Chapter 6 Design of a thermal process applied to hummus (chickpea) dip

Capítulo 6 Diseño de un proceso térmico aplicado al hummus (dip de garbanzo)

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Abstract

A thermal process was designed in three different flavors of hummus dip using the Ball method. To guarantee commercial sterility, the sustaining times of 3 and 5 min were evaluated, a thermal death time ($F_{proceso}$) greater than 2.5 min was obtained, for natural hummus (HN), with chipotle (HC) and with olives (HA), the values were 3.4, 3.4 and 2.8 min, respectively. A treatment was designed with a heating time (t_B) using $F_{proceso}$ = 2.5 min, for *Clostridium botulinum.* The experimental t_B obtained for HN, HC and HA were 14.8, 14.1 and 13.2 min, with these values were obtained the exact times of holding in the autoclave of 1.7, 1.8 and 2.6 min in HN, HC, and HA, respectively, suitable for commercial sterility. This method allowed to know the lethality of the sterilization process for hummus dip.

Thermal process, Ball´s formula method, lethality, sterilization of foods, *Clostridium botulinum*

Resumen

Se diseñó un proceso térmico en tres sabores diferentes de hummus usando el método de Ball. Para garantizar la esterilidad comercial, se evaluaron los tiempos de sostenimiento de 3 y 5 min, se obtuvo un tiempo de muerte térmica ($F_{proceso}$) mayor a 2.5 min, para hummus natural (HN), con chipotle (HC) y con aceitunas (HA), los valores fueron 3.4, 3.4 y 2.8 min, respectivamente. Se diseñó un tratamiento con un tiempo de calentamiento (t_B) utilizando $F_{proceso}$ = 2.5 min para *Clostridium botulinum.* Los t_B experimentales alcanzados para HN, HC y HA fueron de 14.8, 14.1 y 13.2 min, con estos valores se obtuvieron los tiempos exactos de retención en la autoclave de 1.7, 1.8 y 2.6 min en HN, HC y HA, respectivamente, aptos para esterilidad comercial. Este método permitió conocer la letalidad del proceso de esterilización del hummus de garbanzo.

Proceso térmico, método de Ball, letalidad, esterilización de alimentos, *Clostridium botulinum*

6.1 Introduction

Hummus is a widely consumed dip due to its nutritional profile and consumer preferences for plant-based proteins (Ahmed et al., 2020). It is made from chickpeas and sesame seeds, which are roasted and boiled to eliminate pathogens to meet food safety requirements. It is consumed fresh or refrigerated, without any extra processing or treatment, which makes it a potential source of microbial contamination and foodborne pathogens, such as *Salmonella* spp, *Listeria monocytogenes* and *Escherichia coli* (Olaimat et al., 2018). Moreover, if packaging is required to extend its shelf life, proper thermal processing must be performed to ensure that it is free of disease-transmitting microorganisms, such as Clostridium botulinum, which produces a toxin responsible for botulism.

The ideal thermal processing is one that maximizes the inactivation of harmful microorganisms and enzymes, while minimizing heat damage to nutritional and sensory parameters. Therefore, it is not an easy task since foods are complex. Its design must consider an efficient sequence of operation, which generates an economic impact in energy savings and, above all, avoids lawsuits against manufacturers for marketing products with unguaranteed commercial sterility. In addition, not only quality and safety factors must be considered, but care must be taken in the calculation of process time and temperature to avoid insufficient or excessive processing (Kubo et al., 2021).

There are several methods for analyzing thermal processes in foods, such as Bigelow, Stoforos, Stumbo and Ball's method, which allow calculating the lethality of thermal processes and treatment time (Stoforos, 2010). Previous studies of the thermal analysis of natural hummus were carried out with the Stoforos method and with the Ball method, it was found that the Ball method allows optimizing this productive process, which would generate profitability in operating costs. Therefore, based on this, in this work a thermal treatment was designed by means of mathematical procedures and thermal death kinetics of the microorganism to calculate its lethality, guaranteeing the commercial sterility of the product and prolonging its shelf life. Likewise, it was ensured that the holding times used in the autoclave reached the thermal death time of the process with respect to *Clostridium botulinum*, the microorganism of reference in sterilization processes.

6.2 Description of the method

6.2.1 Materials

The three different chickpea hummus products: natural (HN), with chipotle (HC) and with olives (HA) were provided by a local supplier in the state of Yucatan.

6.2.2 Equipment

Extech Instruments Type K thermocouples from -30 to 300 ºC were used to obtain the thermal history. The temperature data were recorded in a Datalogger, Model SDL200 (Extech Instruments). A vertical autoclave, model SM510 Yamamoto, 20 L, 105 - 123 °C and 0.18 MPa was used.

6.2.3 Thermal history

In order to find the optimum holding time, first tests were carried out with natural hummus at 3 and 5 min, once a thermal death time greater than 2.5 min was obtained, the experiments were carried out in triplicate for HN, HC and HA.

6.2.4 Heat penetration curve

It was generated by plotting the temperature difference between the autoclave and the food against the sterilization time.

6.2.5 Process evaluation. Ball's method

Ball's parameters were calculated. The lag time, t_c, was obtained from the thermal history. The heat treatment time to reach sterility, t_B, when starting at t_B=0, was corrected to zero, by multiplying t_c× 0.58. The calculation j_h was with Eq. (1).

$$j_h = \frac{T_E - T_{ip}}{T_E - T_0} \quad (1)$$

The parameter g was cleared from Eq. (2).

$$t_B = f_h\left[log[j_h(T_E - T_0) - log(g)]\right] \quad (2)$$

The ratio f_h⁄U was found by interpolation of the table values of g, for z = 10 °C, using the values of g and jh. This relationship was used to find out the value of U. The lethality of the process was calculated with the

$$L = 10^{\frac{T_E - T_{ref}}{z}} \quad (3)$$

The thermal death time of the process Fprocess was determined with Eq. (4).

$$U = F_{proceso}/L \quad (4)$$

6.2.6 Thermal process design

A Fprocess = 2.5 min was used for Clostridium botulinum. The values of f_h and j_h obtained from the experimental heating curve during the process evaluation were used in the design. U was calculated with Eq. (4) using Fprocess set and the value of L from the process evaluation. With the value of f_h⁄U and j_h, the value of g from the table was determined for z=10 . The value of the heat treatment time to reach design sterility, t_B, was determined using Eq. (2). The holding time, in the autoclave for Fprocess = 2.5 min for *Clostridium botulinum,* was recalculated by subtracting t_B of design from t_(B_exp) of the process evaluation.

6.2.7 Statistical analysis

A completely randomized design was used, considering the type of hummus. From the data obtained for thermal death time, it was analyzed if there is a significant difference for the three different products when the holding time was 3 min, using a one-way ANOVA test with Excel, considering that the population means are equal. In all cases it was required to know if in the three products, with a given holding time an $F \geq 2.5$ min is reached. The independent variable was holding time, 3 and 5 min in the autoclave at 121 °C. The dependent variable was thermal death time.

6.3 Results

6.3.1 Evaluation of the process

In order to find the optimum holding time, tests were first performed with HN at 3 and 5 min. From the heat penetration curve, the parameters of Ball's method were obtained, which are shown in Table 6.1.

Table 6.1 Parameters of Ball's method for HN at different holding times.

Time (min)	T_E (°C)	f_h (min)	j_h (min)	$t_{B_{exp}}$ (min)	g (°C)	f_h/U	L (min)
3	120.0	5.0	0.5	10.8	0.33	1.1	0.78
5	119.9	4.9	0.6	12.6	0.15	0.8	0.76

Source: Own elaboration

For HN at different holding times of 3 and 5, the Fprocess times used were 3.4 and 4.4 min, respectively, values greater than 2.5 min, which ensures commercial sterility, so it was decided to work with 3 minutes of holding time. The recommended Fprocess value range for vegetable-based products varies from 3 to 6 min (Serment-Moreno & Welti-Chanes, 2016). Foods with a similar consistency, such as baby porridges, vegetable creams and tomato puree present Fprocess values of 3 to 4 min (Deák, 2014).

Once the holding time of 3 min was selected, tests were performed for the different hummus products. From the experimental data the initial temperature (t = 0) of HN, HC and HA was 26.5 °C, 25.7 °C and 27.4 °C, respectively. The average sterilization temperature in the autoclave along the constant zone was 121.4, 121.0 and 121.5 °C, for each food. The delay time in the autoclave was 26.5, 30.0 and 27.5 min, and the time at the end of heating in the autoclave was 29.5, 33.0 and 30.5 min. The temperature of the food at the beginning of cooling was 119.4 °C, 119.6 °C and 119.6 °C. All these values were obtained from the thermal histories. The average sterilization temperature, T_E in the autoclave showed no significant difference ($p > 0.05$), this value is to be expected since it is the same food, only the product differs with respect to its flavor. The f_h value for HC was the lowest which indicates that this product was heated faster unlike the others, in this case the heat transfer is more efficient than in solid products, because if we confront the values achieved in canned fish sterilization processes, these have reported f_h values of 27 min (Ansar Ali et al., 2006) as well as f_h values of 8.5 - 13.9 min for Chhana roll (Jat et al., 2014).

The j_h factor cannot be compared because different initial temperatures were used, but the values obtained for hummus in its different products are similar to those with the same consistency such as mashed potatoes and ketchup of 1.1 and 1.2 min, respectively (Govaris & Scholefield, 2007). Similarly, jh values equal to 1.3 min have been reported for cream of celery and values between 0.44 and 1.17 at F_(0)of 12.4, 13.2 and 14.6 min for a Kheer dairy product. Values of jh close to 1, indicate that the product is purely convective (Jha et al., 2011). The t_(B_exp) varied from 14 - 16 min, for HC and HA, but showed no significant difference ($p > 0.05$).

The g value for HN and HC had no significant difference ($p > 0.05$), but did for HA; which is in the range of the g values obtained by Puthanangadi, et al., in 2021 being 2.95 and 1.93 °C for an F0 of 8 and 9 min, respectively. The ratio f_h/U was different for HA with respect to HN and HC, this value decreases when the Fprocess increase, the values obtained for this parameter (Table 2) are greater than the value of f_h/U=0.8 for a holding time at 5 min with which a value of Fprocess = 4.4 min was obtained; a value of 1.41 is reported for f_h/U in tuna in brine (Bindu & Srinivasa Gopal, 2008). A study on heat penetration characteristics of cassava found values of jh 1.91 and f_h/U 2.06, similar to those obtained in Table 2 (Dinakaran et al., 2017).

Table 6.2 Parameters Ball's method for hummus for the evaluation of the thermal process

Paramet	HN	HC	HA
T_E (°C)	121.1 ± 0.7[a]	121.3 ± 0.3[a]	121.4 ± 0.3[a]
f_h (min)	8.4 ± 1.2[a]	7.6 ± 0.3[b]	9.5 ± 1.8[c]
j_h (min)	1.6 ± 0.5[a]	1.2 ± 0.3[b]	0.9 ± 0.6[c]
$t_{B_{exp}}$ (min)	16.0 ± 1.6[a]	14.4 ± 0.3[b]	14.4 ± 0.4[b]
g (°C)	1.7 ± 0.6[a]	1.5 ± 0.2[a]	2.1 ± 0.4[b]
f_h/U	2.5 ± 0.6[a]	2.4 ± 0.2[a]	3.8 ± 1.2[b]
L (min)	1.0 ± 0.1[a]	1.1 ± 0.1[a]	1.1 ± 0.1[a]

-c Different letters in the same row represent significant difference (p < 0.05).
Source of consultation: Own elaboration.

Since the thermal death time is the time corresponding to a theoretical thermal process, carried out at constant temperature, generates the same degree of destruction as the real process in which the temperature of the food is not usually constant, this value at a specific point of the food can be calculated by the change in the concentration of the microorganism at that point, Frequerido, or by the change in temperature at that point from the beginning to the end of the treatment, Fprocess.

The values of thermal death time, calculated by Ball's method for the different hummus products HN (3.4 ± 0.2 min), HC (3.4 ± 0.2 min) and HA (2.8 ± 0.3 min), in all cases this time was greater than 2.5 min, according to the kinetics of the microorganism ensures commercial sterility with respect to Clostridium botulinum. The HA showed significant differences ($p < 0.05$) with respect to the natural and chipotle product, having a lower value, this result can be explained due to the fact that this product contained sliced olives, that is, the increase of solid material, which decreased the heat transfer generating a lower Frequerido value. This is due to the mechanism of heat transfer within the food, in a solid the mechanism is by molecular diffusion, while in a liquid it is by convection associated with the movement of the fluid which enhances this transport phenomenon.

6.3.2 Process design

In this step the heating time, t_B, was determined using the Fprocess = 2.5 min, for Clostridium botulinum. Once the t_(B_exp) was established, the exact autoclave holding time that allowed commercial sterility was known. The design parameters obtained by Ball's method are shown in Table 3. The g value, despite having significant differences ($p < 0.05$), had a maximum value of 2.5 min.

With the t_(B exp) obtained in the evaluation and the t_B calculated by the design it was possible to know the specific holding for the microorganism Clostridium botulinum and the products HN (1.7 ± 0.3 min), HC (1.8 ± 0.2 min) and HA (2.6 ± 0.4 min). This allows efficient use of the energy used in this process, so if we take the upper standard deviation in HN and HC this would be 2 min and for HA it would remain at 3 min for Clostridium botulinum.

Table 6.3 Parameters of Ball's method for the design of the thermal process.

Microorganism	Product	U (min)	f_h/U	g(°C)	t_B(min)
Clostridium botulinum	HN	2.3 ± 0.04[a]	3.1 ± 0.9[a]	2.1 ± 0.4[a]	14.8 ± 1.7[a]
	HC	2.4 ± 0.15[a]	3.2 ± 0.3[a]	2.1 ± 0.1[a]	13.2 ± 0.5[b]
	HA	2.4 ± 0.15[a]	4.1 ± 0.9[b]	2.3 ± 0.2[b]	14.1 ± 0.6[c]

a-c Different letters between columns for each microorganism represent significant differences (p < 0.05).
Source: Own elaboration.

6.4 Acknowledgements

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6.5 Conclusions

A thermal process applied to three hummus products: natural (HN), chipotle (HC) and with olives (HA) was designed and evaluated, using mathematical procedures and the thermal death kinetics of the microorganism, to calculate the lethality that guaranteed commercial sterility. The evaluation of the process allowed determining a holding time of 3 min, with which thermal death times higher than 2.5 min were obtained for all the hummus products studied. In particular, HA, which contained a greater amount of solid material, decreased heat transfer, generating the lowest Frequerido value. From the process design, the specific holding time for Clostridium botulinum and the different products was obtained, which avoids using unnecessary energy, making the process more efficient. This study demonstrated that the use of mathematical procedures and the kinetics of thermal death of microorganisms can be used to guarantee commercial sterility in the food industry.

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