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New control method for the industrial process of cookies manufacturing

Nuevo método de control para el proceso industrial de fabricación de galletas

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Abstract: The Biostructured Process Control Method (BCPM) is a new method similar to the Balance Score Card dashboard with a quantitative control based on compliance with standards which was applied in the industrial manufacture of cookies. The control biostructure, designed considering the characteristics of the process, was made up of five sub-processes (mixing, molding, baking, sandwiching and packaging) and three sub-processes as part of the mixing sub-process; also, 16 control parameters were identified. Control variable data were evaluated over a five-month period. The control was performed according to the efficacies of the sub-processes and control variables, for which target values were set. During the evaluation period, the process achieved between 95% and 98.1% of efficacy, as the company required 95% to meet internal standard. Opportunities for improvement were identified in sub-processes with lower efficacies. This method can be applied in the food industry to identify deficiencies in production processes.

Key words: Biostructured Process Control Method; Cookies company; Efficacy; Food industry; Process control; Productivity.

Resumen: El Método de Control Bioestructurado de Procesos (MCBP) es un nuevo método similar a un tablero de mando como el *Balance Score Card*, con un control cuantitativo en base al cumplimiento de estándares, el cual se aplicó en la fabricación industrial de galletas. La bioestructura de control, diseñada considerando las características del proceso, estuvo conformada por cinco subprocesos (mezcla, moldeo, horneado, emparedado y empaquetado) y tres subprocesos como parte del subproceso mezcla; asimismo, se identificaron 16 parámetros de control. Fueron evaluados los datos de variables de control de un periodo de cinco meses. El control se realizó en función de las eficacias de los subprocesos y variables de control, para lo que se fijaron valores meta. En el periodo de evaluación, el proceso alcanzó entre 95% y 98.1% de eficacia, siendo lo exigido por la empresa 95% como norma interna. Se detectaron oportunidades de mejora en los subprocesos que presentaron eficacias menores. El método puede ser aplicado en la industria alimentaria para identificar deficiencias en procesos productivos.

Palabras clave: Control de Procesos Eficacia; Empresa galletera; Industria de Alimentos; Método de Control Bioestructurado de Procesos; Productividad.

Introduction

In Peru, bakery production was increased by 11.31% in 2019 compared to the previous year, due to increased production of cakes and cookies for domestic and external market (Bolivia, Chile, Ecuador and Mexico) (INEI, 2019); with 54 thousand tons exported (AGRODATA PERU, 2020). A single plant produces 50 thousand tons of cookies per year, exporting 60% of its production to 20 countries in Latin America (Perú Retail, 2019) while 14.7% of Peruvian families consume cookies (Mercados y Regiones, 2019).

Control systems are found in all types of applications, both in chemical and food process industry (Adam, 2020). Statistical processes control (SPC) it is a widely used tool in the control of unit operations in the food industry (Guevara-Guevara and Alarcón-Rivera, 2017; Ferrel-Espinoza, 2016), however they are only limited to specific unit operations, for example: net weight, temperature but no to analysis of the entire system. Cookies manufacturing process is complex because of the nature and interrelation of the sub-processes that form it (Manley, 1989; Cerón-Cardenas *et al.*, 2014; Aristizábal *et al.*, 2017). The impact of having a sub-process out of control directly affects the quality of the final product and hence, an effective tool that facilitates the integrated control of all of the sub-processes involved in the manufacture of food is necessary, in this case for cookies manufacturing, that produce information for the improvement of the manufacturing process (Manley, 1989; Freisleben and Strelen, 1995; Realyvásquez *et al.*, 2018).

A new process control method was applied in the manufacture of cookies at an industrial level that was developed for the quality management of university academic processes (Ureña, 2011), such as training a student, doing research, among others, which are made up of several sub-processes that in turn have others that make them up, generating a very complex process structure for their control (UNSAAC, 2016). The method uses a calculation matrix structured like a biological system (organs, tissues and cells), where the efficacy of a process is the average of the efficacies of the subprocesses that compose it, establishing a control chain. This is how the Biostructured Process Control Method (BPCM) was born (Ureña, 2009). The objective of the research was to demonstrate the usefulness of the BPCM in the industrial manufacture of cooking.

Material and methods

The present study was carried out in a large national bakery manufacturing company located in the city of Lima. Data from five months of 2016 of cookie manufacturing, from the line E that produced 25% of the company's total production, were used for the design and application of the BPCM (Table 1). For its implementation, data were taken through an online registration system, where the values of the controls carried out were recorded according to the frequency required in the product specifications and detailed the following: the process, the author of the record, the value obtained, the time and the date (Table 2). The number of samples taken was a function of the sampling frequency for each control variable evaluated (Table 3).

Table 1. Distribution of the total production of the company by production lines (2016).

	Production Lines							
	A	B	C	D	E	F	G	Total
% of total annual production	12	12	13	12	25	11	15	100
Tonnes per year	48	48	52	48	100	44	60	400
Family of Products per line	2	2	3	4	5	3	3	

Table 2. Total production 2016.

Month	Cookies (tonne/ month)	#Shifts	Batches	Production hours
June	1 003	50	562	401
July	890	45	499	356
August	980	49	549	392
September	748	37	419	300
October	1 018	51	571	408

Table 3. Number of samples per batch for each control variable evaluated.

Variable	Number of samples
First stage (minutes)	2600
kg of water	2600
kg of ammonium bicarbonate	2600
Second stage (minutes)	2600
Third stage (minutes)	2600
kg of sodium bicarbonate	2600
Temperature of dough (°C)	2600
Dough pH	2600
Dough weight (g)	2600
Cookie weight (g)	2600
Moisture (%)	2600
Cookie height (mm)	2600
Cookie pH	2600
Crème weight (g)	2600
Sandwich height (mm)	2600
Net weight (g)	1857

Description of implementation phase.

In Figure 1, the scheme of the phases of the application of the BPCM is explained.

Study of the cookie manufacturing process: Characteristics of cookie manufacturing process were identified: raw material, inputs, processes, equipment and final product, as well as quality control standards. The personnel responsible for its execution were interviewed to deepen the knowledge of its execution with and without processing and quality problems.

Design of the control biostructure. Once the characteristics of the cookies manufacturing process were known, based on the functional analogy with a biological structure (Table 4), the control biostructure was generated (Table 5), in

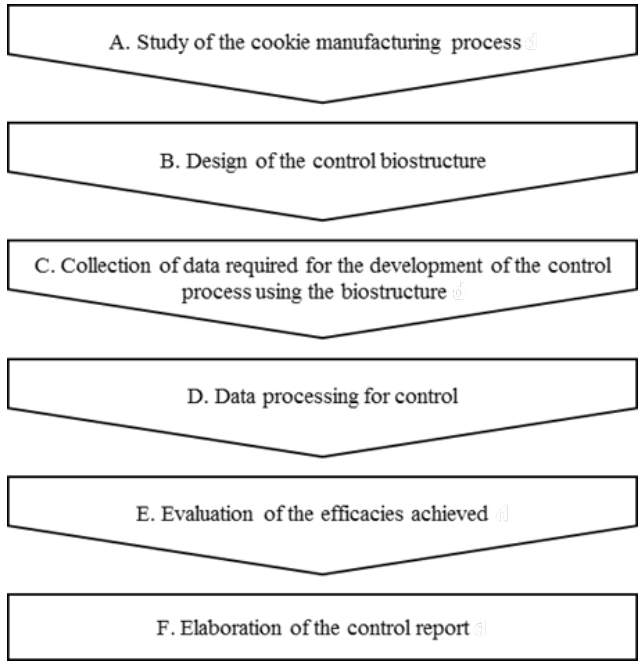

Figure 1. Scheme of the phases of the application of the BPCM.

which the process is observed at level 0, below the level 1 sub-processes that make it up, the level 2 sub-processes that make up level 1, and the level 3 sub-processes that make up level 2.

Collection of data required for the development of the control process using the biostructure. At this stage the main control variables were identified and historical data was collected from them for five months of production. The data collected by production batch was recorded in a calculation matrix for processing (Table 6).

Data processing for control. Table 6 shows the matrix for calculating the efficacies in the biostructure. Ev (Efficacy per variable) is the calculated efficacy for the variable of a sub-process that has a value of 100% if Ov (Observed value of the variable) is equal to Tv (Tarjet value of the variable). Lv is the critical lower limit of the control range, it is the minimum value that the control variable reached in the five months of production evaluated. The same applies to the critical upper limit (Uv). The target value (Tv), as a standard of the control variable, is set for the process to be carried out correctly. Ov is the value that the control variable takes during the execution of the process. Av is the average of the

Table 4. Functional analogy of the respiratory system with the selected process.

Biological structure	Biostructure	
	Process	Level
Respiratory system	Process level 0	0
Organ (Lung)	Sub-process level 1	1
Tissue	Sub-process level 2	2
Cell	Sub-process level 3	3

Table 5. Biostructure of a selected process.

Level	Process	Code
0	Process level 0	C00-000
1	Sub-process level 1	C00-100
2	Sub-process level 2	C00-110
3	Sub-process level 3	C00-111

Table 6. Matrix for calculating efficacies in the biostructure.

Elements for calculating efficacies in the biostructure *

Cv	LV	TV	UV	OV	EV	AV	A3	A2	A1	A0
C1									1(1)	1(0)
C1									2(1)	
C1								4(2)	3(1)	
C2										
C3										
C1							6(3)	5(2)		
C2										
C1							7(3)			

*Elements for calculating efficacies in the biostructure: CV: Control variable; LV: Lower target value; TV: Target value; UV: Upper target value; OV: Observed value; EV: Efficacy of variables; AV: Average efficacy of variables; A(level): Average efficacy of processes of the level 3, 2, 1 y 0. (Ureña, 2009)

Table 7. Matrix of process evaluation in the biostructure.

Elements of the biostructure *

P_0	P_1	P_2	P_3	C_V	E_V	A_V	A_3	A_2	A_1	A_0
$1_{(0)}$	$1_{(1)}$			C_1					$1_{(1)}$	$1_{(0)}$
	$2_{(1)}$			C_1					$2_{(1)}$	
	$3_{(1)}$	$4_{(2)}$		C_1				$4_{(2)}$	$3_{(1)}$	
				C_2						
				C_3						
		$5_{(2)}$	$6_{(3)}$	C_1			$6_{(3)}$	$5_{(2)}$		
				C_2						
			$7_{(3)}$	C_1			$7_{(3)}$			

*Elements of the biostructure: P(level): Process; CV: Control variable; EV: Efficacy of variables; AV: Average efficacy of variables; A(level): Average efficacy of processes of the level 3, 2, 1 y 0 (Ureña, 2009)

Ev values in each sub-process. Process efficacy (A0) is the average of the efficacies of the level 1 sub-processes (A1, A2 and A3). A1, A2, A4, A6 and A7 have the same corresponding Av value. A3 is the average of the efficacies of the level 2 sub-processes.

Efficacy was measured using the values Ov the control variables of the process in relation to those established as a target value (Bouza, 2000; Montero-Vega *et al.* 2013; García-Torres, 2018), applying the matrix in Table 7 and the following efficacy (Equation 1).

$$Ev = 1 - \left|\frac{Tv - Ov}{Tv}\right| \times 100 \qquad \text{(Eq. 1)}$$

Where: Ev = Efficacy per variable/sub-process/process; Tv = Target value of the variable; Ov = Observed value of the variable.

Evaluation of the processes of the biostructure. As only what can be measured can be controlled, the evaluation of the processes was carried out based on the analysis of the values reached in the control variables (Ureña, 2009). Table 7 shows the elements of the biostructure assessment matrix. The column of Control variables (Cv), the values corresponding to the variables of each sub-process are placed. P(0) is the process located at zero level of the biostructure. P(1), P(2) and P(3) are sub-processes of each level. Ev is the efficacy calculated for the variable. Av is the average efficacy of the control variables and A3, A2, A1 and A0 of the processes. In this case, the biostructure corresponds to a process with seven sub-processes: at level 1 it has three, of which two are not made up of other sub-processes; at level 2 it has two, of which one is made up of two sub-processes. Sub-processes 1, 2 and 7 have only one control variable, sub-processes 6 and 4 have two and three, respectively.

Results and discussion

After identifying the processes that are carried out in the company, manufacturing was recognized as the main process. The production area is divided into seven lines (Table1). Each one is assigned to the production of a group of products whose manufacturing processes are similar. For the purposes of this research, the most representative product was chosen by volume of production: cream-filled cookies representing 25% of the total annual volume produced.

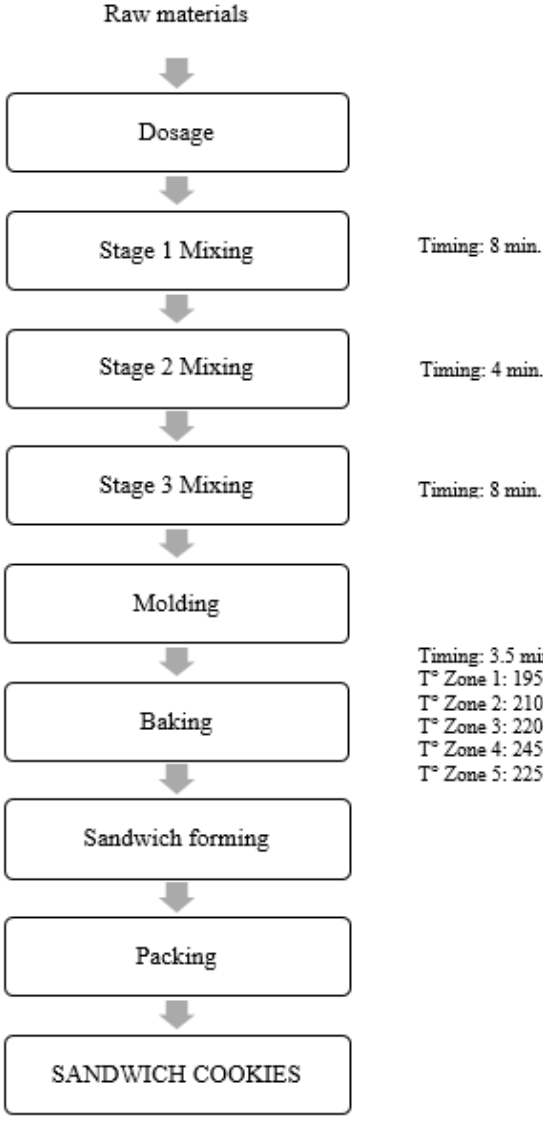

Figure 2. Process flow diagram of sandwich cookies.

The process of making sandwich-type cookies filled with cream is followed according to the process flow diagram presented in Figure 2. Throughout the process, different controls considered critical were undertaken to obtain the desired final characteristics in the product. These controls were applied to guarantee the quality of the final product, as well as the characteristics of the product that the consumer expects to obtain and are governed by limits described in the manufacturing specifications shown in Table 8.

Table 8. Critical specification limits for control variables of the sandwich cookie manufacturing process.

Sub-process level		Control variable	LV*	TV*	UTV*
1	2				
Dosage		Uncritical	-	-	-
Mixing	Stage 1	Mixing Time Stage 1 (min)	-	8.0	-
		Water weight (kg)	70.0	80.0	90.0
		Ammonium bicarbonate weight (kg)	6.0	7.0	8.0
	Stage 2	Mixing Time Stage 2 (min)	-	4.0	-
		Mixing Time Stage 3 (min)	-	8.0	-
	Stage 3	Sodium bicarbonate weight (kg)	7.0	8.0	9.0
		Dough temperature (°C)	28.0	30.0	32.0
		Dough pH	7.5	8.0	8.5
Molding		Dough weight (g)	34.0	36.0	38.0
		Cookie weight (g)	31.0	32.0	33.0
Baking		Moisture (%)	2.0	2.3	2.6
		Height (mm)	45.0	47.0	49.0
		Cookie pH	8.0	8.5	9.0
Sandwich forming		Filling weight (g)	9.4	10.4	11.4
		Sandwich Height (mm)	46.0	47.0	48.0
Packing		Net weight (g)	35.0	36.0	37.0

*LV: Lower target value; *TV: Target value; *UTV: Upper target value.

The mixing operation was carried out in three stages: the first stage is known as creaming, in which minor ingredients and sugar are added; the second stage is for the addition of the major ingredients and the final stage is where the flour is added. Each of them has different mixing times. The control of this variable is performed by the shift operator and is recorded once per product batch. When mixed, the amounts of water, sodium and ammonium are controlled because they have variation ranges.

In moulding, the dough weight is controlled after passing through the mould. Taking care that the dough weight is within the specified range guarantees the control of this parameter in later stages. This variable is recorded by the operator once per batch produced.

During product baking, moisture, pH, weight and height are controlled. These variables are also recorded by the oven operator once per batch. Later, in the production of the actual sandwich, the weight of the filling and the height of the sandwich are controlled once per batch by the operator. Finally, the net weight control per hour is carried out on the packaged product, which must be supported by the controls previously carried out.

In the second phase (Figure 1), the sandwich cream-filled cookie manufacturing process was assigned level zero, which is made up of the level one sub-processes: mixing, moulding, baking, sandwiching and packaging. The mixing, in turn, is made up of three level two sub-processes (stages 1, 2 and 3). No level three sub-processes were identified for this process (Table 9).

In the third phase the data was processed by batch, day, month and five months of production of 2016. In this period the process had an efficacy range of 95% to 98.1%. Table 9 shows the lowest efficacy values in the biostructure evaluation matrix for the month in which the process had the lowest efficacy value of the five months evaluated (95%); this information was used to make corrections and improve the efficacies of the control variables.

Table 10 shows the control variables that did not reach the efficacy of the standard most frequently (5 times) during five months of production of 2016: weight of the sodium bicarbonate (kg), temperature of the dough (°C) and pH of the cookies.

Table 9. Biostructure of the sandwich cream-filled cookie manufacturing process.

	Elements of the biostructure *					
Control variable	**OV**	**EV (%)**	**Av (%)**	**A2 (%)**	**A1 (%)**	**A0 (%)**
Uncritical	-	-	-	-	-	95.0
Mixing Time Stage 1 (min)	8.0	99.9	96.7	96.7	95.8	
Water weight (kg)	87.9	90.2				
Ammonium bicarbonate weight (kg)	7.0	100				
Mixing Time Stage 2 (min)	4.1	98.8	98.8	98.8		
Mixing Time Stage 3 (min)	8.0	100	92.0	92.0		
Sodium bicarbonate weight (kg)	9.5	81.3				
Dough temperature (°C)	33.9	86.9				
Dough pH	8.0	99.6				
Dough weight (g)	38.0	94.4	94.4		94.4	
Cookie weight (g)	33.0	96.9	93.4		93.4	
Moisture (%)	2.6	87.0				
Height (mm)	49.0	95.7				
Cookie pH	9.0	94.1				
Filling weight (g)	11.4	90.4	94.1		94.1	
Sandwich Height (mm)	48.0	97.9				
Net weight (g)	37.0	97.2	97.2		97.2	

Table 10. Low efficacy frequency.

Sub-processes	Control variable	Frequency (5 months)
Mixing	Water weight (kg)	1
Mixing	Sodium bicarbonate weight (kg)	5
Mixing	Dough temperature (°C)	5
Moulding	Dough weight (g)	1
Baking	Moisture (%)	2
Baking	Cookie pH	5
Sandwich forming	Filing weight (g)	1

During five months of 2016, it was important to improve the dosage of the sodium bicarbonate and the control of the temperature of the dough both in the third stage of the mixture (92% efficacy) to obtain the pH of the cookies established as standard (8.5). The weight of the sodium bicarbonate was greater than 9 kg and the temperature of the dough was greater than 32°C, which is not desirable for this type of cookie (Soronja-Simovic *et al.* 2017). Pérez-Castañeda and León-Salazar (2017) found bicarbonate added as the problem in the quality of cookies by DMAIC (Define, Measure, Analyze, Improve and Control) method. With BPCM, it was possible to identify the root causes of the lower efficacy achieved in the sub-process, however, other methods, such as statistical process control (SPC) (Pérez-Castañeda and León-Salazar, 2017) and engineering tools (Sepulveda-Veliz, 2017), do not cover and deepen in one all processes. Here is the great advantage of using this BPCM.

Also, the control variables quantity of water (87.9 kg) in the first stage of the mixture (frequency in five months one time), and humidity of the cookie (2.6%) (Kirk *et al.* 2012) in the baking (frequency in five months two times), had efficacies lower than 95%, so it can be assumed that, considering the other parameters in which the process was carried out and which are recorded in the biostructure, there is a direct relationship between both variables, the greater the amount of water added, the greater the amount of humidity present in the product.

With BPCM processes can be improved by studying their recorded data and identifying inefficacies of sub-processes and control variables. In online control, more effective monitoring can be done in real time.

Based on the results obtained, it was recommended that the company replicate the application of BPCM to all of the company's production lines. It was also recommended that a process capacity analysis method be applied in order to eliminate any deviation that could affect the calculation of efficacies.

Conclusion

The BPCM can be applied to the production process of sandwich cookies. In the biostructure the manufacture of cream-filled sandwich cookies was defined as a level zero process, made up of five level one sub-processes: mixing, moulding, baking, sandwiching and packaging, and three level two sub-processes which were the three stages of mixing.

In the five-month evaluation period, the process was between 95 and 98.1% efficacy. In the least efficacy month, the third mixing stage, identified as level 2 sub-process, reached 92% efficacy, due to the fact that its most frequent control variables obtained values lower than 95% efficacy: weight of the sodium bicarbonate (kg), temperature of the dough (°C) and pH of the cookies.

The biostructure allowed the identification of the sub-processes that caused the decrease or increase in the efficacy of the process per lot, day and month, and the control variables that caused it. It was demonstrated that both the biostructure and the documentation generated by the BPCM provide tools for control and provide a better understanding of the evaluated process: in this case, the cookie-sandwich manufacturing process.

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