


Fig.8.Current threshold for a voltage of 7.07v

2.3.2. Analysis of experimental results

The first aim of the study was to know the behavior of the insect with the current while taking into account certain electrical parameters (voltage and frequency).

It is found that the behavior of the insect becomes more and more severe depending on the frequency or voltage.

In fact, the effects of electric current on insects depended on characteristics of the current (the current threshold and duration).

2.4. Optimization study

There are many types of optimization methods, they all allow us to find the same surfaces responses [16-17]. The analysis by the jmp's version 07 custom designer (software for statistical graphics) allowed use to optimize the latter in accordance to the selected levels for each parameter during the study.

2.4.1.Synthesis diagram according the design of experiments method

The algorithm used to conduct the design of experiments method is summarized in synthesis diagram as shown in figure 9.

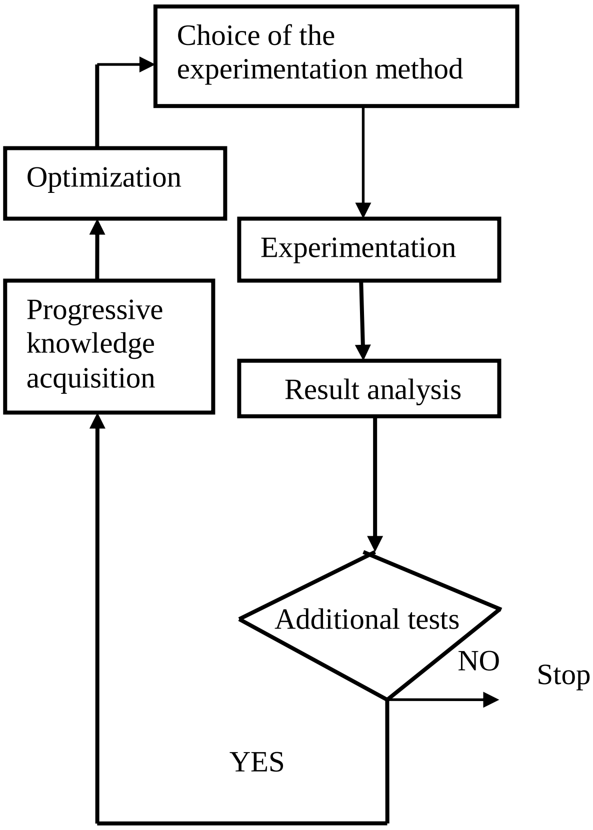


Fig.9. Synthesis diagram

The Composite design gives the mathematical model of the second degree [18]

$y = a_0+\sum a_i x_i+\sum a_{ij} x_i x_j +\sum a_{ii} x i^2; i= 1....k,$ (1)

in which

y - the response

k - the number of factors

a_0, a_i, a_j, a_{ij} - coefficients to be calculated with the software *jmp* 07 [19] .

x - the level of factor in coded units

The total number n of trials of a composite design is given by the following equation [20].

$n = n_f + n_\alpha + n_0$ (2)

in which

n_f - the factorial part of the first degree is a design 2^k and includes, therefore, 4 experimental trials

n_α- the star part is a design $2k$ also includes 4 trials

n_0 - the central part, also include 4 trials

The Composite design has 12 trials for k= 2

The intervals of variation of the factors are chosen according to the responses obtained with the preliminary measurements (Table 1).

Low level: U_{min}=3.5v, F_{min} = 200 kHz
High level: U_{max}=7.07v, F_{max}= 900 kHz

The centre value is:
$A_0 = A_{max} + A_{min} / 2$ (3)

$U_0 = U_{max}+ U_{min} / 2 = 5.3V$
$F_0 = F_{max} + F_{min} / 2= 550$ KHz

The passage of the original variables, denote A, to variables centered reduced, denoted x is given by the following formula [21-22].

$A=A_0+x\ pas$ (4)
in which:

A- the level of factor in current units
A_0- the value in current units from the centre of the field factor.

$Pas=A_{max}- A_o$ (5)

x was chosen in accordance to the factors number [21].

$x = [n_f (n^{1/2} - n_f^{1/2})^2 / 4]^{¼}$ (6)
$x = [4 ((4+ 4+4)^{1/2} - 4^{1/2})^2 / 4]^{¼}$
x = 1.21

The centre values of the two studied factors are given by the following relationships:

F= 550 + 1.21[350] = 973.5 KHz
U= 5.3 + 1.21 [1.8] =7.47V
F= 550- 1.21 [350] =126.5 KHz
U= 5.3- 1.21 [1.8] = 3.13V

There are 12 trials for k=2 according to the voltage and frequency proportions provided by the experimental design. Once the experimental measurements are introduced, the software predicts the responses and calculates the coefficients.

The applied mathematical model of second degree [20-23] according to variables centered reduced for 2 factors (k= 2) is:

$Y_S=2.64+1.73x_1+0.91x_2+0.58x_1x_2+0.10x_1^2+0.34x_2^2$

2.64 - a constant in the centre of the study

The result is defined in (Table 2).

Table 2
Estimation of model effects

Run	F[KHz]	U [V]	Yi [mA]	Yi^{est}	SCE
1	200	3.5	1.38	1.02	0.13
2	900	3.5	3.2	3.32	0.015
3	200	7.07	2.23	1.68	0.30
4	900	7.07	6.4	6.3	0.01
5	550	5.3	2.54	2.64	0.01
6	550	5.3	2.96	2.64	0.1024
7	550	5.3	2.5	2.64	0.0196
8	550	5.3	2.9	2.64	0.0676
9	973.5	5.3	5	4.88	0.0144
10	126.5	5.3	0	0.69	0.48
11	550	7.47	3.8	4.24	0.19
12	550	3.13	1.9	2.03	0.018

Y_i - the measured responses

Y_i^{est} - the estimated responses

$SCE = \sum(Y_i - Y_i^{est})^2$ (7)

2.4.2. The analysis of the mathematical model

We performed simulation analysis to test the validity of the model.

An effect will be significant if it is, for a given risk, significantly different from 0. For that the "*ti*" Student for each effect is given by the equation [24].

$$t_i = |a_i| / S_i \quad (8)$$

S_i - the estimated variances of the coefficients

$$S_i^2 = S^2 / n \quad (9)$$

S^2-valuer of the coefficients

$$S^2 = 1/n\text{-}p \sum SCE \quad (10)$$

n - the trials number

p - coefficients number

In this case, the rule of Student test is :

If $t_i > t_{crit}$ (a, n), we reject H_0 to the accepted risk.

If $t_i < t_{crit}$ (a, n), we accept H_0 to the accepted risk.

Indeed, the effect will be significant at the 5% risk for a = 5% and n = 6, t_{crit} (0.05; 6) = 2.45 (Student's Table) [20]. So, if "t_i" is greater than 2.45, the effect is significant (Table 3).

Table 3
The Student test

Variables	coefficients	t_i	Result
Constant	$a_0 = 2.64$	$t_0 = 19.27 > 2.45$	significatif
x_1	$a_1 = 1.73$	$t_1 = 12.62 > 2.45$	significatif
x_2	$a_2 = 0.91$	$t_2 = 6.64 > 2.45$	significatif
x_1x_2	$a_{12} = 0.58$	$t_{12} = 4.23 > 2.45$	significatif
x_1^2	$a_{11}^2 = 0.10$	$t_{11} = 0.72 < 2.45$	no significatif
x_2^2	$a_{22}^2 = 0.34$	$t_{22} = 2.48 > 2.45$	significatif

The table 3 shows that all the coefficients are significant except x_1^2

The model according to the coefficients considered influential on the variation of the current can be rewritten by the form:

$$Y_s = 2.64 + 1.73\,x_1 + 0.91x_2 + 0.58x_1x_2 + 0.34x_2^2$$

Furthermore, the ANOVA is helpful also to evaluate the quality of the postulated mathematical model R^2 (the coefficient of determination). A good mathematical model must have R^2 close to 1. Over this coefficient is to 1, the more the model correctly expresses the measured responses (Table 4).

$$R^2\ \% = \frac{SCEMC}{SCEMM} * 100 \quad (11)$$

SCEMC is the sum of square between the estimated responses and the mean.

$$SCEMC = \sum (Y_i^{est} - Y_{moy})^2 \quad (12)$$

Y_{moy} - the mean of measured responses.

$$SCEMM = SCEMC + SCE \quad (13)$$

Table 4
The ANOVA: analysis of variance

Source	Sum of square	DF	mean square	F
Model	29.1	5	5.82	25.30
Error	1.36	6	0.23	
Ctotal	30.46	11		

$$R^2\ \% = \frac{29.1}{30.46} * 100 = 95\ \% \quad \text{(Table 4)}$$

This means that the model is validated

2.4.3. Influence of frequency and voltage simultaneously on the current

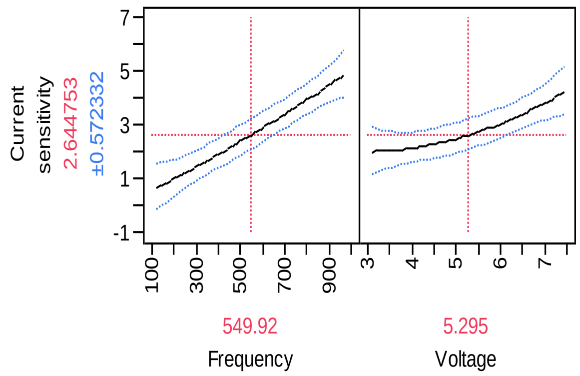
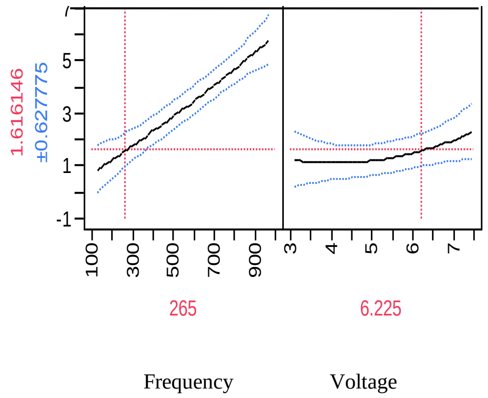


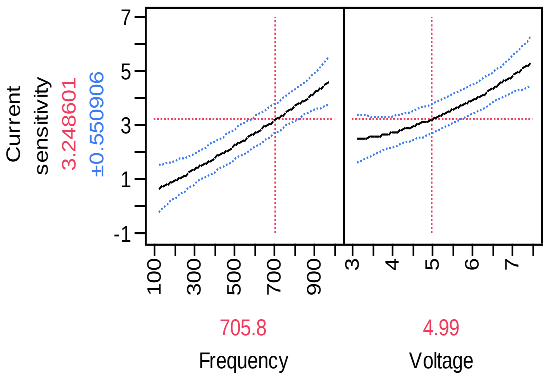
Fig.10. Influence of factors on the current

In this case, the frequency and the voltage have a positive effect on the current, i.e., when, one of them decreases, the current is reduced.
2.64 mA is a coefficient model calculated with the software in the centre of the study for 549.92 KHz and 5.295V.

Among, the others solutions that would be obtained The software can also calculate values factors by looking for levels that promote the value to be obtained (Figure 11 a and b).



a



b

Fig .11. Modifing the level of factors: a) F= 265 KHz and U= 6.225v; b) F= 705.8 KHz and U= 4.99v

3. Discussion

The experimental values proved that insects responded to current crossing their bodies for 0.9 mA compared with human, continuous perception occurs above 0.5 mA [25]. No response was observed up to 2 mA in livestock [26] . The insect became inactive by increasing the frequency or the voltage.

The simultaneous increase of factors at each experimental run by using the optimizing of response surfaces design showed clearly the influence of factors on the current (Figure 10).

The criterion value R^2 allows predicting a good description of the model. The coefficient of determination has 95% which means that the model is satisfactory.

In addition, the software JMP allowed us to study the evolution of the impact factors based on a given criteria and define an optimum for it (figure 12) [27].

However, the optimum point was dependent on the value selected for each parameter level during the study.

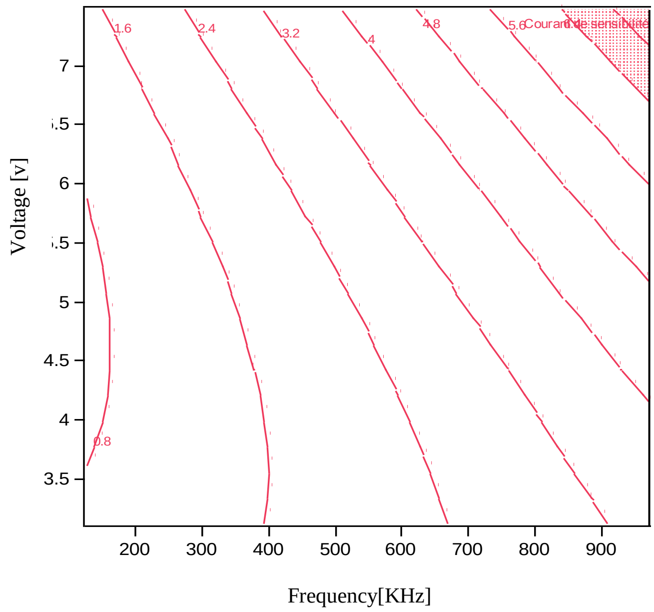


Fig.12.The curve iso-criteria

Figure 11 illustrates the curve iso-criteria from 0.8 to 6.4 mA in according to voltage and frequency.
It can be concluded that the curve iso-criteria can calculate the response for the displayed levels of factors.

In fact, for other types of harmful flying insects, the design of experimental method can be used effectively. Indeed, the current of sensitivity is a parameter difficult to control in view of the variation of the conductivity of the tissue of insect. The analysis with the software *jmp* allows us to obtain results with precision and reduce the number of experiments. The optimum point can be determined according to the levels chosen for each parameter.

4. Conclusion

The design of experiment method must be seen as a set of tools allowing the understanding and the exploitation of simplifying objects of the function response. In our case, it was used to optimize the current sensibility of various levels. The analysis by JMP's custom designer gives a good account of the results found since the current sensitivity varied with the voltage and frequency.

The experimental study we conducted on locusts proved that the insects exhibit stimulation ranging from a sensitive reaction to paralysis. In fact, the effects of electric current on insects depended on characteristics of the current, electrical properties (conductivity.

Finally, for other types of insects, the sensitivity on the current can vary. It is necessary then, to study the physiological and behavioural effects of a large number of insects so that to provide some reasonable judgment. Also, the increase of the factors simultaneously with the design of experimental method makes the immobilization easy. The control of a locust group depends on the charge time of the capacitor and the speed of penetration as well within the insect system.

This selective strategy could be widely used if only researchers in the fields of biology and electricity combine their efforts to develop an advanced cheap technology.

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