

DEVELOPMENT OF MATHEMATICAL MODEL FOR CALCULATION OF THERMAL TREATMENT REGIMES OF POTATO PRODUCTS PACKED IN SOFT RETORTABLE POUCHES

Aija Ruzaike, Sandra Muizniece-Brasava, Kaspars Kovalenko, Aivars Aboltins

Latvia University of Agriculture

aija.ruzaike@gmail.com

Abstract. The most widely used method of meal, ready-to-eat (MRE) preparation directions is the thermal treatment technology. This method of food treatment guarantees long-term storage at room temperature, providing the quality and microbiological safety. Retortable pouches, which are containers made either of laminates of synthetic materials only or laminates of aluminium foil with synthetic materials, are of growing importance in thermal food preservation. The advantage of retortable pouches is their good thermal conductivity in that way reducing the required heat treatment time and retaining the sensory product quality. The sterilization experiments were performed in the pilot autoclave HST 50/100, ZIRBUS Technology GmbH. Ambient temperature in the autoclave was selected – + (80.0, 100.0, 110.0, and 120.0) ± 0.5 °C. The temperature during the thermal treatment process was measured inside the autoclave as well as in the core of the product. The count of colony forming units (CFU·g⁻¹) was determined by standard procedure for potato products at 0 minute of the experiment as well as after every 5, 10, 15 and 20 minutes of thermal treatment.

Keywords: D-value, potato products, retortable pouch, Z-value.

Introduction

The ready meal sector of the food industry has been experiencing increasing growth in the past years. Due to the lack of available time faced by the consumers and the convenience offered, such products have become very popular [1; 2]. Ready-meals have been defined as pre-prepared main courses that can be reheated in their container, requiring no further ingredients, and needing only minimal preparation before consumption [3]. The lifestyle and consumer habits increasingly demand for ready meals with high quality standards and minimum handling [4].

Thermal processing is the most commonly applied technique to control pathogens in foods. Thermal treatment is employed in food processing in order to preserve the product, extend its shelf-life and ensure consumer safety [5]. Heat treatments have long been established as one of the most important techniques to assure the microbial stability and safety of various food products. Examples of these heat treatments are sterilization ($F_0 = 3$ min or 121.1 °C for 3 min) and pasteurization (e.g. $P_{90} = 10$ min or 90 °C for 10 min) [6]. Thermal processing, specifically sterilization (retort processing), has been used as a common preservation technique in food industry for shelf stable low acid foods [7; 8; 9]. Sterilization is defined as the process which can provide nearly complete inactivation of microorganisms (including spores). Sterilization is achieved by applying high intensity heat (normally between 121 °C and 140 °C) to food products [7]. The technology is most commonly used for retort processing to different kinds of containers, e.g., cans, pouches, polymeric trays, jars, cups, and bowls [8]. Generally, canned food products have not been perceived by consumers to have high quality, however, more emphasis is being placed on higher quality shelf stable retort pouch products [9]. The retort pouch minimizes the thermal damage to nutrient, sensory, and other food quality characteristics due to quicker heating based on the thinner package profile when compared to metal cans [10]. Retort pouches have traditionally been a multilayer flexible packaging consisting mainly of polypropylene (PP), aluminium foil, and polyester – polyethylene terephthalate (PET) [9].

Commercial retort processing ensures a reduction or inactivation of spore-forming microorganisms sufficient to guarantee commercial sterility [7; 11]. The lethal effect of high temperatures on microorganisms is dependent on several factors including the temperature, holding time and water activity [11; 9]. Commercial sterilization is achieved through a combination of relatively mild thermal treatment and other processing parameters and storage conditions. The criterion to evaluate the commercial sterilization process is the inhibition of the growth of microorganisms and not their presence or absence. Commercial sterility (as defined by the United States Food and Drug Administration (FDA)) or shelf-stability (U.S. Department of Agriculture (USDA)) refers to conditions achieved in a product by the application of heat to render the product free of microorganisms that are capable of reproducing in the food under normal non-refrigerated

conditions of storage and distribution [10]. Nowadays, the conventional sterilization technology (i.e. thermal sterilization) is still holding a dominating position in food industry. Normally, it is achieved by using high pressure endurance equipment like retorts which allows food products to be heated to higher than 100 °C [7].

Microorganisms in foods are exposed to lethal temperatures during treatment, it is necessary to calculate the cumulative effect of heat on microbial destruction during both heating and cooling as well as the holding time at the target temperature [11]. Microbial lethality needs to be determined by estimating the total destruction value (F_0 -value). In estimating the F_0 -value for specific processing conditions, it is important to know the D - and Z -values. The D -value, the decimal reduction time, indicates the time required to kill 90 % of bacterial population at a specific temperature. The Z -value, the thermal resistance constant (°C), measures the temperature increase required to cause a 90 % reduction in the decimal reduction time. Microbial heat resistance is the key factor for calculation of an effective heat treatment of food so as to be safe for the consumer [12]. These two values offer the basis for calculating the process times in food industry [13].

The aim of this research was to determine the thermal inactivation temperature and time (D -values and Z -values) of the number of mesophilic aerobic and facultative anaerobic microorganisms during thermal treatment of potato products (ready-to-eat meals – potatoes with meat) packaged in soft retortable pouches.

Materials and methods

The research was carried out at the laboratories of Packaging Material Property Testing laboratory at the Department of Food Technology and Institute of Food and Environmental Hygiene, Faculty of Veterinary Medicine, Latvia University of Agriculture. The object of the research was thermally treated potato products (ready-to-eat meals – potatoes with chicken meat).

Peeled potatoes were cut into 10x10x10 mm cubes and chicken fillet was cut into 20x20x20 mm pieces. After mixing potatoes with chicken fillet, the product (300 ± 10 g) was filled in polyethylene terephthalate/aluminium/polyamide/polypropylene (PET/ALU/PA/PP) retortable pouches which are suitable for thermal treatment. The size of the pouches was 200x250 mm with 80 µm thickness. After filling, the pouches of potato products were hermetically sealed using the chamber type vacuum packaging machine *Multivac C350*; hermetic sealing mode – vacuum, 20 MPa, sealing time 5 seconds. The vacuum sealed pouches were then thermally treated in a pilot autoclave *HST 50/100*, *ZIRBUS Technology GmbH* at four temperature regimens $T_{environment} = +(80.0, 100.0, 110.0, \text{ and } 120.0) \pm 0.5$ °C and four cooking times $\tau_{cooking} = 5, 10, 15$ and 20 minutes. After thermal treatment, which consisted of warming, sterilization and cooling, the product samples were put in a water bath at $+5 \pm 2$ °C. All thermally treated samples were subjected to microbiological testing in order to determine colony forming units of aerobic and facultative anaerobic, mesophilic bacteria.

Microbiological testing

Microbiological parameters were determined in the control sample (fresh prepared potatoes with chicken fillet without thermal treatment) and in the product samples after thermal treatment. Total plate count (TPC) (aerobic and facultative anaerobic, mesophilic bacteria, hereafter referred to as TPC) was determined according to the standard EN ISO 4833: 2003 “Microbiology of food and animal feeding stuffs – Horizontal method for the enumeration of microorganisms – Colony-count technique at 30 degrees C” on Plate Count Agar (PCA) agar medium. The microbiological testing was completed with a triplicate repetition in order to obtain more precise results.

Determination of D - and Z -values

The D -values and Z -values were calculated analytically after the obtained results for the thermally treated potato products in packaging. Thermal treatment processing time (min) and temperature (°C) of the potato products were recorded automatically by sensors built-in the pilot autoclave. Thermal inactivation response is described by log linear kinetics where the rate of inactivation is proportional to the number of surviving bacteria, leading to linear survival behaviour (when the survivor curve is plotted as the log of the survivors against time) [10].

For microorganisms, which exhibit linear survival behaviour, the kinetic parameters are the D_τ and Z -values. Together they are the basis for describing inactivation of microorganisms displaying log-linear kinetics as a function of time and temperature. D_τ , the decimal reduction time is defined as the time needed to reduce the viable microorganism count by 1 log at a particular temperature, t . The basic procedure for obtaining these two parameters is to determine the log reduction, $\lg N_0/N$ (where N_0 is the initial microorganism concentration and N is the surviving microorganisms) as a function of time at a specific temperature, which leads to D_τ , then obtaining the values of D_τ at different temperatures which leads to Z [14].

Changes in the number of microorganisms within a specified time moment (τ) at a particular lethal temperature (T) is characterized by the equation:

$$\lg N_\tau = \lg N_0 - k\tau, \quad (1)$$

where N_0 – initial number of colony forming units before thermal treatment ($\text{CFU}\cdot\text{g}^{-1}$);
 N_τ – number of colony forming units surviving thermal treatment ($\text{CFU}\cdot\text{g}^{-1}$);
 τ – time required to reduce microorganism counts by 1 lg cycle, min;
 k – rate constant.

The rate constant can be expressed as follows:

$$k = \frac{\lg N_0 - \lg N_\tau}{\tau}. \quad (2)$$

If we assume that the D -value is expressed as the time in minutes (τ) to achieve a reduction ($\lg N_0 - \lg N_\tau$) in one lg cycle of aerobic colony forming units, the rate constant k can be expressed as:

$$k = \frac{1}{\tau} \text{ or } D = \frac{1}{k}. \quad (3)$$

On the other hand, the Z -value is defined as the temperature T difference ΔT required changing $\lg N_0 - \lg N_\tau$, by 1 lg ($^\circ\text{C}$) and the constant k can be expressed as:

$$k = \frac{1}{\Delta T} \text{ and } Z = \Delta T = \frac{1}{k}. \quad (4)$$

Two key parameters (D - and Z -values) are then determined from the survivor and resistance curves, respectively. The D -value represents a heating time that results in 90 % reduction of the existing microbial population [10].

Results and discussion

In order to ensure consistent quality and microbiological safety of thermally processed potato products with chicken meat in packaging, it is important to choose suitable heat treatment regimens based on the determined D and Z values. It is not possible to obtain an identical temperature and time profiles for each batch processed (in terms for any food products which undergo heat treatment), as it is affected by variable initial product temperature, product thermal diffusion, etc. [15]. The heat treatment process can be affected by several factors: variable heat transfer to the product surface (sterilization temperature, surface permeability coefficient); variable product and packaging characteristics (product formulation, product homogeneity, product thermo-physical properties, thermal diffusion, initial product temperature, amount of product inside packaging, total weight); variable quality of the initial product (initial product microbiological contamination) [16]. In order to apply the process of thermal treatment, it requires a broad understanding of the characteristics of the product and the potential presence of microorganisms [10]. Appropriate time and temperature combinations must be chosen to provide an excellent quality of the final product during the thermal treatment process [8].

The D -value was determined for thermal treatment in the autoclave. The D -value depends on the intensity of the chosen thermal treatment and the initial microbiological contamination level. The D -value, the decimal reduction time (τ), indicates the time required to kill 90 % of bacterial population (from $\lg N_0$ to $\lg N$) at a specific temperature.

The family of microbial survivor curves for the sterilization process of potato products with chicken meat have been calculated (equation 1) and shown in Fig. 1. The results of the calculated D -values from the experimental data are summarized in Table 1.

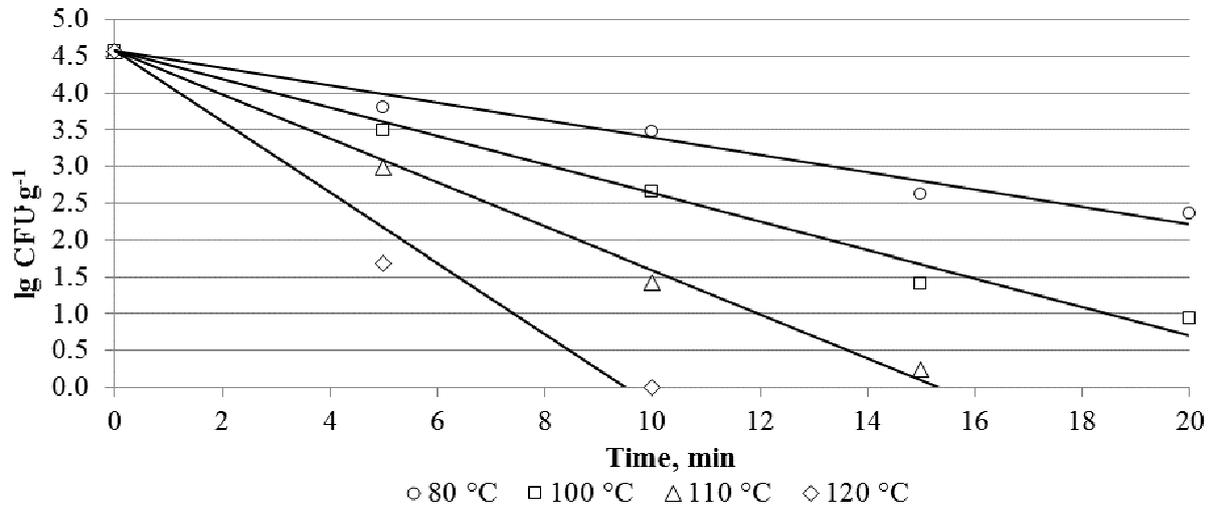


Fig. 1. Dynamics of TPC in potato products during thermal treatment at different temperature and time regimens

When potato products with chicken meat are processed at 120 ± 0.5 °C temperature, the obtained D -value is $D_{120} = 2.08$ min (Table 1), demonstrating that in order to reduce the number of microorganisms by 1 log cycle, when thermal treatment is carried out at 120 ± 0.5 °C temperature, the required time is 2.08 minutes. If the number of microorganisms should be reduced by two-log cycles, the total heat treatment time is $2 \times 2.08 = 4.16$ minutes. On the other hand, if the product should be processed at a lower temperature, e.g., 80 ± 0.5 °C, the D -value for 1 log cycle reduction of microorganisms is $D_{80} = 8.51$ minutes (Table 1).

Table 1

Calculated D -values for sterilization of potato products

Ambient temperature (T_{amb}), °C	Colony forming units function change	Rate constant k , min^{-1}	D -value, min
80 ± 0.5	$N_{T_{amb}} = 4.5682 - 0.1175\tau$	0.118	8.51
100 ± 0.5	$N_{T_{amb}} = 4.5682 - 0.193\tau$	0.193	5.18
110 ± 0.5	$N_{T_{amb}} = 4.5682 - 0.2982\tau$	0.298	3.35
120 ± 0.5	$N_{T_{amb}} = 4.5682 - 0.4811\tau$	0.481	2.08

Adjustment of the optimal heat treatment regimen for a particular type of product also requires the determination of the Z -value. The Z -value is characterized by the difference in temperature (°C) that is necessary to reduce the D -value by one lg [17].

The Z -value can be determined graphically according to the straight line linear equation $\lg D_{T_{amb}} = f(T_{amb})$ (Fig. 2):

$$\lg D = -0.0153 \cdot T_{amb} + 2.1842, \quad (5)$$

where reduction rate of the D -value is $k = 0.0153$ and T_{amb} = ambient temperature in retort. The Z -value at any ambient temperature in retort can be then calculated by equation (4) as ΔT :

$$Z = \frac{1}{k} = \frac{1}{0.0153} = 65. \quad (6)$$

The Z -value is defined as the temperature difference required changing D_r by 1 lg (°C). When reduction of the D -value is by 0.1 factors, the process could be characterized by the Z -value of 6.5 °C (6). Consequently, by the obtained equation (5), one can calculate the D -value of any provided

thermal treatment temperature (T) as chooses. For example, the Z -value for potato products processed at $+115\text{ }^{\circ}\text{C}$ temperature calculated by the given equation will be $D_{115} = 2.7$ min.

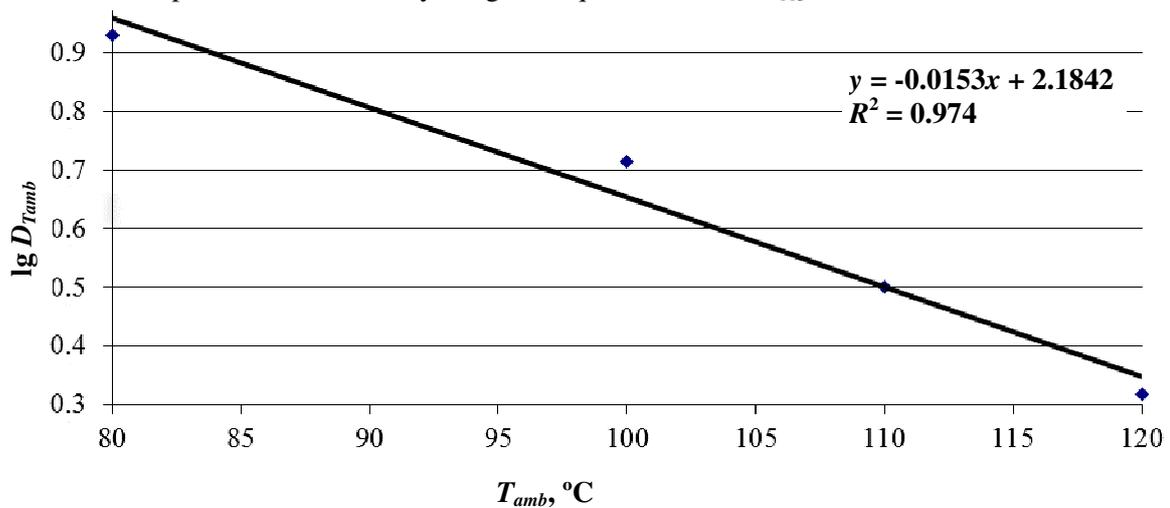


Fig. 2. Dynamics of $\lg D_{T_{amb}}$ in potato products with chicken meat during thermal treatment in retort as $\log D_{T_{amb}} = f(T_{amb})$, (T_{amb} – ambient temperature in retort; $D_{T_{amb}}$ – D -value at temperature T_{amb})

Duration of the thermal treatment process can be affected by several factors, mainly those of the product and packaging properties. Environmental temperature dynamics of the product and autoclave are shown in Fig. 3. Changes in the temperature of thermal treatment environment in the autoclave are marked with (1), and temperature changes in the core of the product are marked with (2). At the start of processing of potato products, the temperature difference inside the autoclave and in the core of the product was approximately $+5 \pm 0.5\text{ }^{\circ}\text{C}$.

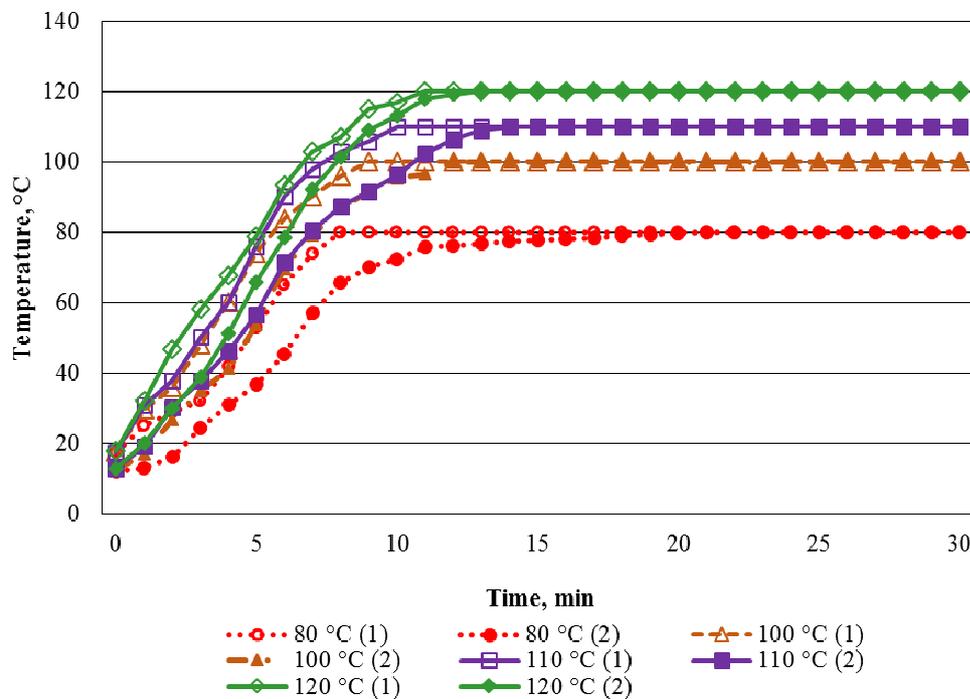


Fig. 3. Temperature changes in the thermal treatment chamber (1) and the product (2) during thermal treatment

The temperature measurements show that the desired temperature inside the product pouches can be reached in a shorter period of time with an increase in thermal treatment temperature, which allows to obtain the desired result more effectively.

Conclusions

1. Microbiological parameters of this study show that the optimal thermal treatment regimen for potato products with chicken fillet in retortable packaging is 120 ± 0.5 °C for 10 minutes, thus providing TPC decrease to zero CFU·g⁻¹.
2. Increase of the thermal cycle temperature from 100 °C to 120 °C decreased the *D*-value 1.6 times; however, increase from 80 °C to 100 °C lowered the *D*-value 2.5 times.
3. Retort pouches can be used in potato product thermal treatment in temperature up to 120 °C.

References

1. Hoffman R. Convenience foods and health in the elderly. *Maturitas*, vol. 86, 2016, pp. 1-2.
2. Stratakos A.C., Linton M., Patterson M. F., Koidis A. Effect of high-pressure processing on the shelf life, safety and organoleptic characteristics of lasagne ready meals during storage at refrigeration and abuse temperature. *Innovative Food Science & Emerging Technologies*, vol. 30, 2015, pp. 1-7.
3. Remnant J., Adam J. The nutritional content and cost of supermarket ready-meals. Cross-sectional analysis. *Appetite*, vol. 92, 2015, pp. 36-42.
4. Calderón L. A., Iglesias L., Laca A., Herrero M. The utility of Life Cycle Assessment in the ready meal food industry. *Resources, Conservation and Recycling*, vol. 54, 2010, pp. 1196-1207.
5. Mesías M., Wagner M., George S., Morales F.J. Impact of conventional sterilization and ohmic heating on the amino acid profile in vegetable baby foods. *Innovative Food Science & Emerging Technologies*, vol. 34, 2016, pp.24-28.
6. Daelman J., Vermeulen A., Willemyns T., Ongenaert R., Jacxsens L., Uyttendaele M., Devlieghere F. Growth/no growth models for heat-treated psychrotrophic *Bacillus cereus* spores under cold storage. *International Journal of Food Microbiology*, vol. 161, 2013, pp. 7-15.
7. Li X., Farid M. A Review on Recent Development in Non-Conventional Food Sterilization Technologies. *Journal of Food Engineering*, [online] [11.03.1016]. Available at: <http://www.sciencedirect.com/science/article/pii/S0260877416300589>.
8. Barbosa-Cánovas G.V., Medina-Meza I., Candoğan K., Bermúdez-Aguirre D. Advanced retorting, microwave assisted thermal sterilization (MATS), and pressure assisted thermal sterilization (PATS) to process meat products. *Meat Science*, vol. 98, 2014, pp. 420-434.
9. Byun Y., Bae H. J., Cooksey K., Whiteside S. Comparison of the quality and storage stability of salmon packaged in various retort pouches. *LWT - Food Science and Technology*, vol. 43, 2010, pp. 551-555.
10. Awuah G.B., Ramaswamy H.S., Economides A. Thermal processing and quality: principles and overview. *Chemical Engineering and Processing*, vol. 46, 2007, pp. 584-602.
11. Mullan, W.M.A. (2007). Calculator for determining the F value of a thermal process. [Online] [10.03.2016]. Available at: <https://www.dairyscience.info/index.php/calculators-models/85-articles/thermal-processing/134-f-value-thermal-process.html>.
12. Sergelidis D., Abraham A. Adaptive response of *Listeria monocytogenes* to heat and its impact on food safety. *Food Control*, vol. 20, 2009, pp. 1-10.
13. Rahman M. S., Guizani N., Al-Ruzeiki M. H. D- and Z-values of microflora in tuna mince during moist- and dry-heating. *LWT - Food Science and Technology* vol. 37, 2004, pp. 93-98.
14. Fleischman G.F. Reducing the experimental effort in measuring D and z values for microorganism inactivation kinetics. *Journal of Food Engineering*, vol. 155, 2015, pp. 1-9.
15. Baucour P., Cronin K., Stynes M. Process optimization strategies to diminish variability in the quality of discrete packaged foods during thermal processing. *Journal of Food Engineering*, vol. 60, 2003, pp. 147-155.
16. Ávila I.M.L.B., Martins R.C., Ho. P., Hendrickx M., Silva C.L.M. (2006) Variability in quality of white and green beans during in-pack sterilization. *Journal of Food Engineering*, vol. 73(2), pp. 149-156.
17. Diao M.M., André S., Membré J. M. Meta-analysis of D-values of proteolytic *Clostridium botulinum* and its surrogate strain *Clostridium sporogenes* PA 3679. *International Journal of Food Microbiology*, vol. 174, 2014, pp. 23-30.