

DETERMINATION OF C_0 -VALUE AS AN INDICATOR OF NUTRITIVE VALUE OF PÂTÉ STERILISED BY REGULAR AND OPTIMIZED REGIMES

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Abstract

Introduction. Heat treatment of food provides appropriate shelf life and safety, as well as adequate sensory properties and better digestibility, but excessive thermal processing leads to the loss of nutritive value. In practice, sterilised meat products are usually overheated, which leads to a loss of nutritive value. Therefore, it is necessary to find the optimum between the preservative effect of heat treatment and maintenance of the nutritive value of food. Control of the sterilisation efficiency is based on the F_0 value, an indicator of the lethal effect of heat treatment, while the cooking (C_0) value indicates a reduction of the nutritive value of heat treated products.

Materials and Methods. During pâté sterilisation processes, two working heat treatment regimes were used: the regime used in regular, commercial production and an optimised regime. Heat treatment measurements were carried out using six thermocouple probes placed in the geothermal centres of six chosen cans. For each heat treatment, schematic diagrams were produced. F_0 values were determined using Ellab software, and C_0 values by the graphic method in a semi-logarithmic Thermal Death Time diagram.

Results and Conclusions. During pâté sterilisation, where the effective time was 55 minutes (regular regime) at 114 °C and 3.2 bar pressure, an average F_0 value of 7.90 ± 0.43 was achieved. By reducing the effective sterilisation time to 45 minutes (optimised regime), an average F_0 value of 3.81 ± 0.5 was achieved. Both regimes were sufficient to ensure product safety ($F_0 > 3$). The average C_0 value for the regular sterilisation regime was 109.83 ± 1.33 minutes, while for the optimised regime, it was 88.67 ± 4.27 minutes, i.e., an average reduction of 19.26%. This corresponds to a proportionally higher nutritional value of the product treated using the optimised regime. Data on the F_0 and

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C_o values achieved during the sterilisation process can make a significant contribution to obtaining products with a better nutritional value through an optimised sterilisation process, without jeopardising product safety.

Key Words: F_o value, C_o value, pate, safety, nutritive value

INTRODUCTION

Heating is a form of energy input in the process of processing and preparing food. It can be of varying intensity (pasteurisation, cooking, sterilisation), and in food processing, depends on the nature and composition of the foods. Heat transfer is carried out by conduction or convection (flow) (Wareing, 2010).

Heat treatment is a physical method of preserving food that uses high temperature to destroy microorganisms and inactivate tissue enzymes. The heat treatment process should eliminate pathogenic and spoilage microorganisms to the extent that they do not pose a threat to consumer health, but heating should not deleteriously affect the quality of the final product. The degree of applied temperature is proportional to the antimicrobial effect (Nitsch and Vuković, 2002; 2003; 2006; FAO, 2010). However, this is not straightforward, since microorganisms are grouped non-homogeneously in solid foods, and the applied heat can have difficulty penetrating to the centre of a microbial colony, while the microorganisms in the centre of a can are more difficult to destroy than those at the periphery. Food is also altered during heat treatment, which causes appropriate sensory property changes (e.g., to flavour, texture) in the food. Excessive, non-optimised heat treatment leads to loss of nutritional value of food. Therefore, it is necessary to find the optimum between the conserving effects of heat treatment and preservation of the nutritional value of food (meat) products (Teodorović *et al.*, 2015).

In the system of integrated control of production and processing of meat according to the Hazard Analysis Critical Control Points (HACCP), a special place is held by the control of heat treatment. In all HACCP plans, heat treatment is designated as a critical control point (CCP) and is represented on a flow diagram as the process where a hazard is eliminated or reduced to the lowest acceptable measure (Surak and Wilson, 2014).

For the purpose of reliable control of heat treatment process efficiency, the F_o value is useful. The F_o value is based on the fact that during humid environment heating, microorganisms die in a logarithmic pattern. F_o value expresses the lethal effect of a reference heat treatment temperature during one minute. If $F_o = 3$ or more is achieved, it is considered that any thermoresistant *Clostridium botulinum* types A and B spores are destroyed (Nitsch and Vuković, 2002; 2003; 2006).

The cooking value (C_o) expresses the reduction in the nutritional value of heat treated products. There are no norms or recommendations for C_o values, so the optimal process of heat treatment is the one that has a lower C_o value for a given F_o value (Vuković, 2012).

Pâtés are meat products derived from meat, fat tissue, connective tissue, intestines, blood, blood products and additives that are conserved by heat treatment in hermetically sealed containers or appropriate envelopes after various forms of heat treatment (Anonymous, 2015). Meat as a raw material for making canned products must have optimal hygienic and technological qualities, provided by measures such as selection of animals, adequate preparation for slaughter and adoption of suitable slaughtering operations, until the meat is sealed in the can. During heat treatment of canned meat products, the characteristic sensory properties (e.g., colour, flavour and texture) of the final product are formed, while the temperature affects the viability of microorganisms, thereby ensuring the product's safety and shelf-life (Rubén et al., 2018). Notably, the canning process uses packaging (cans) which remains its basic hermetic characteristic during the product's shelf-life (Teodorović et al., 2015).

Sterilisation is the process of the heat treatment of cans at a temperature higher than 100 °C, wherein in the thermal centre of the product at least a lethal value of $F_0 = 3$ must be achieved (Anonymous, 2015). Sustainability of the cans depends primarily on the degree of destruction of the bacteria (biological sterility), which is extremely difficult to attain without irreversible loss of the organoleptic properties of the product. The sterilisation regime is, therefore, adjusted to achieve commercial sterility (FSIS/USDA, 2005). Commercial sterility involves the destruction of vegetative forms and spores of *Clostridium botulinum* and *Clostridium perfringens*, destruction of *Enterobacteriaceae* and staphylococci, absence of toxins, enzymes and microorganisms which could produce them, but with a tolerance for non-pathogenic *Bacillus* spp. spores, when these are not capable of causing product spoilage within at least 6 months (FAO, 2010). If the pH value of the filling is lower, the effect of the heat treatment will be higher (*Clostridium botulinum* cannot produce toxin at a pH less than 4.6) (*Codex Alimentarius* 2011). However, since meat products belong to the group of low acid foods (pH >4.5), spores of *Clostridium botulinum* have to be destroyed (Anon, 2011).

The higher the applied sterilisation temperature, as well as the longer the effective operating time, the greater the loss of nutritional value will be. In addition to ensuring food safety and sustainability, an important task of heat treatment is the preservation of the biological value of meat and meat products (Pither, 2003). Also, during the heat treatment of liver, which is an important component of liver pâté, irreversible changes occur to the protein ferritin at temperatures above 80 °C, when it can precipitate (Prochaska et al., 2000). Often, therefore, microbiologically flawless, practically sterile canned liver pâtés have a softer consistency, more or less pronounced brown colour and false aroma. These methods of intense, long-term sterilisation are applied by producers who have problems with hygiene practices in their facilities, in order to produce products with a commercially acceptable shelf-life. Liver pâtés heat treated in this way have a lower biological value, while because of higher energy consumption, the profitability of production is always questionable (Pither, 2003).

The aim of this research was to determine F_0 and C_0 values for the heat treatment regime used in regular liver pâté production as well as for an optimised regime. The

two heat treatment regimes were compared in order to determine opportunities for improving the current sterilisation regime used in the industry, while still producing a safe product with better nutritive value.

MATERIALS AND METHODS

Systematic monitoring of heat treatments (sterilisation) of liver pâté was carried out in a meat processing facility. Pâté (90 g amounts) was packed in aluminium containers. Sterilisation was carried out under saturated aqueous vapour conditions in a horizontal autoclave with an overpressure valve (Steriflow Roanne France, type 1341 EA, year 2013) that accommodated four trolleys. Heat treatments were carried out on three trolleys filled with product, due to the limitation in the time of loading the filled mass in cans of two hours (FSIS/USDA, 2005). During the pâté sterilisation process, two working modes were used: A mode, used in regular production and the optimised B mode. The heat treatment formulas are given in Table 1.

Table 1. Formulations for the sterilisation regimes used for heat treatment of pâté

Regime A (regular mode)			Regime B (optimised mode)		
$T_0 = 15'$	55'	$+ 20'$	$T_0 = 15'$	45'	$+ 20'$
114 °C / 3,2bar			114 °C / 3,2bar		

The heat regime defines the heating time, effective sterilisation and cooling time. The heating time (15 minutes) is the interval needed until the prescribed temperature for the heat treatment (114 °C) and the pressure (3.2 bar) are reached. The effective sterilisation time (55 minutes in regime A and 45 minutes in regime B) should provide the required F_0 value that guarantees the safety of canned meat products according to the Rulebook on the Quality of Minced Meat, Meat Preparations and Meat Products (Anon, 2015). The cooling time (20 minutes) is needed for completion of the defined process temperatures, in accordance with the heat treatment plan.

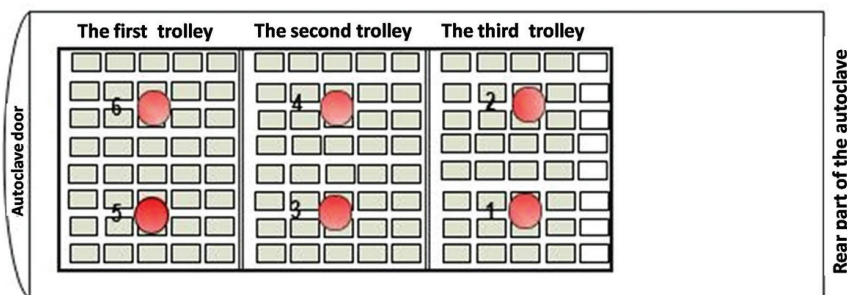


Figure 1. Position of the probes placed in the geothermal centres of the pâté cans in the autoclave trolleys as seen from the side.

Legend: – The probe is placed in the geothermal centre of the product

The measurements were carried out by means of a thermocouple (Ellab model CTF 84). Thermoelements with compensating cables were used, including a total of six probes. The probes were placed in the geothermal centres of the six chosen cans which were placed at different points in three trolleys. The positions of the cans with inserted probes were the same for both sterilisation regimes and are shown in Figures 1 and 2.

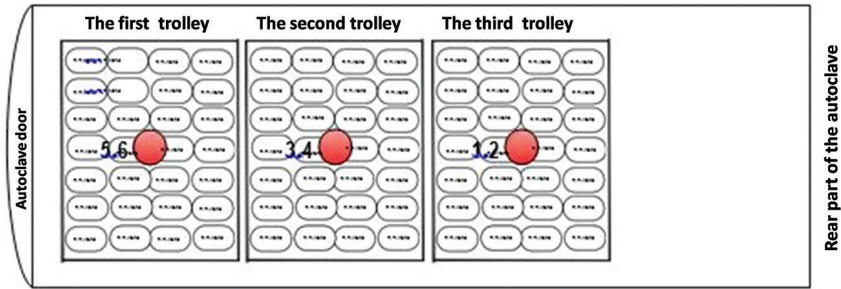



Figure 2. Position of the probes placed in the geothermal centres of pâté cans in the autoclave trolleys as seen from the top.

Legend:  – The probe is placed in the geothermal centre of the product

The F_0 values for each treatment were determined in real time immediately using original Ellab software, which could be observed on the display along with the temperature in the geothermal centres of the examined cans.

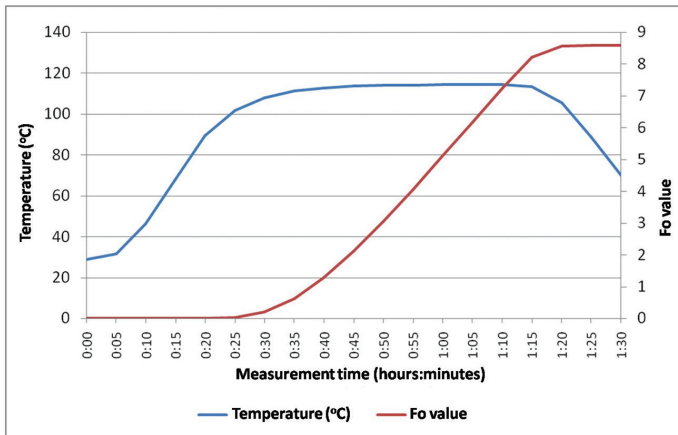


Figure 3. Temperature and F_0 value determined in a can exposed to the regular heat treatment regime (A)

The graphic method described by Vuković (2012) was used to determine C_0 values, using a semi-logarithmic Thermal Death Time (TDT) diagram (Figures 3 and 5), on which two straight lines were previously constructed, representing: $C_0 = 1$ (1 minute at 100 °C, $z = 33$ °C, blue line in Figures 3 and 5) and $F_0 = 1$ (1 minute at 121.1 °C, $z = 10$ °C, rose line in Figures 3 and 5). In order to determine the C_0 value of the examined heat treatment, it is necessary to know the F_0 value of the sterilisation process and

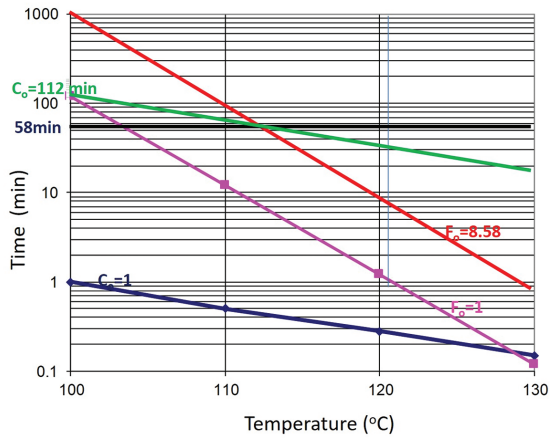


Figure 4. The C_0 value determined in a can exposed to the regular heat treatment regime (A)

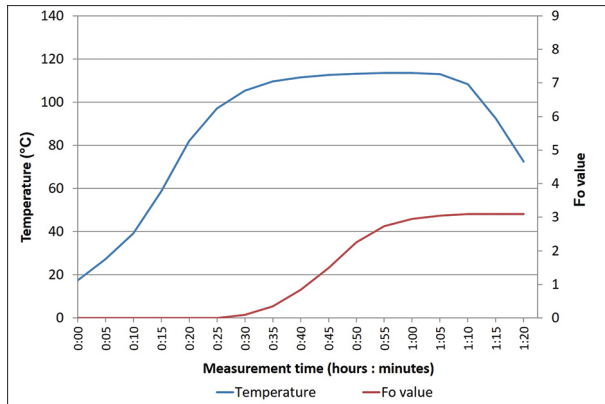


Figure 5. Temperature and F_0 value determined in a can exposed to the optimised heat treatment regime (B)

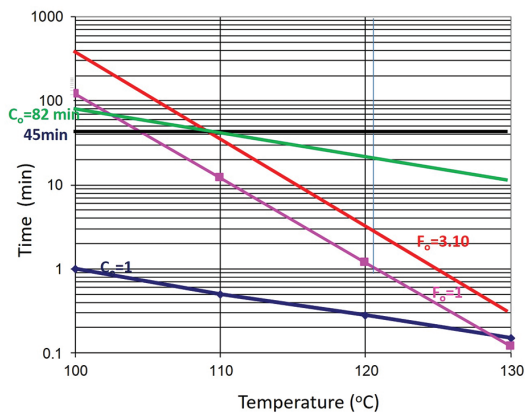


Figure 6. The C_0 value determined in a can exposed to the optimised heat treatment regime (B)

the time (in minutes) the temperature measured in the geothermal centre of the cans is equal to or higher than 100 °C. C_0 value is obtained by drawing a line (green line in Figures 4 and 6) parallel to the line $C_0 = 1$, which passes through the intersection point of the line drawn on the basis of the measured F_0 value (it is parallel to the line $F_0 = 1$, red line in Figures 4 and 6) and the line drawn on the basis of time operating temperature higher than 100°C for the heat treatment regime (black line in Figures 4 and 6). There are no norms or recommendations for C_0 values, unlike for F_0 values, so the optimal process of heat treatment is the one that, for a given F_0 value, has a lower C_0 value (Vuković, 2012).

RESULTS

The following graphs show examples of temperature changes and F_0 values for the regular (Figure 3) and optimised (Figure 5) heat treatment regimes, as well as the procedure for determining C_0 values for the regular (Figure 4) and optimised (Figure 6) regimes. For the regular regime, the example with the highest F_0 and C_0 values in the experiment was taken, and for the optimised regime the example with the smallest F_0 and C_0 values was taken, so the differences between these procedures were the most obvious. The average values with variation measures for the entire study are shown in Table 2.

According to Figure 3, the obtained F_0 value of the chosen regular regime example was 8.58, the temperature of 100 °C was reached after 24 minutes of the process, and it decreased below 100°C after 82 minutes of the process, which means that the temperatures above 100°C lasted for 58 min.

Figure 4 shows the process of C_0 value determination for the regime described in Figure 3. Based on the F_0 value of 8.58 (red line) and temperature above 100°C which lasted 58 minutes (black line), a C_0 value of 112 min (green line) was calculated.

According to Figure 5, the obtained F_0 value of the chosen optimised regime (B) was 3.1, the temperature of 100 °C was reached after 27 minutes of the process, and it decreased below 100°C after 72 minutes of the process, which means that the temperatures above 100°C lasted for 45 min.

Figure 6 shows the process of C_0 value determination for the regime described in Figure 4. Based on the F_0 value of 3.10 (red line) and temperature above 100°C which lasted 45 minutes (black line), a C_0 value of 82 min (green line) was calculated.

Table 2 shows mean F_0 and C_0 values, as well as the duration of temperatures above 100 °C for the all examined cans exposed to heat treatment regimes A or B. For temperature regime A, F_0 values ranged from 7.24-8.58, while the average was 7.9 ± 0.43 , which ensured the safety of the product, and the average C_0 value was 109.83 ± 1.33 minutes. For temperature regime B, the determined F_0 values were in the range 3.1-4.36, with an average of 3.81 ± 0.5 , and the average C_0 value was 88.67 ± 4.27 minutes.

Table 2. Determined parameters for temperature regimes A and B

Parameter	Temperature regime A			Temperature regime B		
	F _o	time* (min)	C _o (min)	F _o	time* (min)	C _o (min)
\bar{x}	7.90	56.0	109.83	3.81	46.3	88.67
SD	0.43	1.79	1.33	0.50	0.82	4.27
min	7.24	53.00	108.00	3.10	45.00	82.00
max	8.58	58.00	112.00	4.36	47.00	93.00
CV (%)	0.05	0.03	0.01	0.13	0.02	0.05

*Operating time t > 100 °C (min)

By comparing the results obtained from the regular and optimised regimes, the reductions in the parameters of interest are presented in Table 3. The results obtained showed that the C_o value was reduced on average by 19.26%, indicating that the products processed by the optimised regime B had a 19.26% better nutritive value than products processed by the regular regime A.

Table 3. The average percent reduction of the parameters for regime B in relation to the regime A

Parameter	Reduction (%)
F _o value	51.77
Operating time t > 100 °C	17.32
C _o value	19.26

DISCUSSION

The Rulebook on the Quality of Minced Meat, Meat Preparations and Meat Products (Anon, 2015) states that sterilisation is a process for the heat treatment of cans at a temperature higher than 100 °C, and that in the centre of the product, an F_o value of at least 3 must be achieved. According to FAO (2010), in order to provide product safety as well as product quality, the sterilisation of meat products packed in cans must achieve F_o values between 2.52 and 5.5, whereby the temperature of the medium itself should range from 117 to 130 °C, depending on the characteristics of the products themselves. The optimised regime B meets both requirements, but the F_o value of the regular regime A is much higher (7.90) than the FAO recommended maximum of 5.5. According to the national regulations (Anon, 2015) as well as FAO (2010) recommendations, the optimised regime B should produce a product shelf-life of four years at storage temperatures up to 25 °C.

The regular heat treatment regime A (Table 1) lasted 1 hour and 30 minutes. For this sterilisation regime, the average F_0 value in the geothermal centre was 7.90 ± 0.43 , which ensured the safety of the product, but this was 2.63 times higher than the value required by regulations. Such a process ensures that any spores of thermoresistant *Clostridium botulinum* types A and B are destroyed (Nitsch and Vuković, 2002; 2003; 2006; Teodorović *et al.*, 2015), but overly excessive heat treatment is not recommended because of the negative influence on the biological value of meat and meat products (Pither, 2003).

In the optimised heat treatment regime, with identical sterilisation conditions (temperature and pressure of the product), but with the effective sterilisation time shortened by 10 minutes, the entire heat treatment process lasted 1 hour and 20 minutes. The average F_0 value 3.81 ± 0.5 also ensured the safety of the product, but was only 1.27 times higher than the value required by regulations. As temperatures higher than 100 °C significantly affect the biological and nutritive value of meat (Pither, 2003; Vuković, 2012), shortening the operating time by 10 minutes also shortened the influence of temperatures higher than 100 °C by 17.32%. Compared to the regular heat treatment regime A, this resulted in an average decrease of C_0 value by 19.26%. Consequently, products processed using the optimised B regime may be considered to have a 19.26% better nutritional value than products processed using regime A.

CONCLUSION

During the sterilisation of pâté in aluminium foil (90 g), with an effective time of 55 minutes (regular regime), at 114 °C and pressure of 3.2 bar, an average F_0 value of 7.90 ± 0.43 was achieved. By reducing the effective sterilisation time to 45 minutes (optimised regime), an average F_0 value of 3.81 ± 0.5 was achieved. Both heat treatment regimes were sufficient to ensure product safety ($F_0 > 3$). Average C_0 values were 109.83 ± 1.33 and 88.67 ± 4.27 minutes for the regular and optimised regimes, respectively. The optimised sterilisation regime provided a 51.77% reduction in F_0 value, while the operating time at temperatures higher than 100 °C was shortened by 17.32%. The C_0 value was reduced by 19.26% which corresponds to a proportionally higher nutritional value of the product treated with the optimised regime, while the safety of the product was not compromised.

Analysis of F_0 and C_0 values achieved during sterilisation processes can make a significant contribution to obtaining products with better nutritional value through milder sterilisation regimes and without compromising product safety.

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Authors contributions

RM – conducted experiment and wrote the paper; MB; ĐV; PV; BŽ; IBL – gave help during the experiment; VD – designed the experiment and gave help during calculation of the results, as well as during the writing of the paper

Competing interests

The author(s) declare that they have no competing interests

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ODREĐIVANJE C_0 -VREDNOSTI KAO POKAZATELJA HRANLJIVE VREDNOSTI PAŠTETE STERILISANE UOBIČAJENIM I OPTIMIZOVANIM POSTUPKOM

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Kratak sadržaj

Uvod. Toplotna obrda obzbeđuje održivost i bezbednost kao i adekvatna senzorna svojstva i bolju svarljivost hrane, ali suviše intenzivna toplina obrada dovodi do gubitka hranljive vrednosti. U redovnoj proizvodnji, sterilisani proizvodi od mesa se uobičajeno obrađuju suviše intenzivnim postupkom toplotne obrade, što dovodi do većeg gubitka hranljive vrednosti. Iz tog razloga, neophodno je da se pronađe optimum između konzervišućeg efekta toplotne obrade i očuvanja hranljive vrednosti hrane. Kontrola efikasnosti sterilizacije se bazira na određivanju F_0 vrednosti kao pokazatelja letalnog efekta toplotne obrade, dok C_0 vrednost (Cooking value) pokazuje smanjenje hranljive vrednosti toplotom obrađenih proizvoda.

Materijal i metode. Za vreme sterilizacije paštete, primenjena su dva radna modela: postupak „A“ koji se koristi u redovnoj proizvodnji (uobičajeni režim) i postupak „B“ (optimizovani režim). Merenja su sprovedena pomoću 6 termopar sonde, koje su smeštene u geotermalnom centru 6 odabranih konzervi. Za svaki od toplotnih tretmana, iscertani su dijagrami. F_0 vrednost je određena Ellab softverom, a C_0 vrednost grafičkom metodom na polulogaritamskom TDT dijagramu.

Rezultati i zaključak. Rezultati su pokazali da za vreme sterilizacije paštete, gde je efektivno vreme sterilizacije trajalo 55 min (uobičajeni režim), pri 114°C i pritisku od 3,2 bara, prosečna F_0 vrednost iznosila $7,90 \pm 0,43$. Redukovanjem efektnog vremena sterilizacije na 45 minuta (optimizovani režim), postignuta je F_0 vrednost od $3,81 \pm 0,5$, pri čemu su oba režima bila dovoljna da osiguraju bezbednost proizvoda ($F_0 > 3$). C_0 vrednost za uobičajeni režim sterilizacije je iznosila $109,83 \pm 1,33$ min, a za optimizovani režim $88,67 \pm 4,27$ min, pri čemu je ostvaren stepen redukcije od 19,26%, što odgovara proporcijonalno većoj hranljivoj vrednosti proizvoda tretiranog redukovanim režimom. Podaci o ostvarenim F_0 i C_0 vrednostima za vreme postupka sterilizacije mogu da daju značajan doprinos u dobijanju proizvoda sa boljom hranljivom vrednosti kroz blaže postupke sterilizacije, a da se pri tome ne ugrozi bezbednost proizvoda.

Ključne reči: F_0 vrednost, C_0 vrednost, pašteta, bezbednost, hranljiva vrednost