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Analysis of Buñuelos Growth Rate Using 2^k Factorial Design

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Abstract

Buñuelos are a traditional food not only in Colombia but in several parts of the world. They are prepared mainly with cassava starch, cornstarch, cheese, water or milk. The purpose of this work is to determine which factors (trademark, time, temperature, serving size) or interactions between them are important to achieve a major volume of the buñuelos. Thus, a 2^k design is proposed to analyze the factors on the growth rate of buñuelos. The growth rate is calculated taking into account the buñuelos diameter before fried and after fried. The results indicate that the serving size has the principal effect on the response variable but followed by the trademark and some interactions between time and temperature.

Keywords: Design of Experiments; 2^k Factorial Design; Food Engineering.

1. Introduction

The buñuelos are the traditional food inside the gastronomy of several countries. The buñuelo can be defined like a dough ball which rises when it is fried. Also, it can be prepared with eggs, cheese and sweetened with honey [1].

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The buñuelos, a typical and high consumption food in Colombia, is a product resulting from the mixture of cassava starch, corn starch, cheese, water or milk; May also contain other ingredients such as eggs, sugar and salt, to make a spherical dough and fried it by immersion in oil. The final product has a crisp crust of uniform golden-brown color, a soft fluffy crumb, and a characteristic smell and taste. In addition, it is a gluten-free product that positions it as an alternative food for people with celiac disease [2].

The frying process used in the manufacture of buñuelos is by immersion, a unitary operation used in the preparation of food, especially for the development of snacks with a unique flavor and texture [3].

This process involves transfer of mass and heat that causes important structural changes in the surface and the body of the product. In addition, numerous complex physico-chemical changes occur during frying, including protein denaturation, starch gelatinization, water evaporation, and color development [4].

Some studies on similar products to buñuelos have focused on evaluating changes in color and texture during immersion frying for different times and temperatures in order to determine kinetic parameters in terms of constant reaction speed and activation energy [5]. In the same topic, the authors in [6] analyzed experimentally the changes in the rheological properties and the color of the donut crust (wheat flour-based) during immersion frying at 80, 190 and 200ºC, and concluded that the moisture content of the samples and the temperature Affect these properties (color and texture).

Also, it is important to mention that cheese is the main ingredient of the buñuelo because it contributes to the characteristic aroma and flavor, promotes the structure of the crumb and improves the texture of the final product, obtaining a better appearance of the crust, and a Greater softness and uniformity of the alveoli of the crumb [7].

There is no information about investigations related to the characterization of the buñuelo. However, there are studies of frying processes in different starch products, made from potatoes, cassava starch and wheat, among others. Cassava flour has a high degree of expansion, a very important property for the quality of fried snack type products. These products are formed, often in pellets, and then they expand and result in a porous product of low density, by the baking process or fried by immersion before consumption [8]. Taking this property of cassava flour into consideration, the present work will evaluate the influence of trademark, time, temperature and serving size on the buñuelos expansion.

2. The 2^k factorial design

As the author states in [9] – [11] factorial designs are widely used in experiments involving several factors where it is necessary to study the joint effect of the factors on a response. So, in this section it is explained briefly the 2^k factorial design taking into account the theory in [9].

The factorial design has several special cases but the most important is that of k factors, each at only two levels. These levels may be quantitative, such as two values of temperature, pressure, or time; or they may be qualitative, such as two machines, two operators, the “high” and “low” levels of a factor, or perhaps the presence and absence of a factor. A complete replicate of such a design requires $2 \times 2 \times ... \times 2 = 2^k$ observations and is called a 2^k factorial design.

The 2^k design is particularly useful in the early stages of experimental work when many factors are likely to be investigated. It provides the smallest number of runs with which k factors can be studied in a complete factorial design. Consequently, these designs are widely used in factor screening experiments.

Because there are only two levels for each factor, we assume that the response is approximately linear over the range of the factor levels chosen. In many factor screenings experiments, when we are just starting to study the process or the system, this is often a reasonable assumption.

2.1. The method

The statistical model for a 2^k design would include k main effects, $\binom{k}{2}$ two-factor interactions, $\binom{k}{3}$ three-factor interactions, ⋯, and one k-factor interaction. That is, the complete model would contain $2^k - 1$ effects for a 2^k design. The notation for treatment combinations is for example; in a 25 design abd denotes the treatment combination with factors A, B, and D at the high level and factors C and E at the low level. The treatment combinations may be written in standard order by introducing the factors one at a time, with each new factor being successively combined with those that precede it. For example, the standard order for a 24 design is (1), a, b, ab, c, ac, bc, abc, d, ad, bd, abd, cd, acd, bcd, and abcd.

The general approach to the statistical analysis of the 2^k design is summarized in Table 1. So, a computer software package is usually employed in this analysis process.

Table 1. The Analysis procedure for develop 2^k Design

1. Estimate the factor effects
2. Form initial model • If the design is replicated, fit the full model • If there is no replication, form the model using a normal probability plot of the effects
3. Perform the statistical testing 4. Refine the model
5. Analyze the residuals
6. Interpret the results

The sequence of steps in Table 1 should, by now, be familiar. The first step is to estimate factor effects and examine their signs and magnitudes. This gives the experimenter preliminary information regarding which factors and interactions may be important and in which directions these factors should be adjusted to improve the response. In forming the initial model for the experiment, we usually choose the **full model**, that is, all main effects and interactions, provided that at least one of the design points has been replicated. Then in step 3, we use the analysis of variance to formally test for the significance of main effects and interaction. Table 2 shows the general form of an analysis of variance for a 2^k factorial design with n replicates. Step 4, refine the model, usually consists of removing any nonsignificant variables from the full model. Step 5 is the usual residual analysis to check for model adequacy and assumptions. Sometimes model refinement will occur after residual analysis if we find that the model is inadequate, or assumptions are badly violated. The final step usually consists of graphical analysis—either main effect or interaction plots, or response surface and contour plots.

Although the calculations described above are almost always done with a computer, occasionally it is necessary to manually calculate an effect estimate or sum of squares for an effect. To estimate an effect or to compute the sum of squares for an effect, we must first determine the contrast associated with that effect. This can always be done by using a table of plus and minus signs, such as Table 3 or Table 4. However, this is awkward for large values of k and we can use an alternate method. In general, we determine the contrast for effect $AB \cdots K$ by expanding the right-hand side of:

$$\text{Contrast}_{AB\cdots K} = (a \pm 1)(b \pm 1) \cdots (k \pm 1) \tag{1}$$

In expanding the previous equation, ordinary algebra is used with "1" being replaced by (1) in the final expression. The sign in each set of parentheses is negative if the factor is included in the effect and positive if the factor is not included.

Once the contrasts for the effects have been computed, we may estimate the effects and compute the sums of squares according to:

$$AB \cdots K = \frac{2}{n2^k}(\text{Contrast}_{AB\cdots K}) \tag{2}$$

And

$$SS_{AB\cdots K} = \frac{1}{n2^k}(\text{Contrast}_{AB\cdots K})^2 \tag{3}$$

Where n denotes the number of replicates.

Table 2. The Analysis of Variance for develop a 2^k Design.

Source of variation	Sum of Squares	Degrees of freedom
k main effects		
A	SS_A	1
B	SS_B	1
⋮	⋮	⋮
K	SS_K	1
$\binom{K}{2}$ two-factor interactions		
AB	SS_{AB}	1
AC	SS_{AC}	1
⋮	⋮	⋮
JK	SS_{JK}	1
$\binom{K}{3}$ three-factor interactions		
ABC	SS_{ABC}	1
ABD	SS_{ABD}	1
⋮	⋮	⋮
IJK	SS	1
⋮	⋮	⋮
$\binom{K}{k}$ k-factor interaction		
ABC…K	$SS_{ABC\ldots K}$	1
Error	SS_E	$2^k(n-1)$
Total	SS_T	$n2^k-1$

Table 3. Algebraic signs for calculating effects in 2^2 design.

Treatment Combination	Factorial Effect			
	I	A	B	AB
(1)	+	-	-	+
a	+	+	-	-
b	+	-	+	-
ab	+	+	+	+

Table 4. Algebraic signs for calculating effects in 2^2 design.

Treatment Combination	Factorial Effect							
	I	A	B	AB	C	AC	BC	ABC
(1)	+	-	-	+	-	+	+	-
a	+	+	-	-	-	-	+	+
b	+	-	+	-	-	+	-	+
ab	+	+	+	+	-	-	-	-
c	+	-	-	+	+	-	-	+
ac	+	+	-	-	+	+	-	-
bc	+	-	+	-	+	-	+	-
abc	+	+	+	+	+	+	+	+

3. Design of experiment and data collection mechanism

3.1. Design of Experiment

The process of doing buñuelos can be subdivided into several parts (or sub-processes), as shown in Figure 1, the first sub-process is the kneaded with mass (flour, water, cheese) and energy (mechanical) inputs. Here the flour is the variable of interest because the manufacturers can compare their products and to make modifications in the processing of the flour. Next the dough is the output of the kneaded sub-process and becomes the input of the buñuelos formed sub-process, here the interest is to know if the serving size or buñuelo portion have a significant influence on the buñuelo growth rate.

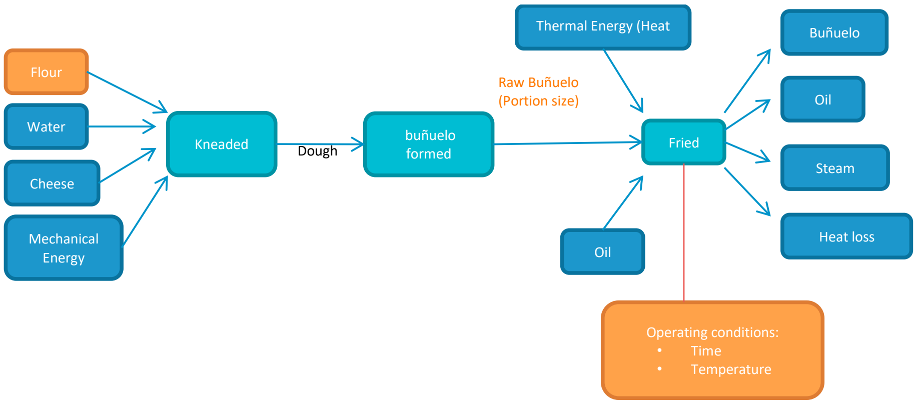

Fig. 1. Sub-Processes of Buñuelo Making.

Now, the fried sub-process has interesting operating conditions which can be manipulated in lab, the time and temperature plays an important role because its interaction control the transfer of mass which can affect the buñuelo growth. Here the thermal energy and oil are fixed. The outputs of sub-process are the heat loss, the steam, the oil with new characteristics and the buñuelo.

Considering the previous statements, the present work consider a 24 factorial design to compare which of the four factors; flour (trademark), portion size of raw buñuelo (serving size), Time and Temperature have a major influence on the buñuelos growth rate, so it is important the interactions between them.

The buñuelos growth rate will be calculated as:

$$\%\Delta V = \frac{V_f - V_i}{V_i} \tag{4}$$

Where V_i and V_f are the initial and final volumes respectively. The volume will be calculated taking into account three measurements of radius (averaged) by each buñuelo and to achieve a better calculation there will be three buñuelo replicates. So, the volume will be calculated as:

$$V = \frac{4}{3}\pi \bar{R}^3 \quad (5)$$

where $\bar{R}$ is the mean value of the three replicates of buñuelo.

3.2. Data Collection Mechanism

The experiment was developed in controlled environment and it was necessary the follow materials:

- Oven with easy manipulation of temperature control.
- Cooking pot
- Scraper
- Multimeter with temperature measurements
- Caliper
- Cheese
- Buñuelo flour.

The procedure followed to prepare the buñelos in this experiment was:

1. Put in a recipient the same amount of buñuelo flour and grated cheese (is better with costeño cheese) and mix them.
2. Add a determined measure of water and mix. The mixture must be soft like clay. (Fix the same amount of water)
3. Knead and give shape to buñuelo
4. Take the three diameter measurements before fried (Figure 2)
5. Measure the time and temperature of frying. Also manipulate the control of oven to maintain the temperature in the adequate levels.

Fig. 2. Measurement of buñuelo diameter.

6. After fried take three diameter measurements

Four factors were considered in the design of the experiment: flour trademark, cooking time, cooking temperature and serving size. The levels of factors are showed in Table 5.

Table 5. Levels of factor

Factor	Low level	High level
Trademark	1 (Kavid)	2 (Maizena)
Time	7 [min]	9 (min)
Temperature	155 [°C]	155 [°C]
Serving size	2 [cm³]	4 [cm³]

4. Analysis Method (Data Processing)

The data analysis was supported on the commercial softwares Statgraphics® from Statpoint Technologies and Design Expert® from Stat-Ease. Thus, the Table 3 shows the calculated growth rate varying given trademark, frying time and temperature and size of serving.

In the same way, the pareto diagram, Figure 3, shows the degree of significance of each factor.

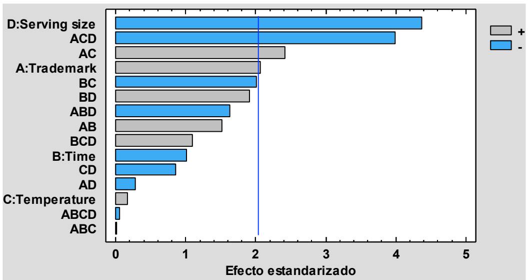

Fig. 3. Pareto diagram

Thus, the growth rate of the buñuelos can be affected by the trademark. In the competitive market, it can be important to understand the internal process of industry leading to better buñuelo manufacture. So, it is important the serving size, there is a major difficult to the buñuelo expansion because the trapped air needs to force a layer bigger of mass, so the mass exchange plays an important role in this process.

Now let consider the normal probability plot (Figure 4, a)

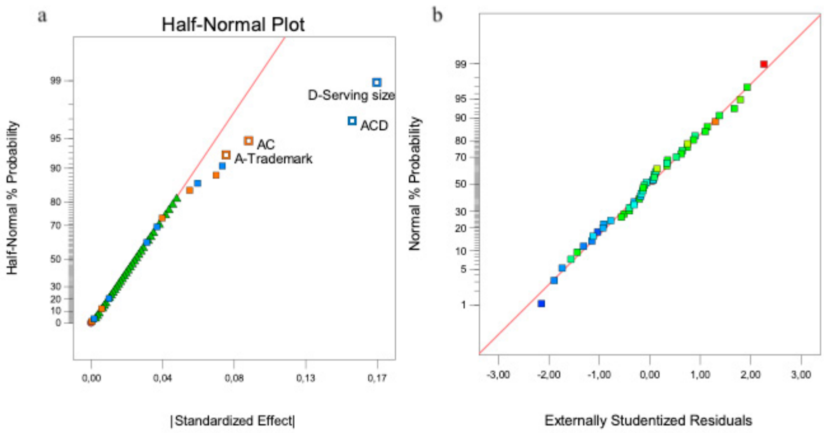

Fig. 4. (a) Normal probability plot of effects (b) Normal plot of residuals.

Now, just to support the validity of the results presented, some diagnostics plots are showed (Figures 4, a to 6) in order to verify assumptions of the analysis of variance carried out. So, the figures show no anomaly behavior in the observations for normality, independence and homocedasticity.

Once verified the anova assumptions, the factors and output correlation can be calculated as showed in Table 6.

Finally, the regression model obtained (which describe the growth rate in the buñuelos preparation process) was

$$\text{Growth Rate} = 0.46 + 0.039A - 0.083D + 0.046AC - 0.076ACD \quad (6)$$

This equation shows the impact of the Trademark and the Serving size and the interactions between them and the Time. So only the time has no significant effect on the growth rate.

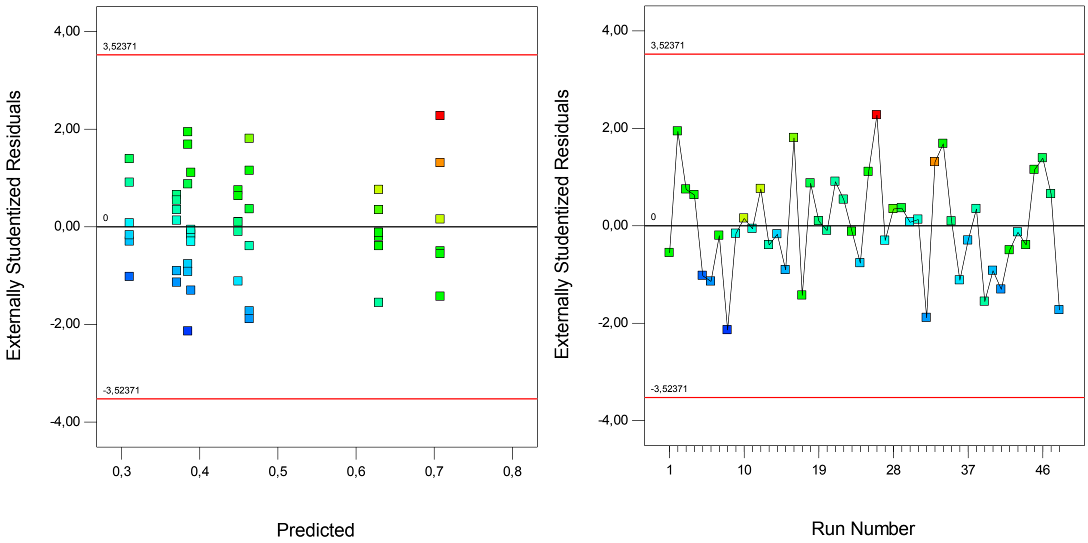

Fig. 5. (a) Residuals vs predicted (b) Residuals vs runs.

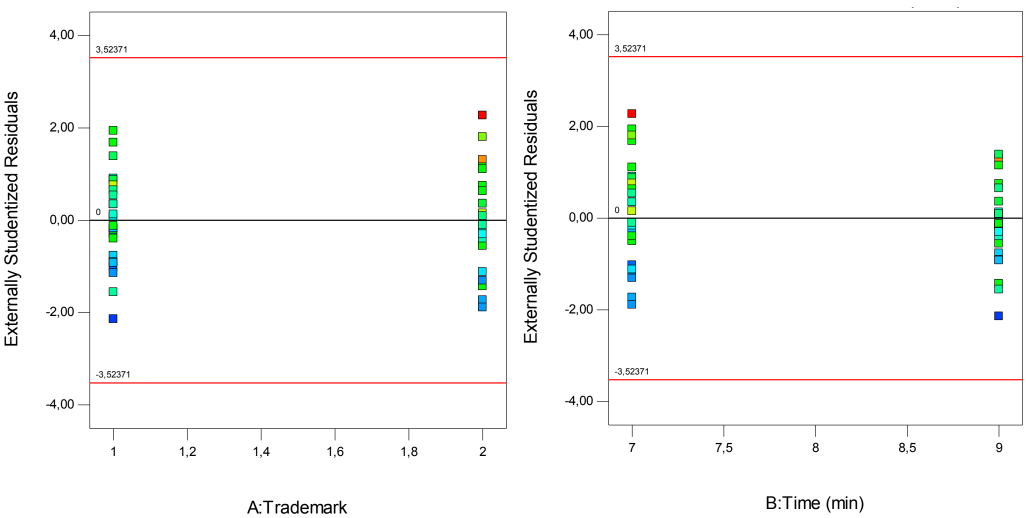

Fig. 6. (a) Residuals vs trademarks (b) Residuals vs frying time

Table 6. correlation between factors and output

	Trademark	Serving size	AC	ACD	Growth Rate
Trademark	1				
Serving size	0	1			
AC	0,98	0	1		
ACD	0,68	0,68	0,69	1	
Growth Rate	0,25	-0,45	0,24	-0,16	1

5. Conclusions

The present work shows the design of a 24 experiment with 5 replicates to find the significant effects in the buñuelo making process. The growth rate of the buñuelos can be affected by the trademark, in the competitive market, it can be important to understand the internal process of industry leading to better buñuelo manufacture. So, it is important the serving size, there is a major difficult to the buñuelo expansion because the trapped air needs to force a layer bigger of mass, so the mass exchange plays an important role in this process. The next step of experiment which is the design of experiment to find the optimal values of the significant factors in the process will be part of future developments.

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