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MODELLING OF THE ECOLOGICAL DRYING PROCESS OF TOMATOES BY THE NON-CONVENTIONAL DESIGN OF EXPERIMENTS METHOD

Khadidja Chiali Charif[1], Nadia Ramdani[2], Mokhtar Bounazef[3]✉

[1]Environmental Sciences department, Faculty of Life and Natural Sciences Djillali Liabes University of Sidi Bel Abbes
[2]Energies and process engineering department, faculty of technology, Djillali Liabes University of Sidi Bel Abbes
[3]Department of mechanical engineering, faculty of technology, Djillali Liabes University, Sidi bel abbes
✉bounazef@yahoo.com

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ABSTRACT

The preservation of perishable foods through their transformation is always a major challenge for producers. Several methods are applied for this purpose, and progresses are recorded by improving these processes or by finding new means. In our work, the method of dehydration and natural drying of tomatoes using a natural dryer with indirect solar energy with air circulation by extractor is used to describe and then predict the process of obtaining the finished product in the form of tiny dried fragments or powder. This is the novelty of this research, which uses the unconventional design of experiments. This consists of finding a mathematical model based on the interaction of 3 parameters that interact with each other, namely the trays temperature, the drying speed and the relative humidity in the solar dryer. The interference of the values of one of these 3 parameters on the 2 other parameters acts directly on the result of the drying process. The matrix treatment of the data of several carried out experiments in the resolution of 13 equations gives us the required responses and permits us to draw the graphs, the contours and the responses surfaces that access us to a more detailed analysis.

1. Introduction

The description of the process of conservation by drying of tomatoes with a mathematical model according to the temperature of the trays on which the tomatoes are deposited, the relative humidity inside the dryer and the drying speed which describes the mass loss of the product during the experimental duration, has never been treated so to date by experimental design. This method does not take into account the heat and mass balances or other parameters often cited in any researches (Badaoui et al., 2019; Eichenlaub et al., 2015; Gary, 2002; Lopez-Quiroga et al., 2019; Azeez and al., 2019; Seyfi, 2014) but considers the parameters that affect the drying process (Akshay, S., Sumit, S.P., Rama, C. P. (2021). It is all the more important as it is considered as a predictive method, since it can predict results in the experimental domain with the values not considered during the manipulations. This is realised by modelling the dehydration and drying process by a quadratic mathematical expression in the form of a polynomial that establishes a linear relationship between a variable called explained variable, and several other variables called explanatory variable (Goupy, 2005; Goupy, 2013; Louvet, 2005).

Therefore, this is different from other modelling done before and based on other criteria than the ones mentioned in this paper. The drying and dehydration process is explained differently (Çelen et al., 2013; Sivakumar et al., 2013; Haddad et al., 2008; Manashi et al., 2013; Nazmi et al., 2018; Petro-Turza, 2009; Pushpendra et al., 2018; Doris et al., 2010; Nagwekara et al., 2020; Chauhan et al., 2021). For this purpose, a series of experiments is carried out in a solar radiation dryer without additional heating by electrical energy, but with forced ventilation of air from the container inside to the outside, thus avoiding the combined process (mixed-method) (Alkanan et al., 2021).

This is deliberately done to lower the price of the completed product. To compensate the low airflow from the bottom to the top, a vacuum cleaner is added at the air outlet of the dryer; it starts whenever the average trays temperature exceeds 56°C, thus lowering the maximum level of tomatoes damage. This means is preferred in the region because the quantity of tomato production is becoming more and more impressive and the conditions for its application exist. The number of sunshine hours reaches 3488.5 hours per year; the temperature in the sun mainly in the months from May to August is 48 °C with a maximum humidity rate of 80%.

The predictive result given by the modelling method using non-conventional experimental designs allows knowing previously the hours number of dehydration and drying of the food under changing conditions of the 3 mentioned parameters without making additional experiments. This method, in addition to being based on experiments: a- It has the ability to be descriptive and predictive at the same time, b- It does not require a high experiments number, c- It is polynomial form. b- It does not include any difficult functions, d- It has an interactive correlation between the factors. The finished product, obtained in the form of powder is preserved for a long time, it is ecological since its density is reduced, does not require great means of packaging and finally nutritional in vitamins that are found in the initial fruit with an accessible price.

2. Materials and methods

2.1. Elaboration of the experimental test rig for the used method

In order to elaborate the experiments of tomatoes dehydration and drying, a test bench constructed by us in our laboratory is used as experimental material. This dryer with indirect solar conversion, composed of 2 distinct compartments, is elaborated with wood. Aluminium sheets envelop the first chamber; it is comported trays. This material is used to reinforce the thermal conduction, while the second chamber with the absorbing plaque is painted with a black colour to avoid the excessive reflection of the solar rays outside.

The first compartment, with a rectangular section, called the drying chamber is designed to contain the grilled trays, while the second, communicating with the first, is of parallel-piped form and is equipped with a glass inclined of 30°, called solar radiations collector; these rays end up at the absorbing tray.

They are destined to be transformed in calorific energy inside the chamber. This ergonomics is studied so that the solar rays do not strike directly on the food; this adaptation allows the heat to dry it, avoiding the deterioration and the putrefaction of the tomatoes (figure 1).

Nine positions for different sensors are chosen on the dryer.

Three positions for sensors at the grilled trays level inside the drying chamber, one at the level of the air inlet, a fourth at the top of the chamber, another at the air outlet, a seventh at the heat-absorbing tray, an eighth at the glazing window level. The last one is installed at the outside to measure the parameters of the ambient air. The used main devices to measure the parameters during the drying process are:

Figure 1. The experimental test rig of drying

Table 1. Experimental and coded values of the 3 parameters

Hours number of	Temperature trays °C	Coded values of temperature	Drying speed g/Hm^2	Coded values of drying	Relative humidity %	Coded values of Relative
1	28.3	-1	11.53	1	66	1
2	36.6	-0.385	5.24	-0.0987	63	0.897
3	41.2	-0.0444	3.15	-0.464	59	0.759
4	45	0.237	2.12	-0.644	52	0.517
5	47.8	0.444	1.51	-0.75	43.4	0.221
6	49.4	0.563	1.11	-0.82	37	0
7	50.3	0.63	0.81	-0.872	43.7	0.231
8	51.5	0.719	0.61	-0.907	36.4	-0.0207
9	53.5	0.867	0.45	-0.935	33	-0.138
10	53.7	0.881	0.32	-0.958	27.9	-0.314
11	54.1	0.911	0.22	-0.976	23	-0.483
12	55.2	0.993	0.14	-0.99	16	-0.724
13	55.3	1	0.08	-1	8	-1

1. Digital hot wire anemometer, wind speed meter, airflow, 0 to 30 m/s, with USB Interface and thin sensor, GM8903.
2. Development board for Arduino, humidity sensor with hygrometer LM393.
3. Temperature sensor probe 0-400 °C, M6 thermocouple thread Type k1/2/3/4/5m, temperature controller.
4. Digital hygrometer with probe, LCD display, integrated temperature and humidity.

2.2. Experimental measures

Thirteen values of each of the 3 parameters influencing the dehydration and drying process were recorded along 13 hours of sun exposure. They are displayed in Table 1 above.

The values of the 3 parameters (Trays temperature, drying speed and relative humidity) are used obligatorily in the polynomial mathematical model in coded form. The sum of the 10 terms (Equation 1) is only possible if they have the same dimensions. However, the parameters have different units and values at different scales. One eliminates the units of the 9 monomials and one gives their values between -1 and +1 (Table 1).

$$y = a_0 + a_1 x_1 + a_2 x_2 + a_3 x_3 + a_{11} x_1^2 + a_{22} x_2^2 + a_{33} x_3^2 + a_{12} x_1 x_2 + a_{13} x_1 x_3 + a_{23} x_2 x_3 \quad (1)$$

Since 13 experimental measurements have been carried out, one then forms 13 equations of type 1 by replacing each time in the polynomial the values of x_i by forming a regression from Y into X. They are represented in matrix form, which facilitates their resolution and allows us to obtain the coefficients a_i and a_{ij} of the researched model (1) by the least squares method in equation (2). The sine qua non condition is the necessity to have a number of distinct experiments (here 13) superior or equal to the number of coefficients (here 10). (Goupy, 2005; Goupy, 2013; Louvet, 2005).

Table 2. Descriptive table of the elements composing the mathematical model.

Name and		Symb	Value
Constant	Cst	a_0	5.08907
Temperature of trays	Tpl	a_1	3.06431
Drying speed	Dry	a_2	-1.98757
Relative humidity	Hum	a_3	-0.731186
Temperature of trays *Temperature of trays	Tpl*Tpl	a_{11}	1.05761
Drying speed*Drying speed	Dry*Dry	a_{22}	-0.27053
Relative humidity *Relative humidity	Hum*Hum	a_{33}	-0.281137
Temperature of trays *Drying speed	Tpl*Dry	a_{12}	-0.141348
Temperature of trays *Relative humidity	Tpl*Hum	a_{13}	-1.39046
Drying speed*Relative humidity	Dry*Hum	a_{23}	0.24204

$$a_{ij} = \left(X^t X\right)^{-1} \left(X^t\right)(Y) \tag{2}$$

Where:

X: Model matrix with 10 columns and 13 lines,
X^t: Matrix transpose (Reverse of X),
$(X^tX)^{-1}$: Information matrix (idem),
(Y): is response matrix with 1 column and 13 lines. The informations and values of the a_{ij} coefficients are shown in table 2.

Then equation (1) takes the final form of the mathematical behavioural model of the dehydration and drying process (Equation 3). (Goupy, 2005; Goupy, 2013; Louvet, 2005).

$$y = 5.08907 + 3.06431x_1 - 1.98757x_2 - 0.731186x_3 + 1.05761x_1^2 - 0.27053x_2^2 - 0.281137x_3^2 - 0.141348x_1x_2 - 1.39046x_1x_3 + 0.24204x_2x_3 \tag{3}$$

3. Results and discussions

This part is composed of 2 distinct analyses, the first one being statistical and consists in evaluating the obtained model by coefficients and tests in order to know its descriptive and predictive quality, and then applying it on the elaborated experiments.

The second is a detailed analysis of the action of the 3 parameters and their interactions on the drying process of tomatoes.

3.1. Quality of the mathematical model

The statistical calculation carried out by the Modde 6 software allows us to obtain the values of two quality coefficients.

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3.1.1. Descriptive and predictive coefficients

The first one being the coefficient of the descriptive quality of the model R^2.

It is the percent of the variation of the response explained by the model ($0 \leq R^2 \leq +1$). It is equal at 0.995 and is very close to +1.

The second one being the coefficient of the predictive quality of the model Q^2 ($-\infty < Q^2 \leq +1$).

It is the percent of the variation of the response predicted by the model. His value is 0.988 and it is very close at +1.

These 2 very satisfactory values show that the expression (3) describes and predicts the studied process. (Goupy, 2005; Goupy, 2013; Louvet, 2005).

3.1.2. Fisher test

The F-Fisher test is a statistical hypothesis test that allows comparing 2 variances by doing their ratio which must not exceed a certain theoretical value that we extract from the Fisher-Snedecor table.

One generally compares the observed Fisher number F_{obs} from the experiments, and the critical Fisher number F_{crit} from the established tables.

The first one must be higher than the second one, then the regression is globally significant, the model is acceptable with a risk of 5% that it is not realised (Choice initially taken at the beginning of the study). (Goupy, 2005; Goupy, 2013; Louvet, 2005). In our case $F_{obs}=336.19>F_{crit}= 8.81$.

3.1.3. Student test The Student "t-test" is a statistical test allowing to compare the means of 2 groups of values having a link (here the values of the observed and predicted responses of "y") in order to know if they are significantly similar or different. It is therefore used to test the significance of the coefficients that compose the mathematical model. The method is based on the following variance (Equation 4), and the t_{crit}-Student coefficient. (Goupy, 2005; Goupy, 2013; Louvet, 2005):

$$S^2 = \frac{1}{n-p}\sum_{i=1}^{30} e_i^2 \qquad (4)$$

The student test shows that 4 coefficients on 10 of model (3), namely a_{22}, a_{33}, a_{12} and a_{23} have a lesser effect on the response and the 6 other are preponderant. This does not affect the quality of this modelling.

3.2. Parameters actions of the model on the response

As the model (3) sh0ows, firstly, each parameter acts separately, and each combination of parameters 2 by 2, acts secondly on it. The sum of these influences gives deviations between the experimental and the theoretical expression.

3.2.1. Deviations analysis

The 10th measure is the one with the lowest deviation evaluated at 0.22%. The drying behaviour of tomatoes at a temperature of 53.7 °C, with a dehydration speed of 0.32 g/Hm^2 and reaching a relative humidity of 27.9% shows that these values are theoretically attained after 9 hours and 59 minutes instead of 10 hours (Figure 2).

The biggest deviation is observed in experiment 7; it is evaluated at 6.48%. At this level, the measured average temperature on the trays is 50.3 °C, the tomatoes speed of dehydration and drying is 0.81 g/Hm^2 when the relative humidity inside the dryer is 43.7%.

These 3 parameters are reached after 6 hours and 32 minutes instead of 7 hours. On the graph in Figure 2, the points with the least deviations are the points of experiments 1, 10, and 13.

Contrary, the most deviated points are located in experiments 6 and 7. The average of the 13 deviations in absolute values is 0.22 hours, while taking into account the positive and negative signs is $7.76.10^{-7}$ hours. This is considered as very encouraging results.

Figure 3 illustrates the initial state of the tomatoes on the 4 trays before the drying process is started. The temperature is equal to the ambient temperature at 18 °C in the morning, the relative humidity is around 80%, and the drying speed has not yet started.

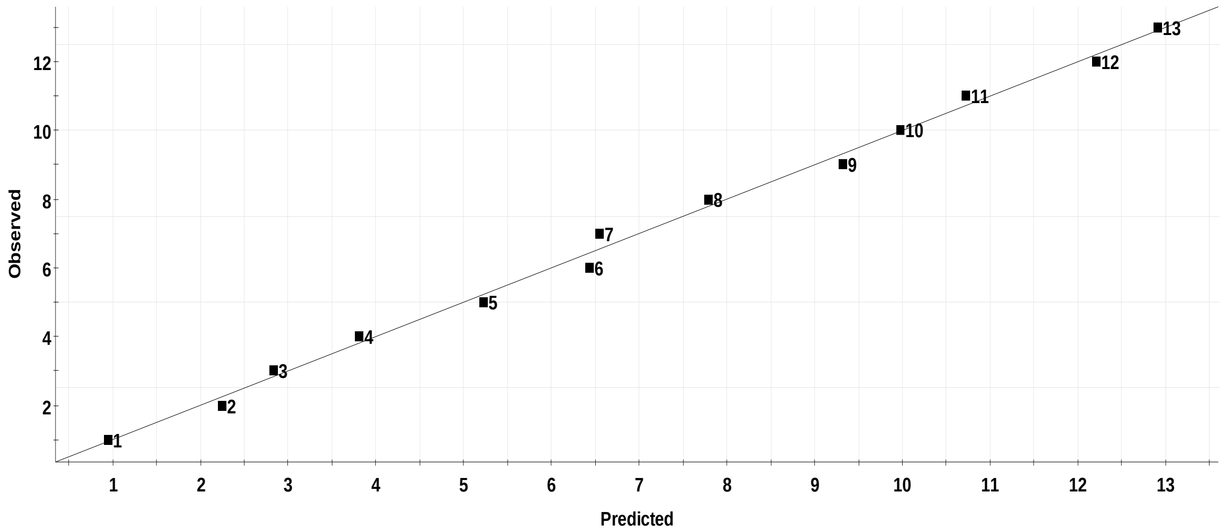
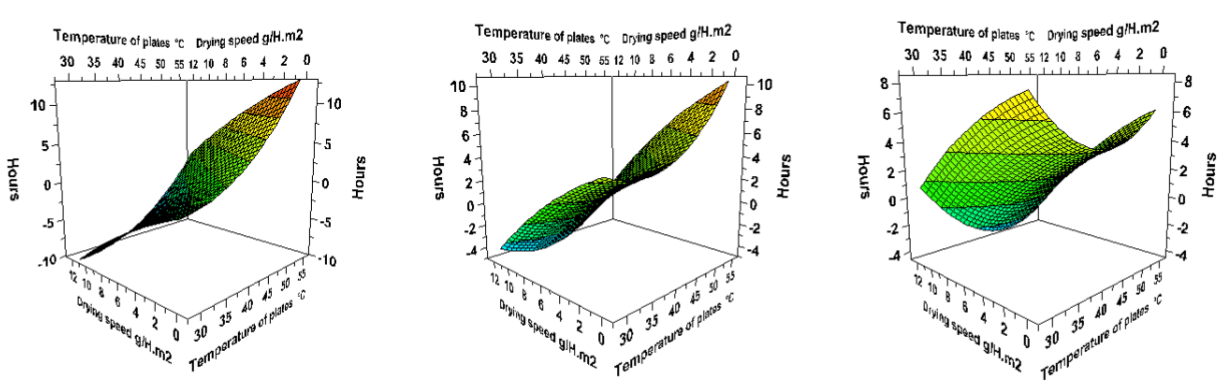


Figure 2. Illustrative figure of the deviations between model and experiments

Figure 3. General view of the 4 dryer trays before drying processes.

3.2.2. Analysis of the drying process under the effect of the parameters interaction

Through these 6 graphs, one can visualize the behavior of the dehydration and drying process along the 13 experiments. As many graphs can be represented as one wishes. Three cases are sufficient to understand the phenomenon, when the relative humidity has its higher value of 66% at 1 hour of drying, when it has its lower value of 8% after 13 hours of drying, then finally for an average intermediate value of 37% at exactly 7 hours of the dryer exposure to sunlight (Figure 4).



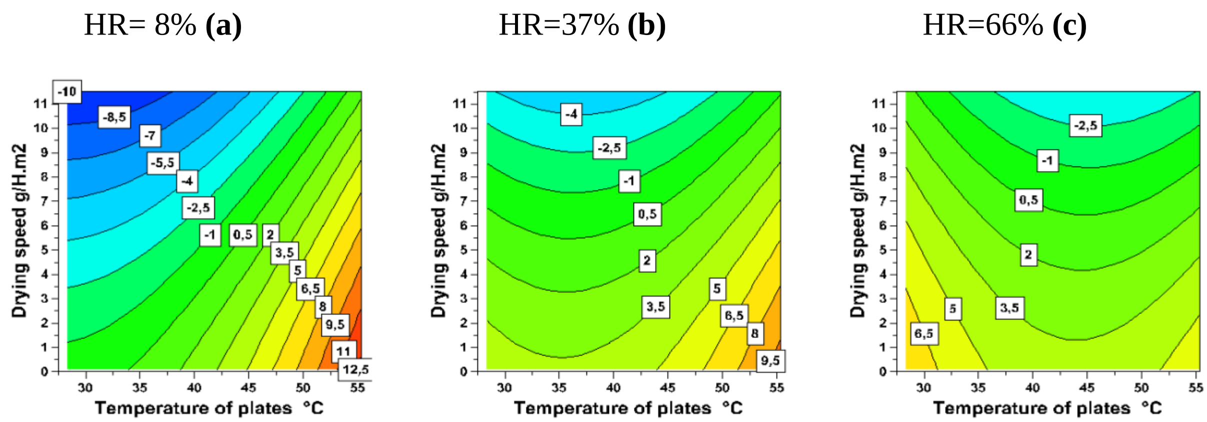


Figure 4. Illustration of the drying process by response surfaces and contours at relative humidity of 8% and 66%

Firstly, the negative hourly values represented on the contours of the 3 cases are only theoretical values, they are given by the model (3) and are therefore rejected. Only the positive dehydration and drying hours values are taken into account and analysed. Secondly, the theoretically negative number of drying hours of tomatoes becomes less by going from 8% relative humidity (-8.5 hours) to 66% (-2.5 hours).

Table 3. Values for drying speed and trays temperature at 8% relative humidity

Relative humidity (%)	**Dryin speed** g/Hm^2	**Trays temp** (°C)	**Time** Hours
8%	6.5	47.5	1.37
	5	50	4.55
	3	51.3	7.36
	1	52.5	9.79

For a relative humidity of 8%, the number of drying hours increases with the increase of the temperature of the trays and the decrease of the dehydration speed, reaching 12.5 hours of drying at a temperature of 55°C and a speed lower than 1 g/Hm^2. The table 3 below mentioning some values confirms what has been said before.

For a relative humidity of 37%, the increase in the number of drying hours is done in 2 steps. For all contours the drying speed decreases to a minimum value and then increases to the maximum value of drying hours. There, the simultaneous increasing of the dehydration speed and the temperature of the trays increases the number of hours of exposure to the sunlight. Table 4 shows the minimum points of each contour. Before this point, it is the decrease of the drying speed and the increase of the temperature of the trays that keeps the drying time constant, but after this point, it is the simultaneous increasing of the 2 mentioned parameters that keeps the dehydration time in constant value.

Table 4. Minimum points of the 3 contours changing the drying behaviour for HR=37%

Relative humidity %	**Dryin speed** g/Hm^2	**Trays temperature** °C	**Time** Hours
37%	5.5	36	0.5
	3.25	35.7	2
	0.5	35.5	3.5

For the case of 66% relative humidity, the domain of definition of the drying process is larger since the negative theoretical number of hours is less.

One notices the same behavior as before with minimal contours points is around 45°. Below, are some values of parameters for a relative humidity of 66% (Table 5).

After 13 hours of the dryer exposure to the sunlight, the tomato dries by shrinking and losing its mass. Its water content, which is at the 1st hour of 11.53 g/kg of dry matter, becomes 1.09 g/kg of dry matter, i.e. a loss of 90.54 % of its initial mass.

These pieces of dried tomatoes are then transformed into tomatoes powder (Figure 5-b) by a mixer with a sharp blade turning at very high speed. (Castoldi et al., 2015).

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Table 5. Values for drying speed and trays temperature at 66% relative humidity

Relative humidity %	**Dryin speed** /Hm^2	**Trays temperature** °C	**Time** Hours
66%	10	32	0.5
	6	36.5	2
	4.5	47.5	2
	8	53.8	0.5

These pieces of dried tomatoes are then transformed into tomatoes powder (Figure 5-b) by a mixer with a sharp blade turning at very high speed. (Castoldi et al., 2015).

What remains in slices or in powder is without diseases and pure raw substance devoid of water, which is a nutritional source of vitamins A, C and E, of minerals, of dietary fiber and of antioxidants with beta-carotene (Figure 5). (Arslan et al., 2011, Clarke et al., 1979, Podsędek et al., 2003, Galhardo et al., 2009).

The water content of the tomato is very high at its harvest, reaching up to 90% of its mass, which favours its degradation in its fresh state and its physicochemical and microbiological deterioration. Its dehydration and its drying are more than necessary (Rajkumar, 2007).

The ascending hot air in the dryer can lead to diseases and degrade lycopene, carotene and ascorbic acid of the tomato; the control of the drying paramete99rs is thus primordial (Manzo et al., 2019, Demiray et al., 2013; Zanonia and al., 1998)

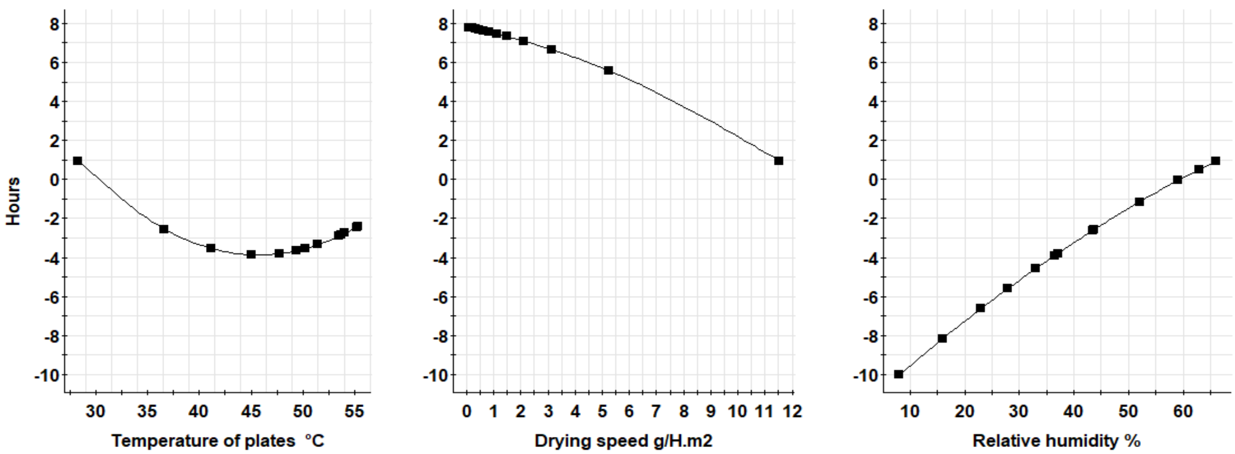
(a) (b)

Figure 5. Tomatoes status (slices and powder) after 13 hours of drying

3.2.3. Variation of the drying time according to the experimental values of the 3 parameters

In the following analysis, one shows the variation of the dehydration and drying time as a function of each parameter acting on the process when the 2 other are invariant and relative to experiments 1, 7 and 13 (Table 1). In the 9 following equations of curves, the parameters x_i are expressed in coded values (Table 1), while the response y (drying time) is expressed in real values, i.e. in hours.

When T_{pl} =28.3 °C, D_{speed}=11.53 g/Hm^2, HR=66% (Experience 1): One remarks that the domain of definition of y=f(T_{pl}) gives a negative number of theoretical hours of tomatoes drying, which is practically impossible to realise, therefore one rejects this case (Figure 6-a).



(a) (b) (c)

Figure 6. Drying time variation with experiment number 1

On the graph of Figure 6-b, the curve designed by y=f(S_{drying}) is decreasing. It shows that with the increasing of the drying speed, the hours number of the tomatoes dehydration process decreases from 7.78 hours at the process beginning to 0.933 hours (at 11.5 g/Hm^2 of drying speed) and this, under the influence of the 2 other parameters, i.e. temperature of plates and relative humidity. The decline of close to 12% of the tomatoes drying hours in the dryer is important with the increase of the dehydration speed. On the 6-c ascending curve y= f(HR), for the values of the 3 mentioned parameters, the ascending variation of the hours number of tomato drying between the beginning of the process and 1 hour is explicable only for relative humidity rates varying between 58.8% and 66%. All the rest of the graph being theoretical with a negative hours number, in other words, an area to be rejected. When T_{pl} =50.3 °C, D_{speed}=0.810 g/Hm^2, HR=43.7% (Experience 7): In Figure 7-a, the number of drying hours decreases from

5.08 hours at 28.2 °C to 3.81 hours at 37.7 °C, and then increases again to 8.98 hours when the average tray temperature reaches 55.2 °C. Roughly speaking, under the influence of the drying rate of 0.81 g/Hm^2 and the relative humidity of 43.7%, the drying hours number decreases from 5.08 hours at 28.2 °C to 3.81 hours at 37.7 °C, and then increases again to 8.98 hours when the average tray temperature reaches 55.2 °C. Roughly speaking, under the influence of the drying rate of 0.81 g/Hm^2 and the relative humidity of 43.7%.

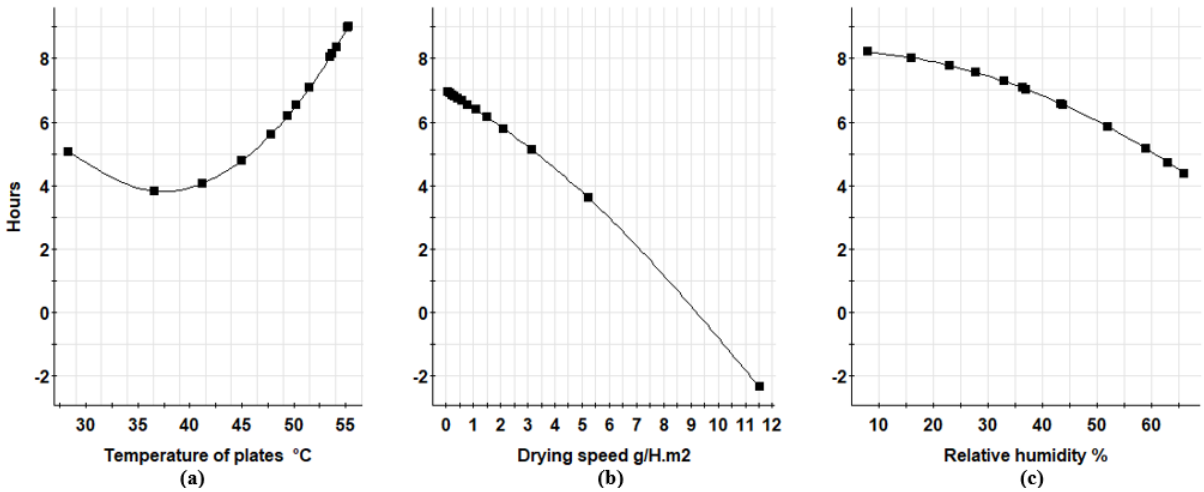


Figure 7. Drying time variation with experiment number 7

Paradoxically, the increase of the trays temperature increases the hours number of tomato drying for the reason of the interactions of the 2 other parameters acting on the mathematical model.

Figures 7-b and 7-c, show both, the decreasing number of drying hours with the increase of the dehydration speed on one hand and the relative humidity on the other hand (table 6), always under the interactions of the 2 other remaining parameters as showing the mathematical model (3).

Table 6. Illustrative values of figures 7-b and 7-c

Figure 7-b		**Figure 7-c**	
Drying speed g/Hm^2	**Drying** time hours	**Relative humidity** %	**Drying time** hours
0.03	6.93	7.89	8.2
9.13	0	65.7	4.36

When T_{pl} =55.3 °C, D_{speed}=0.08 g/Hm^2, HR=8% (Experience 13): In the analysis of this 3rd case, concerning specifically the experiment 13, where the average temperature of the trays takes its maximum value, the drying speed and the relative humidity take their minimum value (Figure 8). One notices that the 3 curves occupy totally a real and large physical definition domain because the dehydration and drying hours are completely positive.

Again, the variation of drying hours under the effect of one of the 3 parameters (Figure 8-a-b-c) is dependent of 2 others, here of the drying speed of the tomatoes which is equal at 0.08

g/Hm2, and of the relative humidity equal at 8% for drying temperature parameter (for example). The interaction of the 3 parameters between them on the drying hours number of the tomatoes is omnipresent, it always responds to the mathematical model (3). Thus, increasing the trays temperature increases the number of drying hours (Figure 8-a), and increasing the drying speed and relative humidity decreases it. (Figure 8-b and 8-c). Below, there are some illustrative values of this behaviour (Table 7).

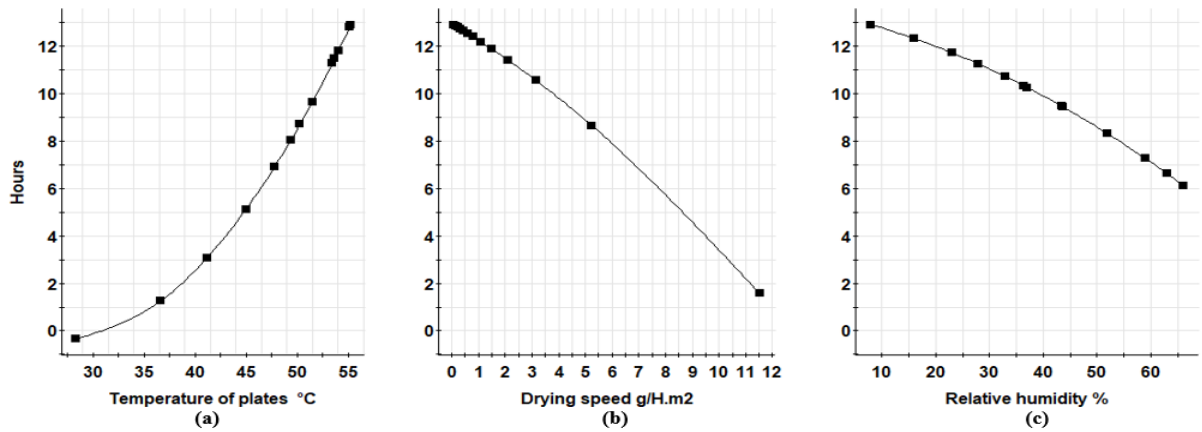


Figure 8. Drying time variation with experiment number 13

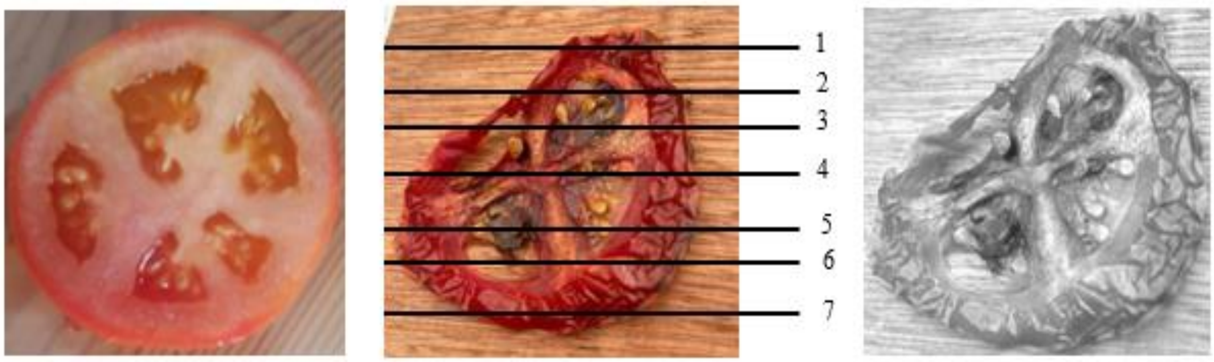
Table 7. Some values of the third case with the experiment parameters 13

Time$_{dry}$= f (T$_{trays}$)		**Time$_{dry}$= f (Dspeed)**		**Time$_{dry}$= f (HR)**	
T°$_{trays}$ °C	**Time** Hours	**D$_{speed}$** g/Hm^2	**Time** Hours	**HR** %	**Time** Hours
36.5	1.25	0.04	12.9	7.72	12.6
44.9	5.12	2.07	11.4	23.1	11.7
49.3	8.03	5.20	8.67	43.5	9.47
53.3	11.3	7.96	5.68	58.8	7.27
55.2	12.8	11.5	1.57	65.9	6.16

By comparing the 3 series of graphs, one notices that the aspect of the curves remains practically the same. The values change of the parameters in the order from "Low-High-High" (experiment 1) to "High-Low-Low" (experiment 13) while passing by "Medium-Medium-Medium" (experiment 7), shows that one tends towards physically real values and towards a practical experimental predictive behaviour of tomato drying.

3.3. Densitometry Study of a dried Tomato slice

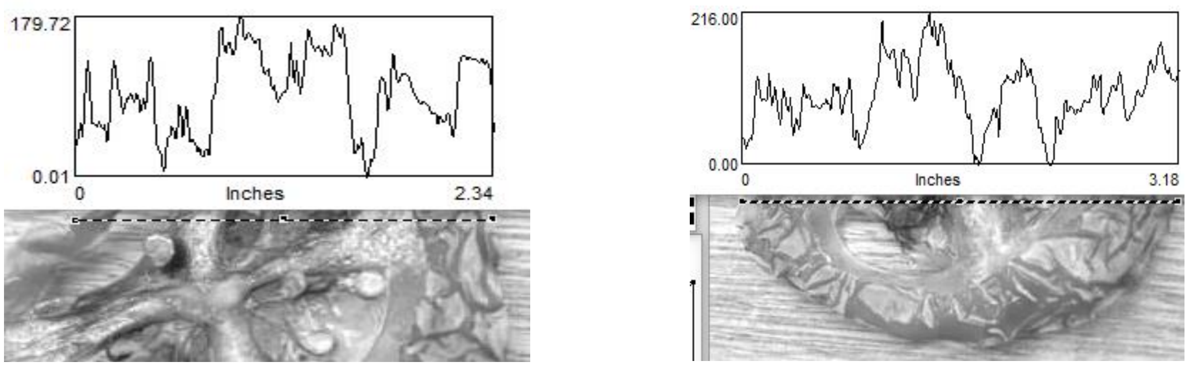
A tomato slice is not dried uniformly in its volume; some parts are subjected to the heat conduction of the dryer, while others contain a remaining quantity of humidity. The following study analyses the areas of the slice using the digital image processing software Scion Image (Software Scion, 2021; Software user guide, 2002.). It shows grey levels scaled from 0 to 255 on a similar of a photonegative. The 0 indicates a grey that tends to absolute black, while the value 255 corresponds to a perfect white. The interpretation of the real grey levels of the areas is therefore done by deducting the value shown on the profile from the value 255. Figures 9-a-b-c show the tomato slice before drying, after drying and finally the digitalised photo by Scion Image.



(a) (b) (c)

Figure 9. States of the tomato slice during the drying process.

If one looks at these figures, one can see that the radial and external peripheral nervures remain white and are therefore the least affected by heat conduction, these are the hard parts of the tomato that are difficult to dry, whereas the lobes (central portions) are blackened, and therefore strongly dehydrated. Sections 3 and 5 in Figure 9 are very close and have similar profiles because they are located on either side of the central circular nervure.



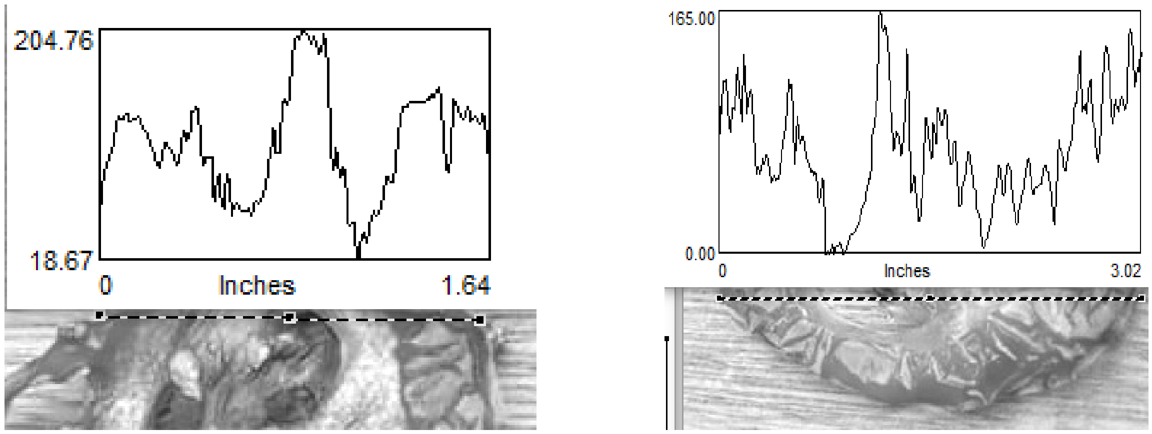
(a) (b)

Figure 10. Densitometry of sections number 3 and 5 of the tomato slice

The first is measured on a width of 59.4 mm and the second on a width of 80.7 mm and reach a high grey of 75.28 (Figure 10-a) and 39.0 (Figure 10-b) (close to 0 value of absolute black) on a scale of 255.

In both figures, there are many peaks synonymous with parts affected by the thermal conduction; the central area between sections 3 and 5 of the tomato slice is suitably dried. However, a minor part of both sections remains white with values reached up to 255; this shows that these small areas have not sufficiently dried and that the 13 hours exposure to the sun is insufficient.

The effect of thermal conduction on the zones 2 and 6 is different. In Figure 11-a, on a width of 41.6 mm, located inside the dryer, a very dried central area reaches a grey scale of 50.24 on a scale of 255, which corresponds to a good drying.



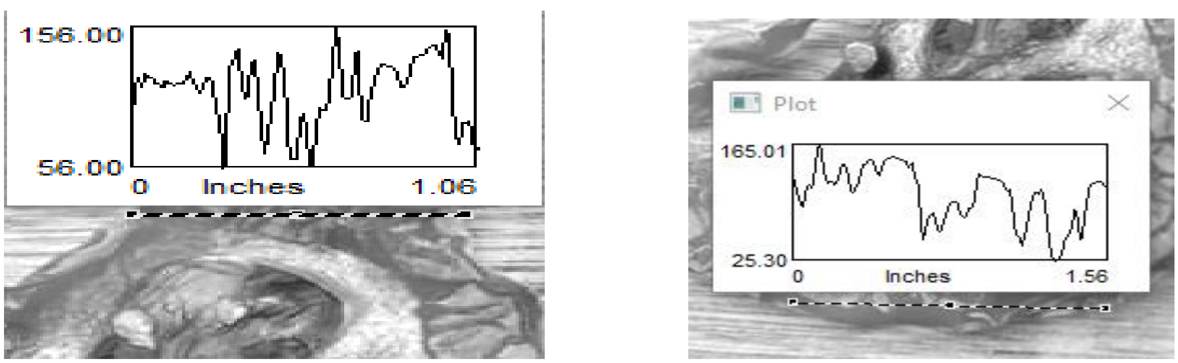
(a) (b)

Figure 11. Densitometry of sections number 2 and 6 of the tomato slice.

Just to its right, a badly dehydrated area reaches a value of 246.33 very close to 255, which corresponds to a zone containing still water, therefore a poorly dehydrated area.

On the contrary, in Figure 11-b, in the area towards the dryer window, the obtained profile with a width of 76.7 mm has several valleys whose values tend towards 255, which corresponds to a nuance of grey tending towards white, in other words towards an absence of drying.

In these areas, drying is done more correctly inside the dryer than on the window side.



(a) (b)

Figure 12. Densitometry of sections number 1 and 7 of the tomato slice

The areas 1 and 7 (Figure 12) represent the external circular nervure of the tomato slice; this is an area subject to direct unobstructed thermal conduction reaching a nuance of 89.99 of grey showing that this external zone is relatively more dried than the previously mentioned radial nervures. The average drying around the perimeter of the tomato slice have a nuance of 100.57 on a scale of 255, which corresponds to a relatively acceptable dehydration.

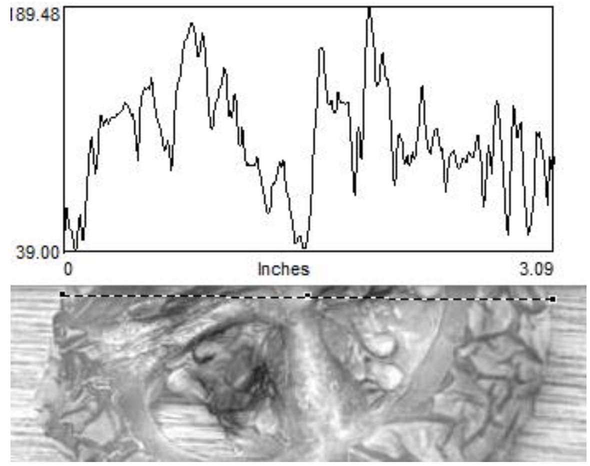


Figure 13. Densitometry of sections number 4 of the tomato slice

Finally, the profile of zone 4 (Figure 13) shows a correctly dried surface, it is characterized by the central nervure whose value reaches a nuance of grey of 216, very close to perfect white. This shows that this nervure remains significantly under-dried.

4. Conclusion

Through the analyses and comments carried out during this study by using the modelling by the non-conventional designs of experiments, one notices that the responses and the solutions are diverse and diversified. This is due to the interaction of the parameters that act separately and then in a combined form on the obtained results. One can see through the proposed graphs, contours and response surfaces without limit in treating an infinity of cases. The established design of experiments is thus a series of rigorously organized tests, in order to determine with a minimum of experiments and a maximum of precision, the respective influence of the 3 various mentioned parameters in the study in order to optimize the performances and the cost. The modelling by design of experiments is thus the only method, which analyses a process, here, the drying hours, by taking into account the effect of each of them, and the effect of each combination of our 3 parameters. These results permit us to describe the experimental dehydration and drying process, to separate it into theoretical values to be rejected and practical values to be applied, and to predict even unknown cases, not executed during the experiments. Since the different areas of the tomatoes, slices are differently affected by thermal conduction, and in order to attenuate this phenomenon, the installation of rotating trays is proposed. This will expose all areas to the same thermal effects.

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Conflict of Interest

There are no conflicts of interest between individuals and institutions since, except the researchers, no other intervention was engaged in this project. The authors report there are no competing interests to declare.

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