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Design, Analysis and Optimization of Hot Air Drying Process of Fresh Sweet Potato

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Abstract: The present study is based on the valorization of Moroccan sweet potato for flour production using the hot air drying process. The choice of this food is justified by its availability on the market, its consumption and its nutritional value.

The objective of this work is to optimize the factors that affect the drying of sweet potato. The study by complete design of experiment has been conducted. After an adequate choice of two factors at two levels, the temperature (55°C ; 70°C) and the thickness of the dried pieces (0.5cm ; 1.5cm), four experiments led to a mathematical model linking the responses (maximisation of yield and minimisation of time and water content) to the factors and allowing a good control of the drying process.

Keywords: Sweet potato, Drying process, Valorization, Flour, Design, Optimization.

I. Introduction

Fruits and vegetables play an important role in human diet and nutrition. The sweet potato belongs to the family Convolvulaceae and is one of the most important food crops in the world. It is believed to be in consumption for centuries. Its history dates back to 750 B.C. in Peruvian records [1]. Sweet potato is a good source of vitamins A compared to other roots and tubers. Its vitamin C content is also remarkable. It contains vitamins B1, B2 and folic acid. It is rich in minerals essential to the functioning of the body such as calcium and zinc.

The production of this product in some regions of the world is so high that sometimes it is not economical for farmers to harvest it. Drying is one of the means proposed for making this cultivation more economical.

This process improves the food stability, since it reduces considerably the water and microbiological activity of the material and minimizes physical and chemical changes during its storage. Therefore, the loss of product could be decreased, in addition to making them available throughout the year [2].

In many countries, especially in Africa, the sweet potato is also eaten as flour. The latter plays a pivotal role in sustaining main food products developments and also can make it to be used as an ingredient in the numerous food formulations such as breads, muffins, pancakes, cookies and crepes, cakes, and doughnuts. It also offers the facilities of creating new income opportunities for farmers such as new markets and new sources of income; changing some of the negative attitudes about sweet potato consumption, and enabling them to be an important commercial crop with a wide range of uses [3].

In this context, the drying process plays an important role in the commercial field, since it allows us to produce a new product in the market, as well as in the field of food safety, in which this process allows the maximum amount of free water responsible for the development of bacteria to evaporate. In fact, with the use of experimental designs that allow to determine and establish the existing links between variables of the process (temperature, thickness) and a quantity of interest (yield, time and moisture content).

The objective of this study is to optimize parameters such as drying temperature and thickness of the dried pieces. With the experimental design, the maximum amount of information is obtained with the minimum number of experiments.

II. Materials and Methods

Plant Matériel

Sweet potatoes (Ipomoea Batatas L.) were bought from the market in Beni Mellal, Morocco in March 2021, Approximately 2kg of fresh sweetpotato was prepared for flour production per drying treatment. The sweet potato used for the experiment had moisture of 75%.

Sample preparation

Preparation of the sample undergoes through several steps:
- Washing: Wash and peel the sweet potato.
- Chipping or slicing: Cut the sweet potato in two pieces (round and cossette) and thicknesses of 0.5 cm and 1.5cm for each form.
- Measure the mass: Measure the initial mass of different forms with electronic scale equal 100g.
- Drying: Drying of the sweet potato in the oven at two temperatures **(55°C, 70°C).**
- Milling: Use a mill to turn dried sweet potatoes into flour.

Drying process

Drying process is removing a large portion of the water contained in a product in order to considerably reduce the reactions which leads to deterioration of the products [4]. Drying is probably the oldest and most important method of food preservation used by humans. Today, drying food products is recognized as the best way to preserve fruits, vegetables and herbs, reducing their size and weight, thereby reducing packaging, storage and transportation costs. In addition, taste and texture profiles have changed, resulting in a new generation of products [5]. The purpose of drying is:
- food preservation
- Decreasing the weight and bulk of food to economize shipping and canning costs

Experimental analysis

The EN 322: 1993, EN 13183-1 :2002, ASTM D4442 - 07 and ASTM D2216 - 10 standards are based on gravimetry, and this methodology should be considered as the most convenient to measure the MC. The above standards don’t provide any theoretical definition of the MC. They only establish how to calculate the MC, expressed in percent (%), and the recommended formula constitutes an implicit mathematical definition [6] .

$$MC = (mi-mf) /mf*100$$

Where mi and mf are the initial and final mass of the flour, respectively.

In order to calculate the content, two tests were performed on sweet potato flour and two tests were performed on raw sweet potatoes. The mass of each flour of different conditions (shape, temperature, thickness) that was initially dried at 55°C measured about 1g, and the mass of raw potatoes was measured about 1g, and then these samples were placed in an oven and dried at a certain temperature 80°C.

Yield

The yield of sweet potato samples after pretreatments were calculated by the following equation:

$$\eta = (mf /mi) *100$$

mi: the mass of the sweet potato before drying
mf: the mass of the sweet potato after drying

Experimental plan

The experimental design allows the evaluation of the effects of the main factors and of all the possible multi-factor interactions. All the experiments were performed in a randomized order to avoid possible memory effect of the analytical apparatus [7].

In order to optimize the parameters influencing the drying of the sweet potato the experiments were designed according to a full experimental design with two factors, each with two levels 'max and min', the parameters are:
- **Temperature:** First temperature set at 55°C and second temperature set at 70°C, it is based on the results of a field experiment [8-9].
- **Thickness**: First thickness set at 0.5 cm and second thickness set at 1.5cm. The choice of this thickness based on sweet potato drying experiments [10].

Table 1 Experimental areas of the factors studied

Test number	Temperature (°C)	Thicknesses (Cm)
1	-1	-1
2	+1	-1
3	-1	+1
4	+1	+1
Level -1	**55°C**	**0,5 Cm**
Level +1	**70°C**	**1,5 Cm**

III. Results and Discussion

1) Optimization of drying parameters the round shape

The objective of this study is to optimize two essential parameters in the operation of the drying process such as the temperature and the thickness of the pieces to be dried; in order to minimize the moisture content, the drying time and to maximize the yield.

The table 2 represents the different combinations of the two factors, as well as the experimental results.

Table 2 Experimental design of the drying process of the round shape with the responses recorded for each trial

Test Number	Temperature	Thickness	% Yield	Time	% Moisture content
	X1	X2			
1	-1	-1	18,81	20	43
2	1	-1	23,51	15	30
3	-1	1	20,77	32	32,76
4	1	1	21,55	18	47,5

Effects of factors

In order to determine the influences of the studied factors and their interactions. The following table represents the values of coefficients and their significance with:

b0: constant
b1: temperature coefficient
b2: thickness coefficient
b12: interaction coefficient between temperature and thickness

Table 3 Effects of model coefficients relating response to factors

Term	Coefficient	Estimate			Meaning
		Yield	Time	Moisture content	
Constant	b0	21,16	21,25	38,315	S
Temperature	b1	1,37	-4,75	0,435	S
Thickness	b2	0	3,75	1,815	S
Temperature* Thickness	b12	-0,98	-2,25	6,935	S

From the table 3 we notice that the estimation of the coefficients varies from one response to another. This variation influences the significant impact of the factors. Indeed, the temperature is more significant than the thickness for the yield. On the other hand, for the second response "time" the effect of the thickness is more significant than the temperature. Finally, the two factors are significantly close in the variation of the moisture content.

Mathematical model

From the results mentioned in the table 3, we can derive a first degree mathematical model that links the estimated responses with the studied factors [11].

$Y_{*1}=21,16+1,37\boldsymbol{X_1}-0,98\boldsymbol{X_1X_2}$

$Y_{*2}=21,25-4,75\mathbf{X_1}+3,75\boldsymbol{X_2}-2,25\boldsymbol{X1X_2}$

$Y_{*3}=38,315+0,435\boldsymbol{X_1}+1,815\boldsymbol{X_2}+6,935\boldsymbol{X_1X_2}$

With:
Y_{*1}: Represents a mathematical model expressing the yield
Y_{*2}: Represents a mathematical model expressing time
Y_{*3}: Represents a mathematical model expressing the moisture content

Optimization of responses

After defining the model, it is then necessary to determine the optimization of the parameters that enter into the operation of the drying process. This means finding the optimal conditions for each of the factors, taking into account their interactions.

The following graphs represent the effects of the factors, their interaction and the optimal areas.

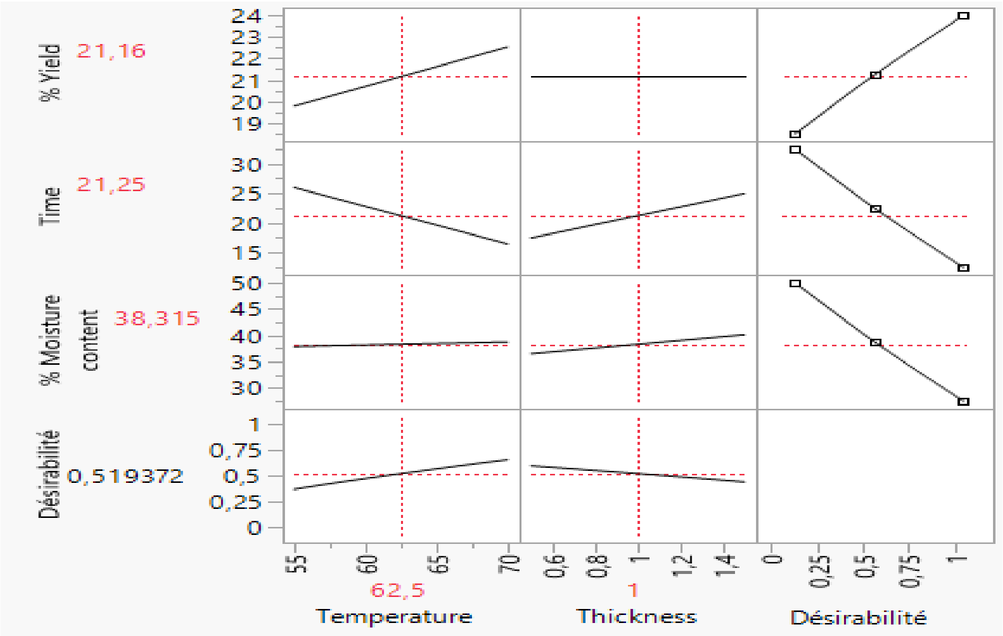

Figure 1. Prediction profile of optimal drying factor conditions.

The graph in figure1 tells us about the influence of the main effects on the responses. Indeed, for both responses, time and moisture content, the effects of the factors are almost identical with a small difference between the latter for moisture content, in which we notice that the thickness has a significant impact compared to temperature. After wards, we can clearly see that the temperature has a very important role in the yield. And these results are comparable with the one mentioned in the table 3

In addition, the results indicate that obtaining an optimal area that includes the three responses, maximizing the yield, minimizing the time and the moisture content, require average values for the two factors; in which we find a value equal to 62.5 ° C as temperature and 1 cm for thickness.

These results are confirmed by the figures 2, 3 and 4, which represent a 3D variation of the factors to be studie.

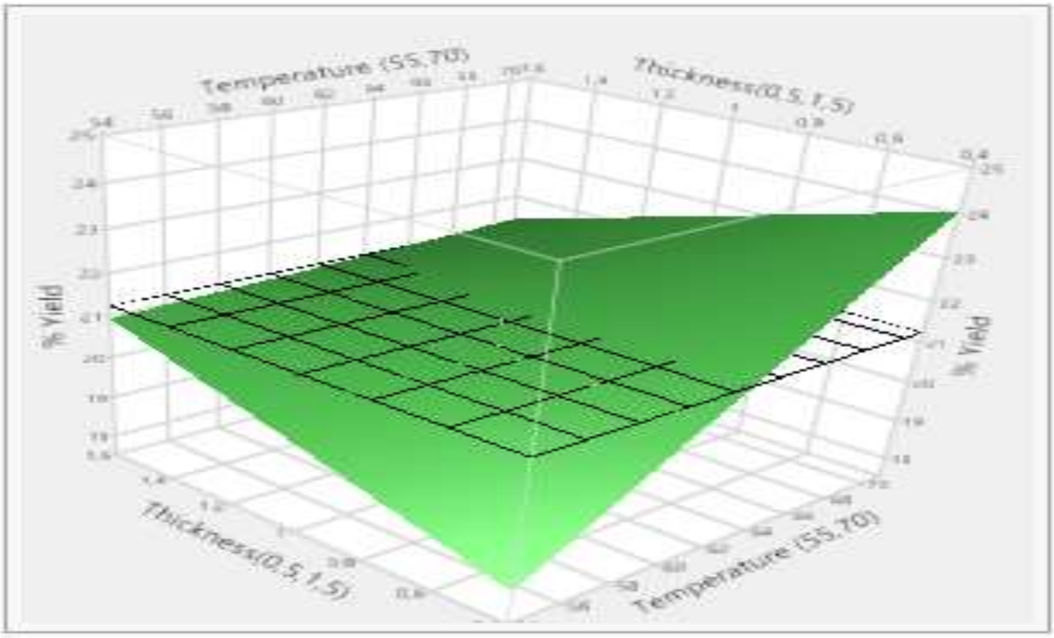

Figure 2. 3D presentation of the variation of factors as a function of yield

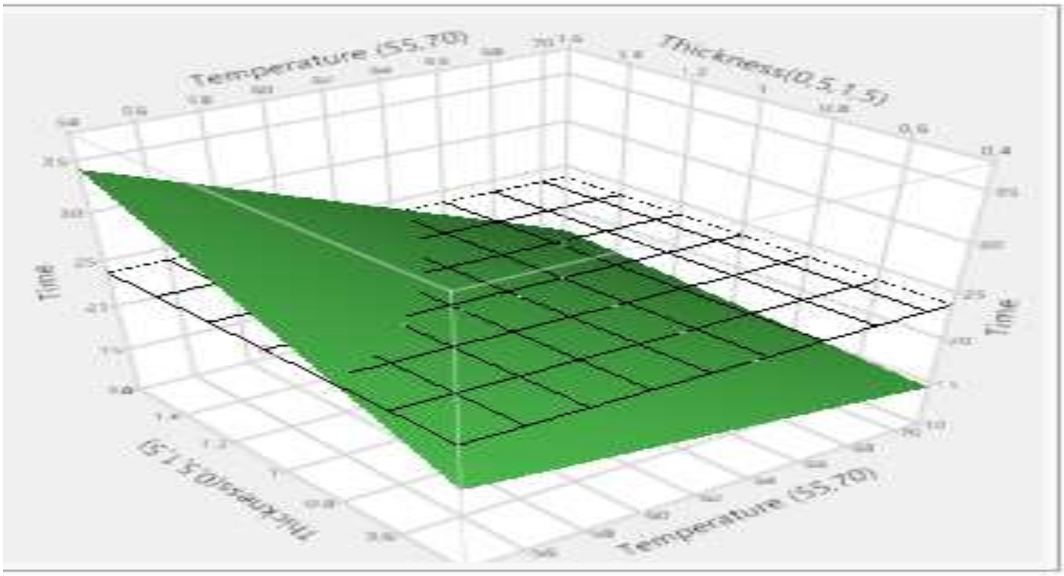

Figure 3. 3D presentation of the variation of the factors as a function of time

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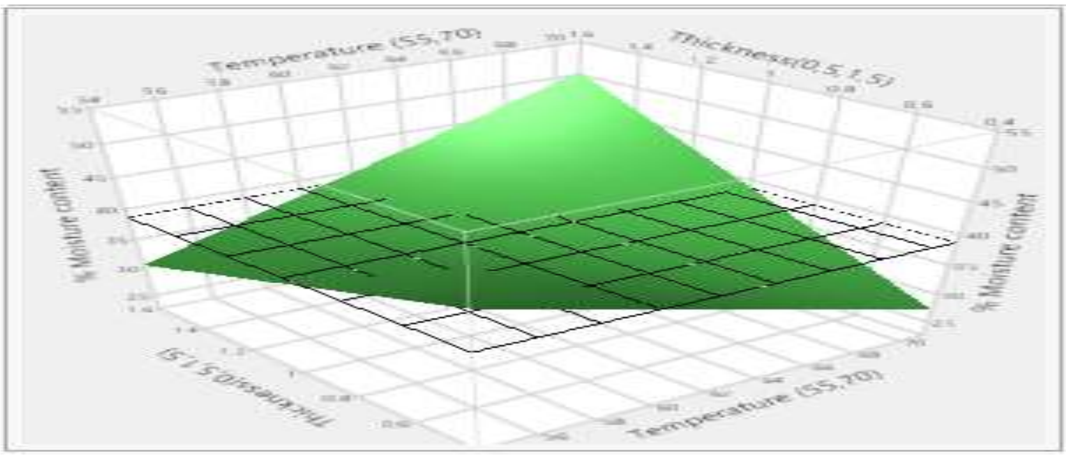

Figure 4. 3D presentation of the variation of the factors according to the moisture content.

The results of the figures 2, 3 and 4, show that the optimal range (62.5°C; 1cm) corresponds to a yield of sweet potato flour equal to21.16%. This value remains logical because the sweet potato contains a large quantity of water.

This area also gives a minimum value in time arrives until the 21h 25min of drying. In addition, a percentage of 38.35% in moisture content.

2. Optimization of the drying parameters for the cossette shape

An experimental design including the two factors studied as well as their interactions with the three responses: yield, time and moisture content as the first experiment shows.

The table 4 represents the experimental results of the tests performed

Table 4: Experimental design of the drying process of the cossette shape with the responses recorded for each trial

Test number	Temperature	Thickness	%Yield	Time	%Moisture content
	X1	X2			
1	-1	-1	20,23	16	37,31
2	1	-1	21,97	12	28,66
3	-1	1	19,1	20	35,7
4	1	1	22,4	18	32,23

Effects of factors

The statistical studies took into account both factors and their interactions. The table 5 represents the results processed by the JMP IN4 software.

With:
b0: constant
b1: temperature coefficient
b2: thickness coefficient
b12: interaction coefficient between temperature and thickness

Table 5. Effects of model coefficients relating response to factors

Term	Coefficient	Estimate			Meaning
		Yield	Time	Moisture content	
Constant	b0	20,925	16,5	33,475	S
Temperature	b1	1,26	-1,5	-3,03	S
Thickness	b2	-0,175	2,5	0,49	S
Temperature * thickness	b12	0,39	0,5	1,295	S

According to the table 5 the results showed that the effects of the factors is significant with a medium difference on the effectiveness of the studied parameters on the responses, in which we distinguish a significant effect of the temperature in the percentage of the moisture content and the yield. Again, for the minimization of time we notice that both parameters have a similar significant impact.

It is concluded that the effect of temperatureis important in the drying of two forms of sweet potato (round and cossette).

Mathematical model

From the results mentioned in the table 5, we can derive a first degree mathematical model that links the estimates with the factors studied for the cossette form.

Y_{*1}=20,925+1,26X_1-0,175 X_2+0,39X_1X_2

Y_{*2}=16,5-1,5X_1+2,5X_2+0,5X_1X_2

Y_{*3}=33,475-3,03X_1+0,49X_2+1,295X_1X_2

With :

Y_{*1} : represents a mathematical model expressing the yield

Y_{*2} : represents a mathematical model expressing time

Y_{*3} : represents a mathematical model expressing the moisture content

Optimization of responses

In order to maximize the yield and minimize the drying time and the percentage of moisture content, we can also consider different solutions regarding the operating conditions.

The following graphs (Figures 5, 6, 7 and 8) represent the effects of the factors, their interactions and the optimal areas.

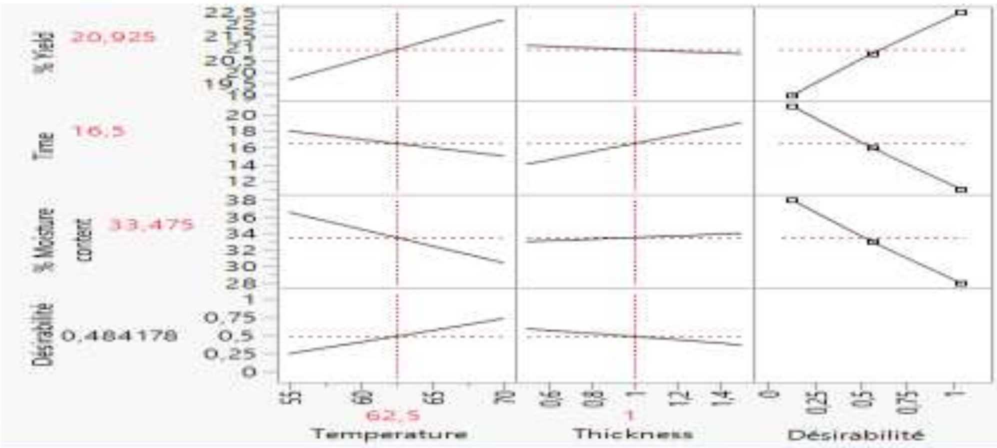

Figure 5 .Prediction profile of optimal drying factor conditions.

The results mentioned in figure 5 show that the most influential factor on the yield and the percentage of moisture content is the drying temperature. It is also noticed that in the minimization of time both factors are important with a small difference.

Then, for the interaction of the three responses we find the following operating conditions: 62.5°C and 1cm for temperature and thickness respectively; with a desirability equal to 0.4841. The desirability obtained is relatively low compared to the results found by Mr. Fadil who finds a value equal to 0.9687 [12].

These results are confirmed by the figures 6, 7 and 8 below which represent a 3D variation of the factors to be studied.

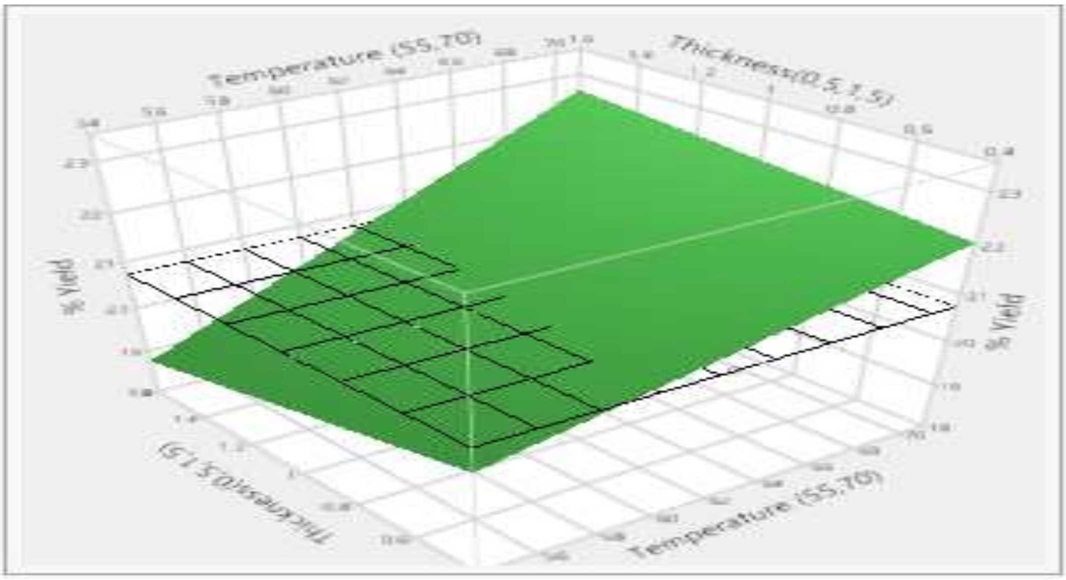

Figure 6. 3D presentation of the variation of factors as a function of yield.

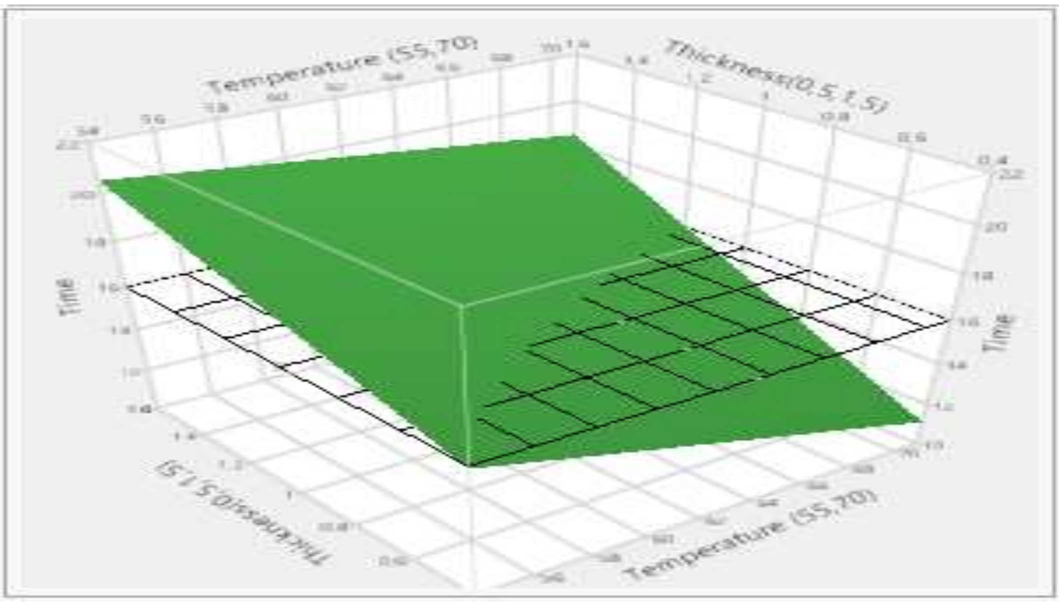

Figure 7. 3D presentation of the variation of the factors as a function of time

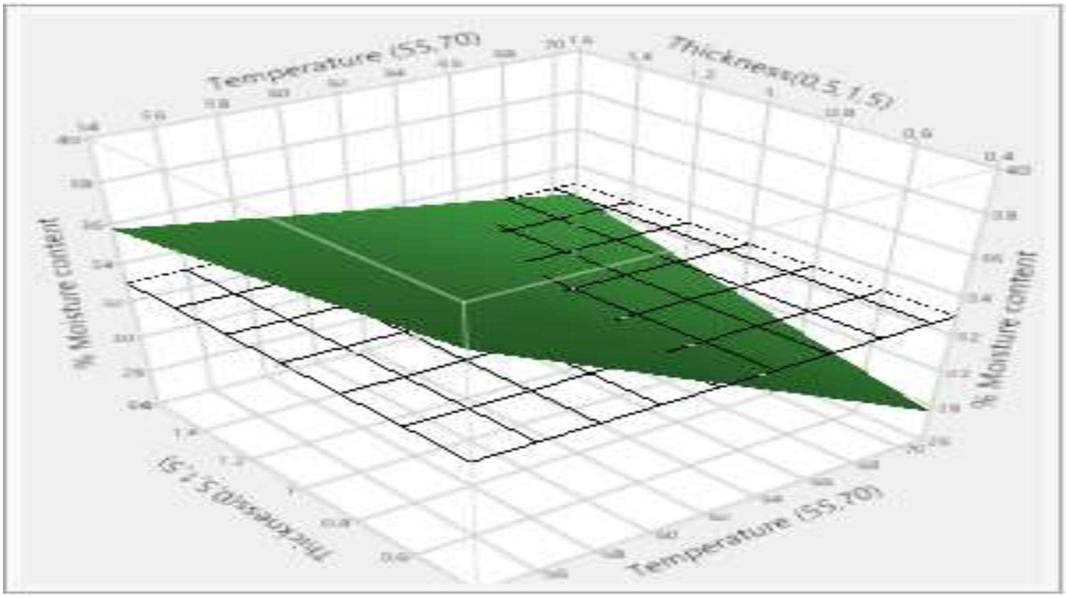

Figure 8. 3D presentation of the variation of factors as a function of moisture content

According to the figures (6,7 and 8), when we set the operating conditions to their optimal value: 62.5°C and 1cm for temperature and thickness, this allows to have a percentage in yield arrives until 20.925%, and a drying time equals 16h 50min and finally a minimum percentage in moisture content arrives until 33.475%.

Optimal domains

To finalize the study of the parameters influencing the drying process, the following table summarizes the results found

Table 6. Optimal values of the two factors for the two studied shapes

	Parameters	Optimal domain	%Yield	Time	% moisture content
Round shape	**Temperature**	62,5°C	21,16	21h25min	38,315
	Thickness	1cm			
Cossette shape	**Temperature**	62,5°C	20,925	16,5	33,475
	Thickness	1cm			

From the results presented in the table 6 it is clear that both forms appropriate the same optimal domain.

In fact, the cossette shape is efficient for drying; in which a maximum yield is reached in a short time compared to the round shape.

These results remain comparable but moderately inferior with the results found by LI KE in which it obtains a temperature equal to 73, 89°C [13].

IV. Conclusion

To undertand the variability of some parameter Related to the drying process operation, two essential factors were studied to quantify and compare their influence on the maximization of yield and the minimization of time and moisture content; with a full factorial design 2^2 replicates.

Indeed, for this food, a temperature of 62.5°C and a thickness of 1cm for both shapes (round, cossette). These results correspond to the following responses:

Round:
- Yield: 21.16
- Time: 21h25min
- Moisture content: 38.35%.

Cossette:

- Yield: 20.925%
- Time: 16h 30 min
- Moisture content: 33.475%

The saving of time and energy of the drying process the cossette form with a thickness of 1cm remains the best, in which a maximum yield is reached in a minimum time.

References

[1]. Parle Milind and Monika.Sweet potato as a super-food.Int. J.Res.Ayurveda Phar.2015;6(4):557-562. doi:10.7897/22774343.064104

[2]. M. S. Hatamipour ,H. Hadji Kazemi, A. Nooralivand and A. Nozarpoor. Drying Characteristics of six varieties of sweet potatoes in different dryers. Chemical Engineering Department, University of Isfahan, Isfahan, IR, Iran, review. 2007;85(C3): 171–177. doi:10.1205/fbp07032

[3]. M. S. Kamal, M. N. Islam and M. G. Aziz. Effect of sweet potato flour of two local varieties on quality of breads. J. Bangladesh Agril. Univ. 2013; 11(2): 301–306. doi: 10.22004/ag.econ.209872

[4]. Uwem Inyang, Innoccent Oboh , Benjamin Etuk . Drying and the Different Techniques. International Journal of Food Nutrition and Safety. 2017;8(1): 45-72. doi: 10.4236/aces.2018.82003

[5]. Sehrawat, R.; Nema, P.K.; Kaur, B.P. Quality evaluation and drying characteristics of mango cubes dried using low-pressure superheated steam, vacuum and hot air drying methods. LWT. 2018; 92, 548–555. doi: 10.1016/j.ijheatmasstransfer.2014.01.001

[6]. Dario Camuffo, Chiara Bertolin.Towards standardization of moisture content measurement in cultural heritage materials. 2012; Review, 9, 23-35.

[7]. F. Bianchi, M. Maffini , A. Mangia , E. Marengo ,C. Mucchino . Experimental design optimization for the ICP-AES determination of Li, Na, K, Al, Fe, Mn and Zn in human serum. Journal of Pharmaceutical and Biomedical Analysis. 2006; 43, 659–665. doi : 10.1016/j.jpba.2006.07.054

[8]. Fessehaye Hdremariam Desale, Rungarun Sasanatayar. Effect of Drying Temperature on Functional and Digestive Properties of Sweet Potato Flour. International Journal of Advances in Science Engineering and Technology, ISSN. 2017; 2321-9009.

[9]. İbrahim Doymaz. Infrared drying of sweet potato (Ipomoea batatas L.) slices. J Food Sci Technol. 2012; 49(6), 760–766. doi: 10.1007/s13197-010-0217-8

[10]. Kolawole O. Falade and Oluwakemi J. Solademi. Modelling of air drying of fresh and blanched sweet potato slices. International Journal of Food Science and Technology. 2010;45, 278–288. doi: 10.1111/j.1365-2621.2009.02133.x

[11]. E. Wognin, Z. Tonzibo, K. Toure, Y. N'Guessan. Contribution à l'optimisation de la distillation des huiles essentielles extraites des fleurs de chromolaena odorata L king and robinson grâce a un plan factoriel complet 2^2. Rev. Voir. Sci. Technol. 2010; 15, 23-37.

[12]. M.Fadil, A.Farah, B.Ihssane, T.Haloui,S.Rachiq. Optimization of parameters influencing the hydrodistillation of *Rosmarinus officinalis* L.by respons esurface methodology. J.Mater. Environ.Sci. 2015;6 (8), 2346-2357.

[13]. Li Ke,Wang Meng-meng, Shen Xiao-ping, Lu Xiao-li.Study on optimization of hot-air dring process parameters of cooked sweet potatoes by mathematical models. Departement of food engineering. Sichuan University, Chengdu 610065.2008; China. www.cnki.com.cn.