Advance Journal of Food Science and Technology 5(7): 843-854, 2013
DOI:10.19026/ajfst.5.3171
ISSN: 2042-4868; e-ISSN: 2042-4876

Submitted: February 20, 2013 Accepted: March 21, 2013 Published: July 05, 2013

Research Article

Analysis and Evaluation of Cooking Parameters for Sweet Bakery Products

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Abstract: Cooking process is essential for the preparation of sweet bakery products, such as Panettone, a typical Italian seasonal dessert. This study is aimed at evaluating the features of the finished product leaving the oven chamber using the Design of Experiments technique. Four features of the product like “water activity”, “humidity”, “pH” and “sensorial judge” have been explained as functions of independent variables: recipe of the dough, affecting the dough strength and cooking process parameters, such as time, temperature and oven chamber configuration. A two-level, complete four-factor design has been used to carry out the experiments; consequently the analysis of variance has pointed out the effects of main factors and some of their interaction effects; multiple regression analysis was also carried out to explain the variability and to predict the process. The model can be profitably adopted in order to adjust the cooking process parameters in accordance to the dough recipe or the boundary cooking conditions. This study can be further developed by optimizing the input factors in order to maximize the “overall rating” response of the finished product.

Keywords: Bakery oven, cooking parameters, design of experiments, sweet bakery products

INTRODUCTION

Cooking, together with rising, is the most important phase of the bakery process, because it affects the sensorial and nutritive characteristics, appearance and shelf life of the product (Agte *et al.*, 2002). Visually, this process occurs with the increase in volume and solidification of the dough. The cooking process takes place in the oven with the development of an exothermic reaction, i.e., with production of heat, with many variables in play.

The product must appear perfectly risen and not overcook; it also should respond to visual characteristics and taste, defined on the expectations of the end customer (Purlis, 2010). These qualitative features must be connected also to an adequate production capacity, according to the type of product to be processed (Bottani and Vignali, 2011).

In the specific case we considered the bakery process of some products for seasonal recurrence (Panettone[1] and Colomba[2]), which are produced and sold in a limited period of time close respectively to Christmas and Easter. Sweet bakery products can be realized using several type of oven:

- Oven using a fuel burner, with direct flame or convection heating.
- Electric oven
- Microwave oven
- Mixed oven, adopting different kind of energy

Rotary ovens could be also adopted, nevertheless their use is not useful for an industrial production. Among these, tunnel oven with gas convection heating is the mainly adopted in the industrial process for cooking sweet bakery products (Xue *et al.*, 2004).

The cooking process of bakery products has been described in detail by several authors by means of analytical models (Demirkol *et al.*, 2006a, b; Sosa-Morales *et al.*, 2005; Zareifard *et al.*, 2006), or thanks to numerical Computational Fluid Dynamics (CFD) modeling of the phenomenon (Therdthai *et al.*, 2004; Wong *et al.*, 2006, 2007; Williamson and Wilson, 2008; Purlis and Salvadori, 2009; Navaneethakrishnan *et al.*, 2010). All these models have the purpose of analyze and optimize the heat transfer inside the product, based on what has been found in previous experimental campaigns or from specific literature for bread or other baked goods (Demirkol *et al.*, 2006c).

Other studies instead aim evaluating through experimental tests, how the properties of the cooked product change in function of the main process parameters. Tests have been performed on bakery products like sponge cakes (Grau *et al.*, 1999) and baked white layer cake (Bilgen *et al.*, 2004), analyzing different sensorial and chemical parameters of the products.

On the basis of these latter works, the objective of the present study is the assessment of the correlation between the features of the finished product, like “water activity”, “humidity”, “pH” and “sensorial judge” and the parameters governing the cooking process, such as

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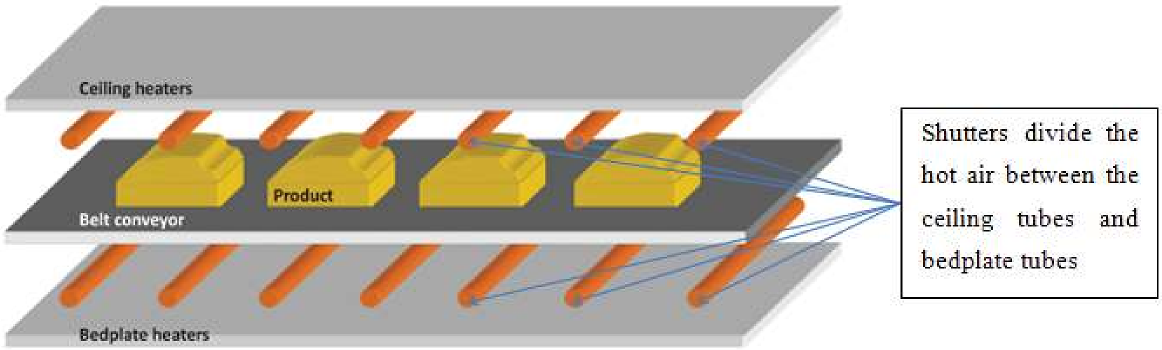

Fig. 1: Oven schema

Table 1: Final composition of the dough for the analyzed product (Panettone)

Ingredient	(%)
WeatFlour	32.6
Anhydrous butter	21.4
Eggs	20.4
Sugar	18.4
Liquid milk	3.30
Natural yeast	2.00
Cacao butter	0.50
Salt	0.50
Monodiglycerides	0.50
Compressed yeast	0.40[1]
Total	100.0

[1]: According to The New Regulations of the Ministry of Industry (DM July 22, 2005)

time, temperature and oven chamber configuration. The study focuses on the design and subsequent analysis of experimental tests, with the purpose of understanding the link between the goodness of the finished product and the cooking conditions. In order to reach this aim, an experimental campaign has been carried out only on classic Panettone product. A further development of the project could encompass other analysis on different types of recurrence cooking products, to assess the differences among them.

MATERIALS AND METHODS

Materials and tested product: The analysis of the baking process was carried out exclusively on the classic Panettone, whose number of doughs, made at the same time, is equal to a variable number from 2 to 3. The composition of the product before the final phase of rising and baking is shown in Table 1, in which does not appear the indication of raisins and candied citrus peel that will be added at the final dough composition.

Equipment details: The analyzed oven uses a gas thermal cycle with indirect convection (www. imaforni.com) and it is composed by:

- Rising compartment with carousel
- Oven chamber equipped with two heaters (ceiling and bedplate) independently adjustable
- Carousel for the cooling of the product

Each product can be cooked receiving heat from below (the area known as the bedplate) or above (the area known as ceiling), or both, according to the distribution and the amount of heat required for the specific product. To adjust the process, the oven has therefore different set point temperatures in the two cooking zones. In the first zone, the oven reaches a temperature of 170-175 Celsius degrees, while in the second zone the temperature rises to 175-180 Celsius degrees. To facilitate the transfer of the heat coming from the bedplate to the product, the used conveyor belt has several metal bars provided with holes. It is possible to separate the hot air flow between ceiling and bedplate tubes thanks to shutter positioned in the returned manifold (Fig. 1). The average temperature of the oven is monitored and any variation is reported on an external control panel. Each oven is also equipped with small openings for the visual inspection of the product during cooking.

The doughs are put into the oven using a robot for aligning the molds on the conveyor of the oven; in case of misplacement some operators manually correct the dough alignment. The same operators spray sugar and water on the loaf to give shine or brush it with egg to enhance browning, if required by the recipe.

The oven is managed by a PLC (Programmable Logic Controller) and controlled through a control panel on which are currently stored three recipes for main references (Panettone normal and high, plus another typical recipe of the company). For each recipe there is a set of parameters enabling automated management of baking and cooking processes.

The objective of the experimental phase will then find the most appropriate set of parameters to optimize the cooking process. The above described technology is thus aimed at reached the best consumer judgment on the product thanks to:

- Retaining greater humidity inside the product: increasing the amount of bound water, which therefore, doesn't have to evaporate over time

- Reducing water activity: peculiarity that allows the product to maintain good organoleptic characteristics throughout its shelf life

Methods: The purpose of this study wants to be achieved by means of two series of experimental tests performed on the Panettone:

Tests for the set-up of the line: Designed to evaluate the possibility of adjusting the cooking parameters suggested by the supplier of the plant.

Tests for the process analysis: The parameters were varied simultaneously, using specific factorial designs.

The first set of tests has been made to analyze the characteristics of the plant, testing the features of the parameters, which can be set with the new configuration and same types of adjustment.

These first experimental tests during the starting phase of the oven, referred to the classical Panettone recipe (1 kg), have been especially performed in order to determine the range of variation of the process parameters. This preliminary study of the oven shows that the parameters mainly influencing the cooking process of the product are:

- **Temperature [T]:** The mean temperature of the cooking chamber is controlled automatically by means of a temperature controller and a thermocouple placed inside the cooking chamber. The temperature sensor is used by the controller to monitor the chamber temperature and to drive the burner accordingly in order to maintain the set point value. Any over temperature activates light and audible alarm; moreover, in the case of extremely high temperatures, the burner is switched off
- **Cooking time [τ]:** It depends on the speed of the conveyor belt, which is set by a potentiometer installed on the control panel of the conveyor and acts directly on the motor speed. The operator, depending on the recipe to be performed, can vary the speed of the conveyor and thus increasing or decreasing the cooking time
- **Position of the shutters [S]:** the amount of combustion gases is distributed across the ceiling and the bedplate thanks to two shutters placed on the return manifold. Modifying the position of the shutters from open to close it is possible to decrease the flow of fumes inside the bedplate heating pipes, thus varying the distribution of heat between ceiling and bedplate
- **Steam flow rate to extract [Q_s]:** The extraction system of the steam is forced and consists of a series of outlets of variable section located in the upper part of each cooking chamber. The outlets are connected to a duct, through which the steam is conveyed to an extraction chimney with regulation shutter and fan. After the exit of product from the cooking chamber, an additional fan on the final suction hood collects the residual steam and avoids leaking of product's gases in the working environment
- **Dough strength [W]:** This factor represents the rising capability of a specific kind of flour in a dough, tested in different conditions as reported in Table 2. This property is related to the content of proteins, in particular of gliadin and glutenin, which together comprise the gluten (Metakovsky *et al*., 1997). Stronger flours tend to absorb a greater quantity of water in the mixture and make it more resistant and tenacious. These features allow a greater resistance to rising thanks to a more solid mesh because of gluten, thus avoiding the doughs deflation and improving the final quality of the product. The dough strength of the flour is measured by appropriate mechanical tests on the dough (extensibility and strength tests by Chopin Alveograph). The indicator W is used to classify the flours according to their dough strength (Edwards *et al*., 2007). Two different commercial formulations of flour have been used in the design of experiments.

Only the first three and the last parameter were considered for the Design of Experiments (DoE), since the extracted steam flow rate is difficult to measure due to the adjustment of the shutter, which position is thus maintained constant during the execution of the test campaigns.

After selecting the design factors of the DoE, the response variables have been identified, namely:

- **Water activity [Aw]**
- **Humidity percentage [H]**
- **Acidity [pH]**

- **Judge [J]:** A panel of experts judge the organoleptic characteristics of the product in a numerical scale from 1 to 5
- **Overall rating [O_R]:** of all the above mentioned features. This value is computed from the four previous results according to the following methodology: each output is assigned a weight that expresses the importance of the factor in a scale from 1 to 7. Output are expressed in normalized terms (percentage scale) to make results uniform and comparable. Normalization has been computed for each variable by calculating the range between

Table 2: Experiments plan

Run ID	T [°C]	τ[min]	S	W
1	170	57	1	339
2	170	60	1	375
3	175	60	1	375
4	170	57	1	375
5	170	57	-1	375
6	170	60	-1	339
7	175	60	1	339
8	175	57	-1	339
9	175	60	-1	375
10	175	60	-1	339
11	170	60	-1	375
12	175	57	1	375
13	175	57	1	339
14	170	60	1	339
15	175	57	-1	375
16	170	57	-1	339

minimum and maximum value; each value has then been subtracted from the minimum value and result was divided by the range amplitude.

Total value is calculated as a weighted average of each output value, being the weight the importance of each output.

After this preliminary stage and after a meeting with the project team, the complete DoE was planned to test all possible factors (including interactions) influencing the process. The choice of the four design factors (temperature, time, shutters' position and dough strength) is then followed by the definition of the respective ranges. In particular two levels for each factor (+ and -) are defined; these levels have been chosen properly distributed in order to avoid overlapping effects due to experimentation errors.

A preliminary series of tests has been used for the computation of the variance σ^2 of the experiment and to check the parameters' behavior, in order to use suitable factors' ranges according to the real scenario of the experiment.

The intervals for each factor are defined as it follows: 170 and 175°C for temperature; 57 and 60 min for cooking time; closed (-1) or open (+1) for shutters; 339 and 375 W for the dough strength (representing the property of two different standard flours).

A full factorial plan 2^4 with only one replication for each configuration has been designed; thus the total number of tests equals 16. After the execution of the tests, the results of the less influential factors have been discarded, increasing the number of degrees of freedom of the error in order to assess the significance of the considered effects. This assumption has been taken according to the previously mentioned principle of rarity which will be then verified by observing the normalized probability graph of the effects and considering effects as significant in case they are distant from the straight line characteristic of the graph (Montgomery, 2001).

The designed plan of the experiments, reported in Table 2, is computed by means of a randomization of the design, in order to avoid a possible variation of the effect estimation due to a variation of uncontrollable factors of the process.

A series of Excel spreadsheets and the statistical software Design-Expert® have been simultaneously used to design the experiments and identify statistical relationships between variables and their interactions. The relationships explaining most of the variability of response factors have been also defined by means of regression equations.

Data analysis has been performed according to the following steps:

- **Preliminary analysis:** It qualitatively assesses if there are correlations between input parameters and response variables. Multiple scatter diagrams have been computed using Design-Expert®, in order to display the trends of individual output variables. Furthermore, for each input factor the percentage of variability is then calculated, representing the contribution of the factor to explain the variability of each individual response variable
- **Analysis of variance (ANOVA):** it identifies the most significant variables in the model, i.e. those with an associated *p-value* less than 0.05. Only these variables were considered significant to describe the cooking process

The ANOVA allows highlighting the most important factors in the model, which can explain most of the variance of the response. We consider as significant variables those which have a p-value less than 0.05, that means a probability lower than 5% of obtaining a test statistic at least as extreme as the one that was actually observed, assuming that the null hypothesis is true (Montgomery, 2001); if the value exceeds 5%, the variable can be neglected.

The ANOVA for factorial plans is computed by calculating the F value as the ratio between the mean value of the quadratic effects and the mean value of the quadratic error. As recommended by Montgomery (2001), the error is decomposed in pure error and lack of fit, the latter being introduced by the neglected effects that provide little contribution to the model. Each individual response variable was then analyzed using analysis of variance with different degrees of freedom for the model and the error; pure error is always equal to zero in the performed tests due to the absence of replications. Finally, a models adequacy check has been performed.

According to this method of analysis, the results obtained by statistical analysis of data collected are reported in the following section.

RESULTS

Experimental measurements of controlled process have been carried out by means of suitable measurement tools, as reported in the previous section,

Table 3: Data collected during test execution

Run design	T (°C)	T (min)	S	W	Aw	H (%)	pH	J	O_R
1	170	57	1	339	0.90	27.0	4.8	3	8.7450
2	170	60	1	375	0.83	25.1	4.7	3	8.2375
3	175	60	1	375	0.79	25.2	4.7	3	8.2525
4	170	57	1	375	0.85	24.8	4.9	4	8.5475
5	170	57	-1	375	0.82	24.6	4.8	5	8.8250
6	170	60	-1	339	0.89	26.0	4.8	2	8.1425
7	175	60	1	339	0.89	25.0	4.7	2	7.8775
8	175	57	-1	339	0.86	26.0	4.9	3	8.5000
9	175	60	-1	375	0.85	25.1	4.8	3	8.2575
10	175	60	-1	339	0.90	27.0	4.8	2	8.3950
11	170	60	-1	375	0.81	24.7	4.7	4	8.4825
12	175	57	1	375	0.85	24.9	4.7	4	8.5425
13	175	57	1	339	0.92	26.0	4.8	3	8.5000
14	170	60	1	339	0.86	25.0	4.8	3	8.2350
15	175	57	-1	375	0.81	25.1	4.8	4	8.5975
16	170	57	-1	339	0.85	27.0	4.7	2	8.3675

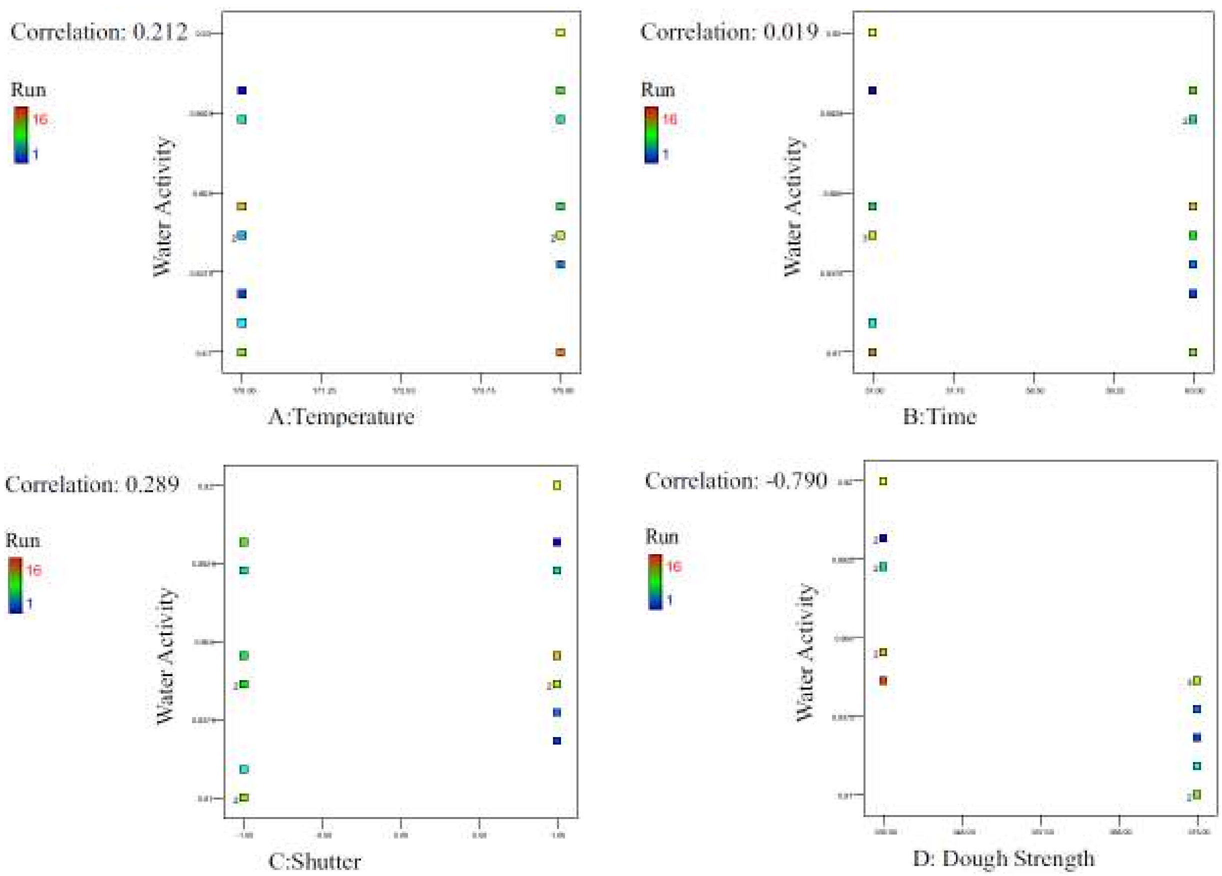

Fig. 2: Water activity plots against the four input parameters

in order to preliminary identify some possible error affecting data. The results obtained during the experiments for the considered response variables are reported in Table 3.

Dispersion diagrams and correlation coefficients: The first analysis of the results is the representation on dispersion diagrams of the response variables (water activity, moisture, acidity, judge and overall rating) depending on the four input factors: temperature, time, shutters' position and dough strength.

Figure 2 reports a sample diagram set of the performance of a single variable against the input parameters. This preliminary analysis of the results is useful for providing an overall visualization of the most significant effects (Montgomery, 2001). Thanks to this analysis it can be noticed that the value of water activity shows a strong dependence on the dough strength.

Similar plots have been computed for each response variable versus the considered factors. The plots of the variable water activity show no differences of variance among different levels of the

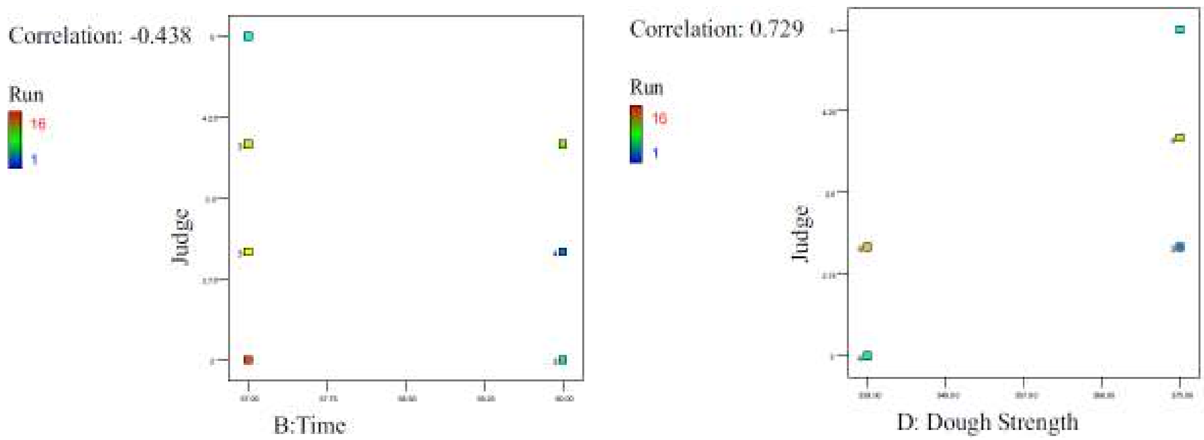

Fig. 3: Dispersion diagram rating vs; time and rating vs; dough strength

same factor, thus it is possible to assume at a glance the homogeneity of variance. The analysis of the other plots, not reported in the text, points out that the moisture percentage has a greater variance for low values of dough strength rather than higher; this phenomenon is however not very stressed so that specific evaluations are not required.

The correlation coefficient has then been computed for the variables. As far as it concerns water activity, the first three cases show that this response has low correlation coefficients with respect of temperature, time and shutters (respectively 0.212, 0.019 and 0.283), while the correlation coefficient with the dough strength this higher and equal to -0.790. The negative sign implies that the stronger flour, the smaller the amount of water remaining in the product after cooking.

"The same analysis carried out for the other response variables with respect to individual factors highlights" the strong correlation between moisture and dough strength, stronger than the correlation with temperature and time. Further consideration, reported in Fig. 3 and computed by means of Design-Expert® software, regards rating variable, which has better values if time is low (correlation equals -0.438) because of the degradation of organoleptic properties (Toledo, 1999) and even better if the dough strength is high (correlation equals 0.729).

A more detailed statistical analysis of the results is thus necessary and below reported, in order to achieve an overall assessment of each response variable.

Statistical analysis of the results: The results coming from the designed and performed experiments have been statistically analyzed; specific evaluations for each response variable were obtained adopting Design-Expert® and appropriate Excel spreadsheets.

We firstly evaluated the results regarding water activity parameter. The detected range of this response variable is between 0.81 and 0.92, with a ratio between maximum and minimum value equal to 1.1358. In this case transformation of data doesn't involve significant benefits, since the ratio is less than 3 (Montgomery, 2001).

Before carrying out the ANOVA, in Table 4 has been highlighted:

- The Standardized effect
- The Sum of the squares of the variance of the individual effect
- The Percentage of contribution of the factor to the model

According to this preliminary analysis, at this point it is possible to select the most significant factors for the data model in order to reduce the degrees of freedom of them, increasing the degrees of freedom of the internal error.

Referring to the water activity variables, the table reports the third and fourth level effects, which appear not relevant during the execution of the tests:

The main contribution is given by the dough strength (62.37%) while other significant factors are:

- Temperature: 4.49%
- Shutters: 8.37%
- Time ˙shutters: 16.36%

On the basis of this consideration it is thus possible to reduce the number of considered factors for the description of the modele evaluated by the ANOVA. The neglected factors are treated as error, increasing its degrees of freedom; it is thus possible to perform a valid analysis also for experiments that don't present replications of individual design, as the considered one, relying on the principle of rarity of effects (Montgomery, 2001).

Table 4: Evaluation of the factors' effect on the model for water activity response

Factor	Standardized effect	Sum of the squares of the variance	Contribution (%)
A Temperature	0.014000	0.000756	4.4900
B Time	0.001250	0.00000625	0.0370
C Shutters	0.019000	0.01406000	8.3700
D Dough strength	-0.05100	0.01100000	62.370
AB	0.008750	0.00030620	1.8200
AC	0.001250	$6.25 \cdot 10^{-6}$	0.0370
AD	-0.00375	$5.62 \cdot 10^{-5}$	0.3300
BC	-0.02600	0.002756	16.360
BD	-0.00125	$6.25 \cdot 10^{-6}$	0.0370
CD	0.001250	$6.25 \cdot 10^{-6}$	0.0370
ABC	-0.00375	$5.62 \cdot 10^{-5}$	0.3300
ABD	0.006250	0.0001563	0.9300
ACD	-0.00625	0.0001563	0.9300
BCD	0.011000	0.0005630	3.0100
ABCD	0.006250	0.0001563	0.9300

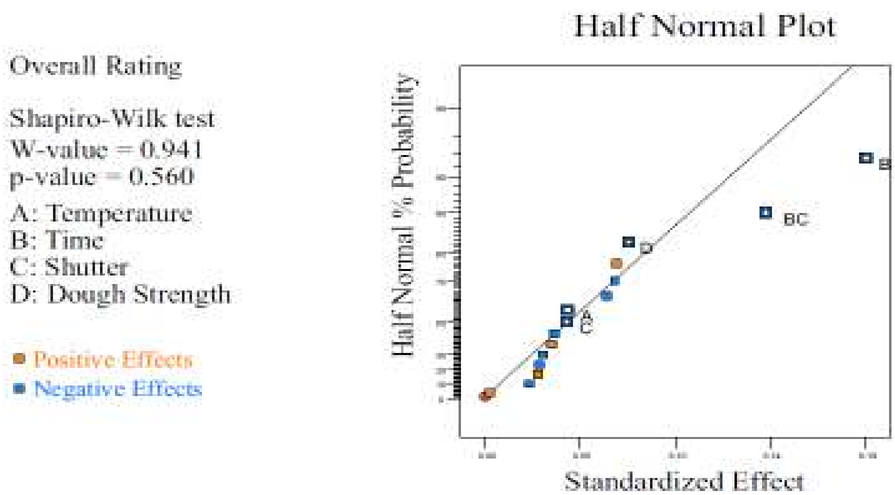

Fig. 4: Half normal probability plot for overall rating response

In the analysis of other response variables it is possible to consider different factors of first, second and third level, supporting the significance of the model. Regarding water activity, all factors of the first level and the interaction time˙shutters (BC) have been considered; regarding moisture, only the four main factors have been considered. As far as it concerns acidity (pH), four first level factors (temperature considered only within interactions due to its low contribution as singular factor) plus three second level factors (AC, AD and BD) and a third level factor (ABD) were considered. For the variable judge, in addition to the three first level factors (time, shutter and dough strength), one second level interactions was considered (BD). The evaluation of the overall rating response variable has been done taking into account all first level factors and the interaction BC time shutters. This specific case is reported in Fig. 4 showing the half normal plot of effects; this graph, computed by Design-Expert® software, shows the most relevant effects as those more distant from the line (Daniel, 1959).

The analysis of variance (ANOVA) is thus restricted to models encompassing the most significant effects.

ANOVA and regression analysis: The results obtained by the ANOVA for all the response variables (Aw, H, pH, J, O_R) confirm the significance of the simplified models previously proposed. Nevertheless, not all the factors are significant to the model, since different behaviors, depending on the response variable tested, can be noticed. The results in Table 5, related to water activity response, show that time does not affect significantly this variable, according to the predefined levels (57 min and 60 min).

For each analysis of variance, some indicators of the reliability of the regression model are computed, such

$$R^2 = \frac{SS_{model}}{SS_{total}}$$

measuring the part of the total variance explained by the model. As reported by Montgomery (2001), a common problem of this statistical model is that its reliability is "affected by the number of variables present, increasing with the number of them".

Table 5: ANOVA for water activity

Source	Sum of squares	d.f	Mean square	F value	p-value
Model	0.015	5	$3.086 \cdot 10^{-3}$	21.85	< 0.0001
A Temperature	$7.563 \cdot 10^{-4}$	1	$7.563 \cdot 10^{-4}$	5.350	0.0432
B Time	$6.250 \cdot 10^{-6}$	1	$6.250 \cdot 10^{-6}$	0.044	0.8376
C Shutters	$1.406 \cdot 10^{-3}$	1	$1.406 \cdot 10^{-3}$	9.960	0.0102
D Dough strength	0.011	1	0.011	74.38	<0.0001
BC	$2.756 \cdot 10^{-3}$	1	$2.756 \cdot 10^{-3}$	19.51	0.0013
Residual	$1.412 \cdot 10^{-3}$	10	$1.412 \cdot 10^{-4}$		
Total	0.017	15			

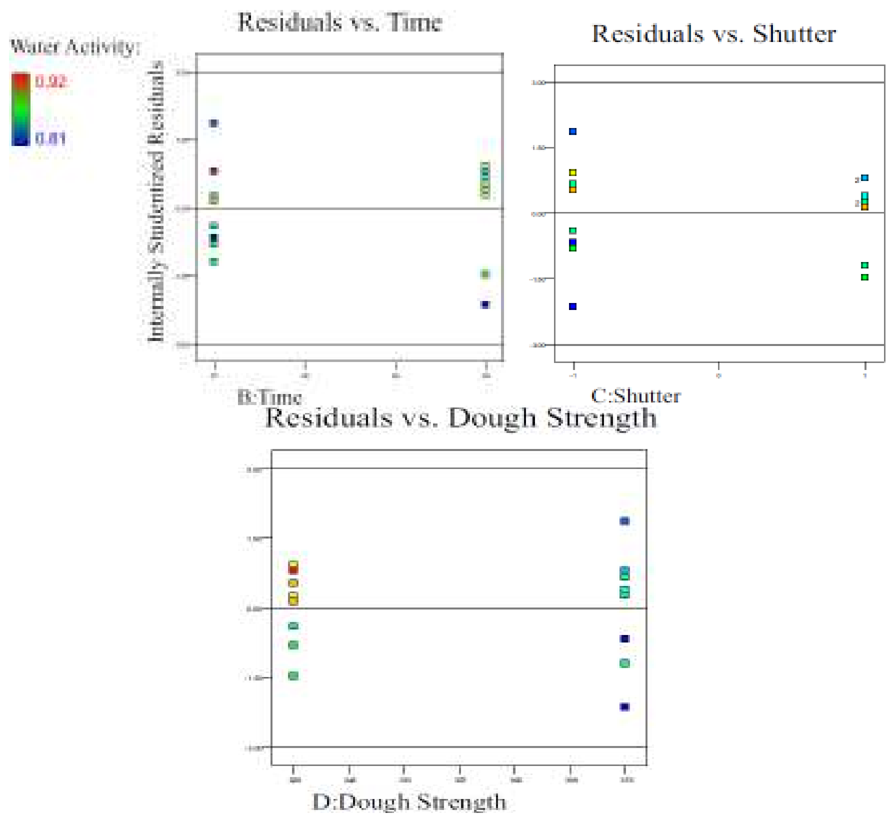

Fig. 5: Residual plots for water activity

In order to understand how the adopted model explains variability, corrected R^2 is reported, being equal to

$$R^2_{Adj} = 1 - \frac{SS_E / df_E}{SS_{total} / df_{total}}$$

Another parameter

$$R^2_{pred} = 1 - \frac{PRESS}{SS_{total}}$$

is considered, which show how the model explains the variability due to the introduction of new data. The Prediction Error Sum of Squares (*PRESS*) represents the sum of the squares of the forecast error and estimate how the experimental model provides accurate forecast in a new experiment.

These values make the authors understand whether the model can explain all the variability or if it is too simplified, although is significant in the ANOVA.

The proposed model has an R^2 of 0.9477 and a R^2_{Adj} of 0.8692; the predicted value of R^2 equals 0.6280 with a PRESS equal to 0.13.

These values confirm the validity of the proposed model, with a value of R^2_{Adj} comparable with other experiments (Banooni *et al*., 2008); the same validity can be observed for other response variables showing R^2_{Adj} values of 0.87 for water activity and 0.68 for judge.

A regression model was also built in Excel considering interactions and eliminating irrelevant factors for the ANOVA; as previously mentioned only 3 of the first level factors have been included, since they are significant or involved in interactions. The factors involved are: time (significant in interactions), shutters, dough strength, time ·shutters.

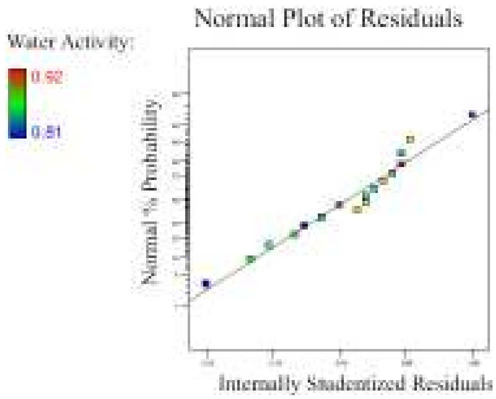

Fig. 6: Normal probability plot for water activity

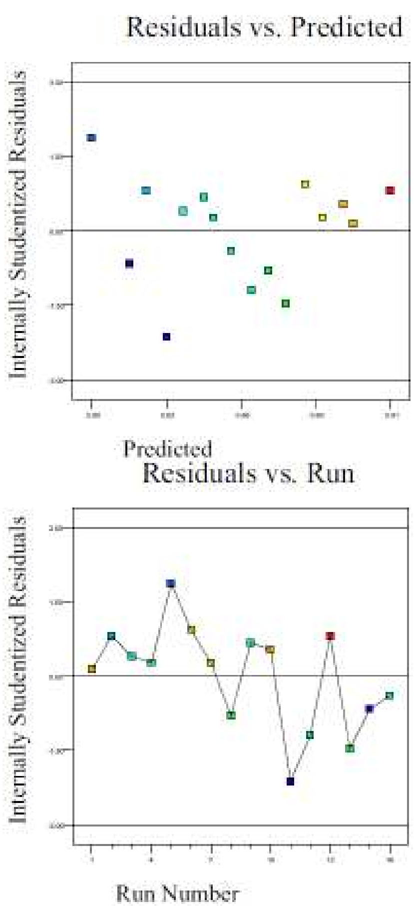

Fig. 7: Residual plots against predicted values and test runs

Since all input variables are significant except the time, in a further development of the model this variable will be neglected as standalone factor in order to simplify as much as possible the regression model.

This operation is not feasible in Design-Expert® because time is also used in the interaction time·shutters, thus Excel has been used. The regression equation is then:

$$Aw = 1.523 + 0.64 \cdot S - 0.001 \cdot W - 0.011 \cdot \tau \cdot S \quad (1)$$

This equation matches better the behavior of the system than the equation with only main factors, although it doesn't consider all the factors and their interactions.

The regression equations obtained for the other response variables are:

$$H = 42.48 + 2.5 \cdot 10^{-3} \cdot T - 0.096 \cdot \tau - 0.156 \cdot S - 0.033 \cdot W \quad (2)$$

$$pH = -2{,}022.21 + 11.701 \cdot T + 34.361 \cdot \tau + 2.575 \cdot S + 5.68 \cdot W - 0.198 \cdot T \cdot \tau - 0.015 \cdot T \cdot S - 0.033 \cdot T \cdot W - 0.096 \cdot \tau \cdot W + 5.555 \cdot 10^{-4} \cdot T \cdot \tau \cdot W \quad (3)$$

$$J = 4.958 \cdot S - 0.25 \cdot \tau + 0.034 \cdot W - 0.134 \cdot S \cdot W \quad (4)$$

$$O_R = 6.342 - 8.346 \cdot 10^{-3} \cdot T - 0.064 \cdot \tau + 2.755 \cdot S - 2.027 \cdot 10^{-3} \cdot W - 0.047 \cdot \tau \cdot S \quad (5)$$

The pH acidity equation is very complex because to validate the model we have also considered a significant interaction of the third level; thus the expression of acidity as a function of the factors it is not appropriate.

Model adequacy checking: In order to verify how the proposed model matches the behavior of the response variables, it is necessary to perform a series of tests concerning residue analysis as described above in paragraph 2.2. To this extent, residual plots of the different runs have been charted; the results are generally good and don't show particular patterns, thus the homoscedasticity of residuals is verified, i.e., they maintain the same variance and errors are independent.

The plots in Fig. 5 show the graphs of the residuals in the assessment of the water activity with respect to considered factors, while Fig. 6 reports the normal probability plot.

No anomalous trends are shown in the normal probability plot, so transformation of the data is not required. Figure 7 shows the residual plots against predicted values and different test runs, even for water activity response variable.

Since the match tests are satisfied, the model appears suitable for the water activity and likely for all the other factors. The stepped trends of acidity, judge and humidity are caused by the few discrete values of the analyzed variables.

The analyses have been carried out in Excel and in Design-Expert®, both showing the same results. Design-Expert® has however other specific functions such as Box Plot to verify the need for data transformation; it is thus particularly useful in such analysis in order to significantly reduce analysis time.

DISCUSSION

ANOVA and regression analysis performed have showed interesting results. The main aspect of variance for each response variables is due to the dough strength. If we have flour with the higher level of dough strength, we obtain a better sweet bakery products respect to every response variables. Time also is relevant for the sensorial judge of the product (57min are better than 60min), but not significant for the pH, water activity and humidity. Temperature of the oven, in the considered range (170 to 175°C) impacts only on the water activity, showing at higher temperature a higher value of water activity.

The shutters' position becomes important only to define the activity water of the products, although it is involved many times in interactions. If the shutters are closed (-1) the flow of hot air not recirculate in the bedplates tubes and so the mean temperature of the oven is reached thanks to a major contribution of heat from ceiling. Results show also a possible but not statistically significant improvement of the overall rating if the shutters are closed (correlation of -0.324). Thanks to Design-Expert® software it is possible plot the interactions between two factors; the following Fig. 8, 9 and 10 report some significant interactions regarding the positions of shutters, referred to an average value of the other factors not involved in the graph.

As can be seen from Fig. 8, water activity increases with the time if the shutters are closed and decreases if they are open. This significant interaction involving shutters and time is also described in Fig. 10, where it can be observed how shutters and time are inversely related with respect to overall rating variable. Moreover the judgments on the sensorial quality of the products improve if the shutter is in a lower position with a weaker dough, instead they decrease if it is used a stronger dough.

This means that open shutters (+1) allow a not uniform temperature inside the product, so the lower part presents a crust while the upper one is not perfectly cooked; this effect is particularly stressed if time is higher. If shutters are closed (-1) the product cooks in homogenous way and the results is better with a lower time.

CONCLUSION AND FUTURE RESEARCHES

The analysis of the cooking process by means of DoE methodology enables the development of a mathematical regression model that can predict the variables activity water, acidity, humidity, judge and overall rating of the finished product according to the cooking parameters.

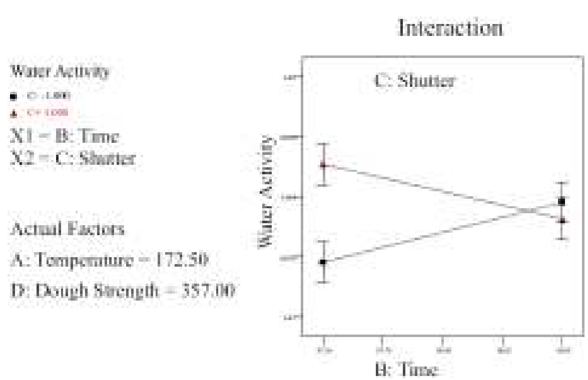

Fig. 8: Time-shutters interaction against water activity

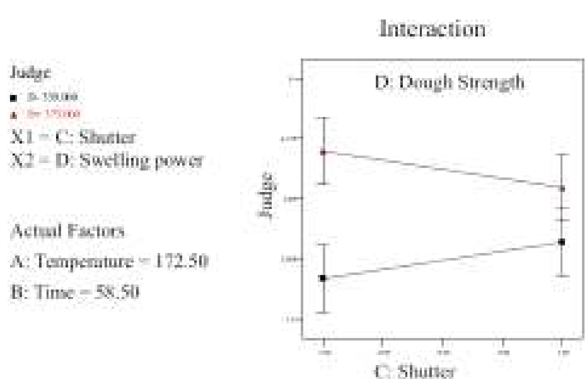

Fig. 9: Shutters- dough strength interaction against judge

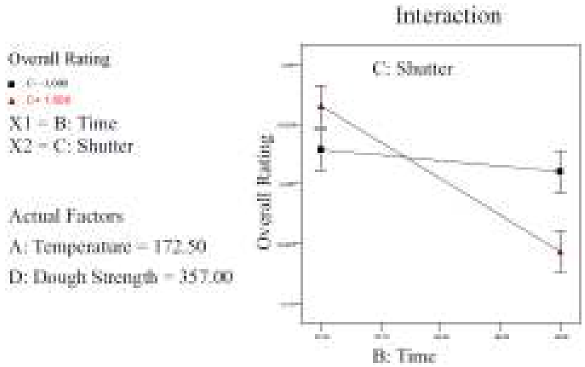

Fig. 10: Time-shutters interaction against overall rating

The careful design of the experimental campaign and the statistical analysis of the results clarify some technological issues previously discussed and help to highlight some conclusions about the considered process such as:

- Some response variables, such as acidity, don't depend on the cooking process, but are intrinsic features of the product: the acidity value depends only on the recipe and the features of some used ingredients.
- The variable needing more accurate monitoring is the sensorial judge, as both the rising and cooking processes influence it. The introduction of a dynamic rising cell could bring to better product, since the final phase of the rising takes place during the cooking process. The position of the shutters may enhance some visual and organoleptic features of the product and interact with the factor dough strength.
- An accurate check of raw materials is required. The product being worked is alive, because of the chemical reactions among its ingredients. Kneading and rising processes develop the texture and the organoleptic properties of the product. It has been seen that dough strength affects significantly the judge response, as well as the water activity and humidity percentage.
- Technological innovation introduced in the oven allows obtaining a good product with lower cooking temperature and time. Time in particular appears to be more significant than temperature (between the considered values) in explaining the qualitative properties of the product.

The abovementioned considerations were obtained analyzing the results of the tested runs; increasing the number of runs it is possible to improve the estimation accuracy of the parameters involved in the process; the same improvement can be achieved by increasing the number of levels of input factors driving the process.

Both improvements require more resources, which the industry carefully spends; consequently the industrial management particularly appreciates an experimental strategy mainly oriented to the reduction of testing costs rather than to the increase of analysis accuracy.

Other possible analyses, not addressed by this study, exploit the block-tests: they can better highlight the latent factors that affect the process and that are not controllable.

The results obtained with this experimental campaign can be represent as a source of data set in order to apply a further analysis adopting the principles of numerical optimization thanks to the use of response surface methodology.

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End note:

1: Typical Christmas cake from Milan made from flour, butter, eggs and sugar, with candied citron and sultanas.

2: Easter cake baked in the shape of a dove.