Development of Mathematical Model for Calculation of Cooking Regimes of *Sous Vide* Packaged Mayonnaise-based Salad with Meat
Matemātiskā modeļa izstrāde termiskās apstrādes režīmu aprēķināšanai salātiem ar gaļu un majonēzi *sous vide* iepakojumā

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Abstract. Mayonnaise-based salad with meat has been identified as a ready-to-eat food with high incidence of microbial contamination. Experiments were carried out at the Department of Food Technology of the Latvia University of Agriculture to determine thermal inactivation (D-values and Z-values) of aerobic colony count (ACC) during pasteurization of *sous vide* packaged ready-to-eat mayonnaise-based salad with meat at the ambient temperature of t_a=+(50.0, 55.0, 60.0, 65.0, and 70.0)±0.5 ºC. The temperature of the product during thermal treatment process was measured in the core of the pouch every minute, and ACC colony forming units (cfu g^{-1}) were determined by standard procedures for fresh prepared salad at 0 minute of the experiment as well as after every 10, 20, 30 40, 50, 60, 70, 80, 90, 100, 110, and 120 thermal treatment minutes. The experiments proved that D-values, required for tenfold reduction of ACC population in mayonnaise-based salad with meat thermally treated in a water bath and a convection air/steam oven, are equivalent. The graphically calculated Z-values can be used to determine the pasteurization time at any ambient temperature in a water bath as well as in a convection air/steam oven. The pasteurization time for both thermal processes at one and the same temperature was equivalent.
Key words: D-value, mayonnaise-based salad with meat, *sous vide* packaging, Z-value.

Introduction

A mayonnaise-based salad with meat is a ready-to-eat product widely consumed in Latvia. It is consumed as an appetizer and side dish. Mayonnaise-based salads with meat belong to perishable foods having a short shelf life. A commercially made mayonnaise-based salad with meat can be obtained as a microbiologically stable food through applications of hurdle technological principles and Good Manufacturing and Hygiene Practices, and it needs refrigerated storage to achieve prolonged shelf life in order to be commercially viable (Muižniece-Brasava, Levkāne, Dukaļska, 2008). For such microbiologically stable, complex foods, end of shelf life is usually signalled by an unacceptable loss of sensory attributes (Juneja, 2006).

Sous vide packaging is successful for the shelf life extension of ready-to-eat foods. This technology has been used in restaurants, catering establishments and industrial processing companies. Many studies have proved that s*ous vide* packaging is effective particularly for meat and meat products (Church, Parsons, 1999; Juneja, 2006; Nishimura, Miyamoto, Higasa, 2004; O'Mahoney, O'Riordan et al., 2004; Rybka-Rodgers, 2001). Nowadays it is becoming increasingly popular, because it affords convenient, ready-to-eat foods of high sensory quality, prevents evaporation losses of water and flavour volatiles during heat treatment, at the same time also maintaining nutritional quality by reducing oxidative reactions of nutrients during preparation and storage (Carlin, 2000; Sheard, Rodger, 1995).

Sous vide packaging is an interrupted catering system in which raw or precooked foods are packaged under a vacuum in heat-stable, high barrier packaging materials, and then thermally treated (pasteurized) by controlled cooking in water, in hot air, or in water steam below +100.0 ºC. The heating is followed by rapid cooling. Afterwards the products are stored refrigerated at 0 to +4.0 ºC, and then distributed and retailed under refrigerated conditions so as to inhibit the growth of aerobic microorganisms (Armstrong, McIlveen, 2000; Cobos, Diaz, 2007). Some studies (Gonzalez-Fandos, Garcia-Linares et al., 2005; Nissen, Rosnes et al., 2002) declare results obtained from a three-year experimental *sous vide* packaged ready-to-eat food testing, and find that in such products the chances of survival and growth of pathogens seem very low since psychotropic, toxin-producing strains of *Bacillus* or *Clostridium spp.* are rare or nonexistent due to the low oxygen tension produced in foods. Therefore at low storage temperature the health risk of these products seems small. Thereby, according to microbial testing of ready-to-eat end products, *sous vide* packaged foods have received a lot of attention from the researchers (Nyati, 2000; Siripon, Tansakul, Mittal, 2007).

Pasteurization is critical to minimize the growth of spoilage microorganisms during storage of *sous vide* packaged foods. The processing parameters, however, should be kept at a minimum in order to retain maximum quality. The pasteurization parameters must be developed individually for each product (Ghazala, Ramaswang et al., 1995). The advantage is due to the reduction of natural spoilage bacteria via pasteurizing and storage under refrigeration conditions that limit competitive bacterial growth. To develop effectiveness of in-package thermal treatment processes for a mayonnaise-based salad with meat, the rate of inactivation of target microorganisms (i.e. *L. monocytogenes*, *Salmonella, S.aureus)* at various processing temperatures must first be determined (Mazzotta, 2001). To establish an effective heat processing treatment for production of a pathogen-free, ready-to-eat mayonnaise-based salad with meat, decimal reduction of microorganisms (D-values and Z-values) must be determined (Murphy, Marks et al., 2000). The term "D-value" refers to decimal reduction time and denotes the amount of time that it takes at a certain temperature to kill 90% of the organisms being studied. Thus, after an organism has been reduced by 1 D-value, only 10% of the original organisms remain. Z-value of an organism is the temperature, in degrees Celsius, that is required for the thermal destruction curve to move one log cycle. While the D-value shows the time needed at a certain temperature to kill an organism, the Z-value relates the resistance of an organism to differing temperatures. So, the Z-value allows calculating the thermal process of equivalency, if there is one D-value and the Z-value.*

The experiments were carried out to determine thermal inactivation (D-values and Z-values) of the aerobic colony count (ACC) of microorganism survival during pasteurization of a *sous vide* technology packaged, ready-to-eat mayonnaise-based salad with meat at various ambient temperatures in a water bath and a convection air/steam oven at t_a=+(50.0, 55.0, 60.0, 65.0, and 70.0)±0.5 ºC.

Materials and Methods

The experiments were carried out at the Department of Food Technology of the Latvia University of Agriculture in the year 2009. The object of the research was *sous vide* packaged mayonnaise-based salad with meat.

Materials. Mayonnaise-based salads with meat produced for a local market were used for the experiments. The ingredients of the salads were: boiled potatoes and eggs, cooked beef, pickled cucumbers, salt, and mayonnaise "Provansa" (containing ingredients: vegetable oil, water, dehydrated eggs, sugar, salt, acetic acid and citric acid as acidity regulators, as well as sodium bicarbonate, dehydrated yolk, thickening agent, xanthan gum as stabilizer, mustard seeds as flavouring, and potassium sorbate as preservative) produced by manufacturing company "Spilva" Ltd and purchased on a local supermarket. The experiments involved preparation of the precooked materials, vacuum packaging of the salads in polyamide/polyethylene (PA/PE) film pouches with high barrier properties (size – 200×300 mm, film thickness – 20/45 μm), and *sous vide* thermal processing. Mass of each sample was 200±1 g.

The thermal treatment of samples. The samples after packaging in pouches were vacuum-sealed by chamber-type machine Multivac C350. The samples were pasteurized by two thermal treatment methods:

a) in a water bath Clifton Food Range at the ambient temperature t_a=+(50.0, 55.0, 60.0, 65.0, and 70.0)±0.5 ºC. The thermal treatment time was within 120 min, while the core temperature

* All Experts Encyclopedia: D-value: http://www.associatepublisher.com/e/d/d/d-value.htm – Accessed on November 15, 2010.

of the samples was held constant at t_c=+(48.0, 53.0, 58.0, 63.0, and 68.0)±0.5 ºC;

b) in a convection air/steam oven FCV10E Tecnoinox at the ambient temperature t_a=+(50.0, 55.0, 60.0, 65.0, and 70.0)±0.5 ºC. The thermal treatment time was within 120 min, while the core temperature of the samples was held constant accordingly at t_c=+(48.0, 53.0, 58.0, 63.0, and 68.0)±0.5 ºC.

Immediately after preparation, all salad samples were frozen in Foster FXBC10 freezer at the temperature of -25 ºC, and were stored frozen at -18 ºC for one day.

The structure of the performed experiments. The temperature of the product in the core of the pouch during the thermal treatment process as well as the ambient temperature in the water bath and in the convection air/steam oven were measured every minute by Hanna Checktemp 1 thermometer.

The structure of the performed experiments is summarized in Fig. 1.

Microbiological analysis. Samples were kept frozen and, prior to testing, were defrosted at the ambient temperature of (+18.0)–(+27.0)±0.5 ºC for 1.5 hours in accordance with International Standard ISO 6887. The samples of fresh prepared salads were analyzed for ACC by standard procedure at zero minute of the experiment, and after every 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, and 120 minutes of thermal treatment. The ACC test was performed by the method of colony count technique at +30 ºC in accordance with International Standard ISO 4833:2003. The analyzed samples (amount of each sample – 10 g) were removed from packages and placed in a stomacher bag. Afterwards, 90 ml of 0.1% peptone water were added and then homogenized with the stomacher (Bag Mixer 400) for thirty seconds. After preparing serial decimal dilutions of the homogenate with 0.1% peptone water, duplicate plates were prepared using pour plate method for enumeration. The ACC was determined on Plate Count Agar and incubated at +30.0±1 ºC for 72.0±3 h. After an appropriate period of incubation (each plate containing 15–300 colonies), the ACC was summed up and multiplied by the dilution factor to determine CFU g^{-1} of sample. The results were evaluated by Guidance Note No. 3 "Guidelines for the Interpretation of Results of Microbiological Analysis of Some Ready-to-eat Foods Sampled at Point of Sale" (Food Safety …, 2001). According to the guidelines, salads were ascribed to the vegetable (prepared mixed salads and crudités) and meat food group (meat, sliced cooked ham, tongue), i.e., category D foods for which up to 10^6–10^7 cfu g^{-1} of ACC could be acceptable. The results were defined as satisfactory when ACC was $<10^6$ cfu g^{-1} (means that test results indicate good microbiological quality), as acceptable when ACC was within 10^6–10^7 cfu g^{-1}, and unsatisfactory when ACC was $\geq 10^7$ cfu g^{-1} (indicates that acceptability threshold has been exceeded). All the determinations were made in duplicate.

Determination of D- and Z-values. Vacuum-packaged samples were thermally treated in a water bath or a convection air/steam oven for pasteurization,

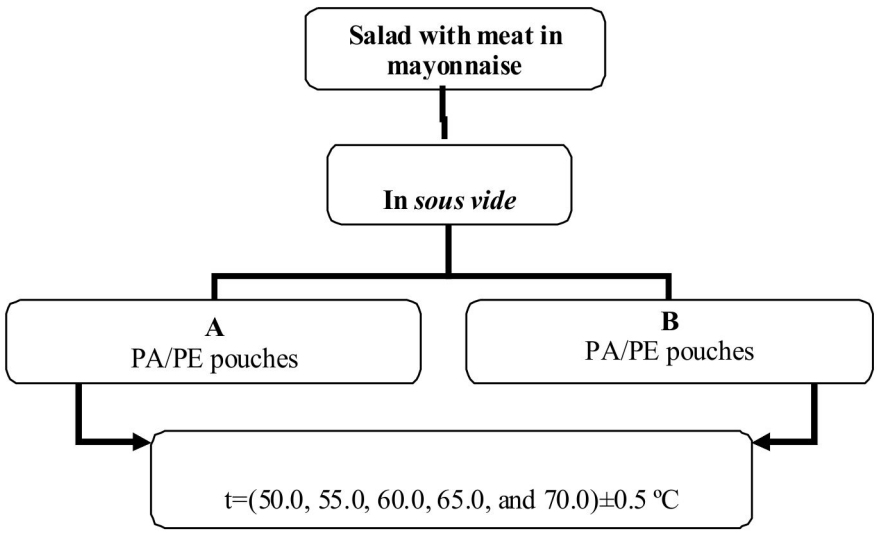

Fig. 1. The structure of the performed experiments:
A – sample pasteurization in a water bath; B – sample pasteurization in a convection steam oven.

and step by step at timed intervals were removed for analyses. D-values and Z-values were calculated graphically.

Thermal inactivation of bacteria known as a survivor curve generally follows first-order kinetics and can be described by logarithmic reduction in the concentration of bacteria with the time at any given lethal temperature (equation 1). The decimal reduction time D, is expressed as the time in minutes (in our experiments) to achieve one log cycle reduction of ACC survivor (from N_0 to N_τ). D-value is temperature-dependent and varies logarithmically with the temperature as log D=f(t). The slope of the curve that describes this relationship is expressed as the temperature difference Z-value, required for the curve to traverse one log cycle of D-value (Drive, Bozeman, 1999; Garbutt, 1997; McCormik, Han et al., 2003; Teixeira, 1992):

$$\log N_\tau = \log N_0 - k\tau \,, \qquad (1)$$

where

N_0 – aerobic colony forming units (cfu g^{-1}) at zero time (before pasteurization);

N_τ – aerobic colony forming units (cfu g^{-1}) after reduction of microorganisms by one log cycle;

τ – time for reduction of microorganisms by one log cycle, min;

k – rate constant.

The rate constant of the straight line can be expressed as follows:

$$k = \frac{\log N_0 - \log N_\tau}{\tau} \,. \qquad (2)$$

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

$$k = tg\alpha = \frac{1}{\tau} \quad \text{and} \quad D = \tau = \frac{1}{k}, \qquad (3)$$

where

α – a slope angle of straight line (equation 1).

Consequently, D-value can be expressed by equation (4):

$$D = \frac{\tau}{\log N_0 - \log N_\tau} \,. \qquad (4)$$

D- and Z-values are used to describe the thermal killing behaviour of microorganisms. These values are specific for each strain and can be used to compare the biological impact of different combinations of pasteurization temperature and holding time.

Statistical analysis. The results were processed by mathematical and statistical methods. Statistics on completely randomized design were determined using the General Linear Model (GLM) procedure SPSS, version 16.00. Two-way analyses of variance ($p \leq 0.05$) were used to determine significance of differences between means of microbiological properties.

Results and Discussion

Pasteurization is the most critical point of *sous vide* processing as it determines the sensory properties of a mayonnaise-based salad with meat and the quantity of microorganisms in the finished product. The pasteurization temperature of that product should not exceed 70 ºC because of the thermal sensibility of one of the main components of salad – mayonnaise which melting starts at a higher temperature. The rate at which the bacteria die depends on many factors, including temperature, added species, ingredients of salads, fat content, acidity, salt content, and water content. The addition of acids, salts or spices in mayonnaise can decrease the number of pathogens – this is why mayonnaise (with a pH less than 4.1) does not need to be cooked. Food additives – acidity regulators such as sodium lactate and calcium lactate – are often used in the food industry to reduce the risk of spore forming pathogens like *Clostridium spp*. and *Bacillus cereus* (Aran, 2001; Rybka-Rodgers, 2001).

The heating time of a mayonnaise-based salad with meat packaged in polymer pouches is calculated on the basis of achieving sufficient bacterial inactivation in each container in order to comply with the public health standards (Food Safety …, 2001).

The family of microbial survivor curves for the pasteurization process of *sous vide* packaged mayonnaise-based salads with meat in a water bath is shown in Fig. 2. The results of calculated D-values (equation 1) from the experimental data

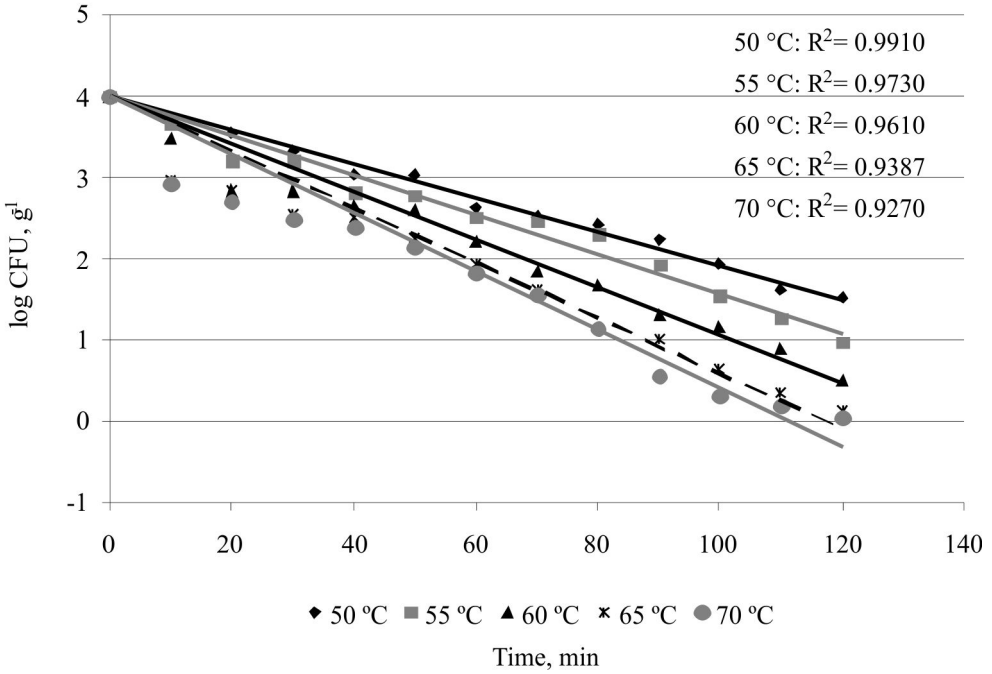

Fig. 2. Survivor curves (D-values) showing logarithmic order of death for ACC as the time (min) required for tenfold reduction in the microorganism population of sample A (pasteurization in a water bath).

Table 1

Calculation of D-values for pasteurization of a mayonnaise-based salad with meat in a water bath (sample A)

Ambient temperature (t_a), ºC	Equation of the straight line $\log N_\tau = \log N_0 - k\tau$	R^2	Rate constant k, min^{-1} $k = tg\alpha = \frac{1}{\tau}$	D-value, min $D = \tau = \frac{1}{k}$
50±0.5	N_τ=3.9900-0.0207 τ	R^2=0.9910	0.0207	48.31
55±0.5	N_τ=3.9900-0.0243 τ	R^2=0.9730	0.0243	41.15
60±0.5	N_τ=3.9900-0.0295 τ	R^2=0.9610	0.0295	33.90
65±0.5	N_τ=3.9900-0.0340 τ	R^2=0.9387	0.0340	29.41
70±0.5	N_τ=3.9900-0.0360 τ	R^2=0.9270	0.0360	27.78

of *sous vide* thermal treatment process in the water bath are summarized in Table 1.

The decimal reduction time (D-value) is expressed as the time in minutes to achieve one log cycle of reduction in the concentration of ACC (N). D-value is temperature-dependent and varies logarithmically with the temperature difference (Z-value expressed as temperature in ºC) required for the curve to traverse one log cycle.

When the ambient temperature of 70 ºC was provided in the water bath, the calculated D-value (D_{70}) was 27.78 minutes (Table 1) for each log cycle reduction in the population, for example, if a three-log cycle reduction is required, the total time of 3×27.78=83.34 minutes will be required for the given ambient temperature. Whereas if the ambient temperature in the heating retort is established lower, for example, 50 ºC, the calculated D_{50}-value will be higher – 48.31 minutes for each log cycle reduction in the population, and 3×48.31=144.93 minutes will be required for a three-log cycle reduction at the ambient temperature of 50 C.

The family of microbial survivor curves for the pasteurization process of *sous vide* packaged mayonnaise-based salads with meat in a convection air/steam oven is shown in Fig. 3. The results of calculated D-values (equation 1) from the experimental data of *sous vide* thermal

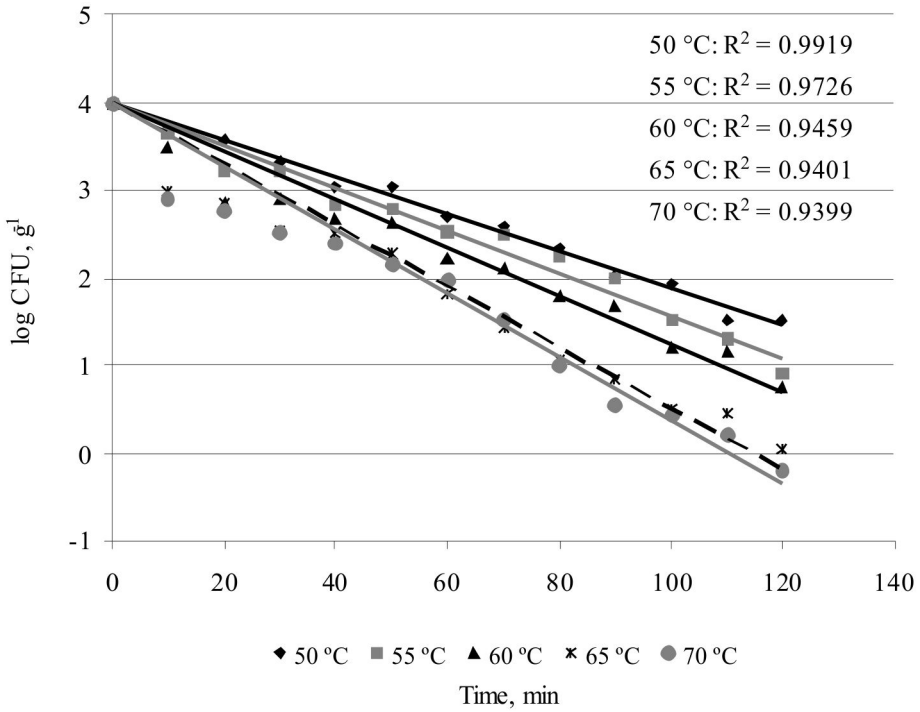

Fig. 3. Survivor curves (D-values) showing logarithmic order of death for ACC as the time (min) required for tenfold reduction in the microorganism population of sample B (pasteurization in a convection air/steam oven).

treatment process in the convection air/steam oven are summarized in Table 2.

When the ambient temperature of 70.0 ºC was provided in the convection air/steam oven, the calculated D-value (D_{70}) was 27.62 minutes (Table 2) for each log cycle reduction in the population. If a three-log cycle reduction is required, the total time of 3×27.62=82.86 minutes will be required for the given ambient temperature; whereas if the ambient temperature in the heating retort is established lower (50.0 ºC) than that mentioned above, the D_{50}-value will be higher – 46.08 minutes for each log cycle reduction in the population, and 3×46.08=138.24 minutes will be required for a three-log cycle reduction at the given ambient temperature.

The D-value of particular microorganisms will decrease exponentially with the increase in the temperature (Hyytia-Trees, Skytta et al., 2000; Murina, Quimby et al., 2002). A line-of-best-fit is a statistically correct method for representing our data points (Figs 4 and 5).

Table 2

Calculation of D-values for pasteurization of a mayonnaise-based salad with meat in a convection air/steam oven (sample B)

Ambient temperature (t_a), ºC	Equation of the straight line $\log N_\tau = \log N_0 - k\tau$	R^2	Rate constant k, min^{-1} $k = tg\alpha = \frac{1}{\tau}$	D-value, min $D = \tau = \frac{1}{k}$
50±0.5	N_τ=3.9900-0.0212 τ	R^2=0.9919	0.0212	46.08
55±0.5	N_τ=3.9900-0.0243 τ	R^2=0.9726	0.0243	41.15
60±0.5	N_τ=3.9900-0.0274 τ	R^2=0.9459	0.0274	36.50
65±0.5	N_τ=3.9900-0.0348 τ	R^2=0.9401	0.0348	28.74
70±0.5	N_τ=3.9900-0.0362 τ	R^2=0.9399	0.0362	27.62

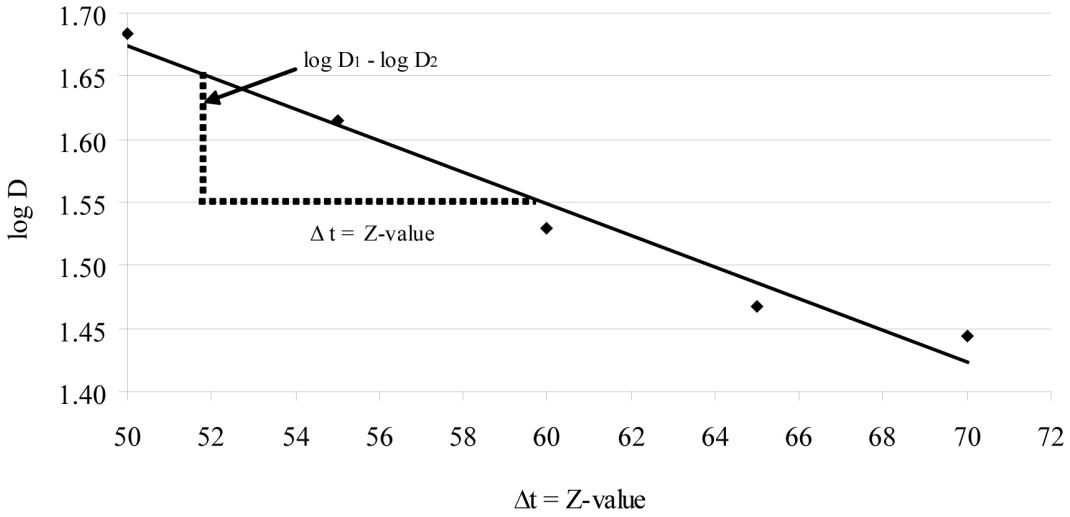

Fig. 4. The dynamics of ACC in a *sous vide* packaged mayonnaise-based salad with meat during thermal treatment process in a water bath (sample A) as log D=f(t).

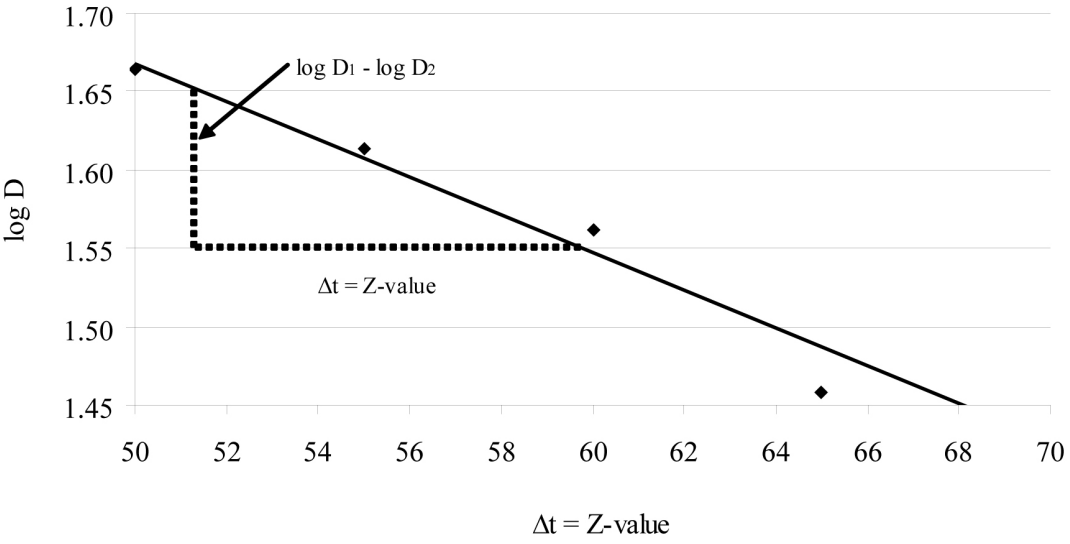

Fig. 5. The dynamics of ACC in a *sous vide* packaged mayonnaise-based salad with meat during thermal treatment process in a convection air/steam oven (sample B) as log D=f(t).

When depicting the Z-value of sample A (pasteurization in the water bath) graphically (Fig. 4), the calculated D-values and temperature pairs (Table 1) were plotted on a semi-logarithmic graph and the straight line was described by equations 5 and 6 (R^2=0.9702):

$$\log D = -0.0125t + 2.2992, \quad (5)$$

$$D = 10^{-0.0125t+2.2992}, \quad (6)$$

where

t – ambient temperature in the water bath, °C.

The calculated Z-value, required to change the D-value by one factor of 10 can be 79.81 ºC (equation 5). In our experiment, the calculated D-values were from 48.31 to 27.78 (Table 1), therefore the Z-value could be related to reduction of D-value by 0.1 factors, and the process could be characterized by Z-value of 8.0 ºC.

When depicting the Z-value of sample B (pasteurization in the convection air/steam oven) graphically (Fig. 5), the calculated D-values and temperature pairs (Table 2) were plotted on a semi-logarithmic graph and the straight line was described by equations 7 and 8 (R^2 = 0.9649):

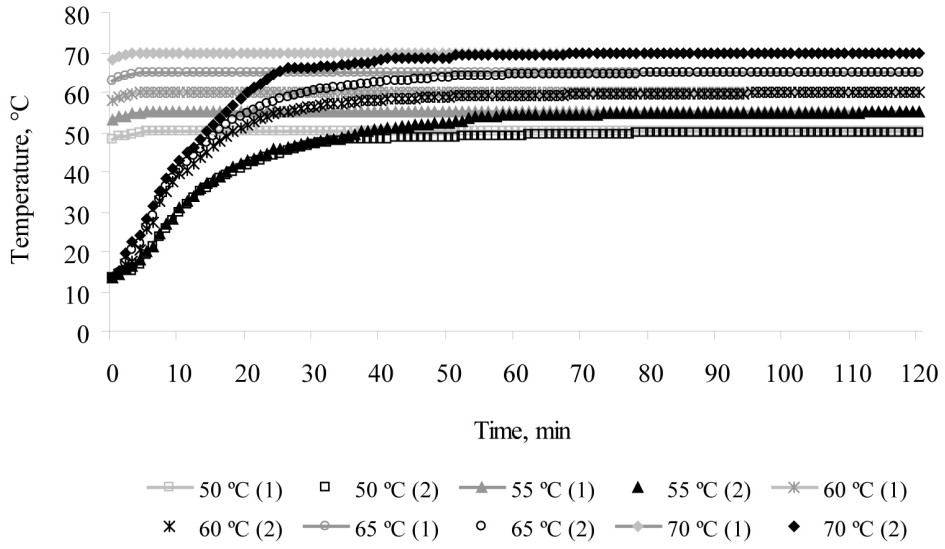

Fig. 6. Heat penetration curves for sample A (pasteurization in a water bath) showing ambient temperature (1) and temperature of food (2) in the core of the pouch.

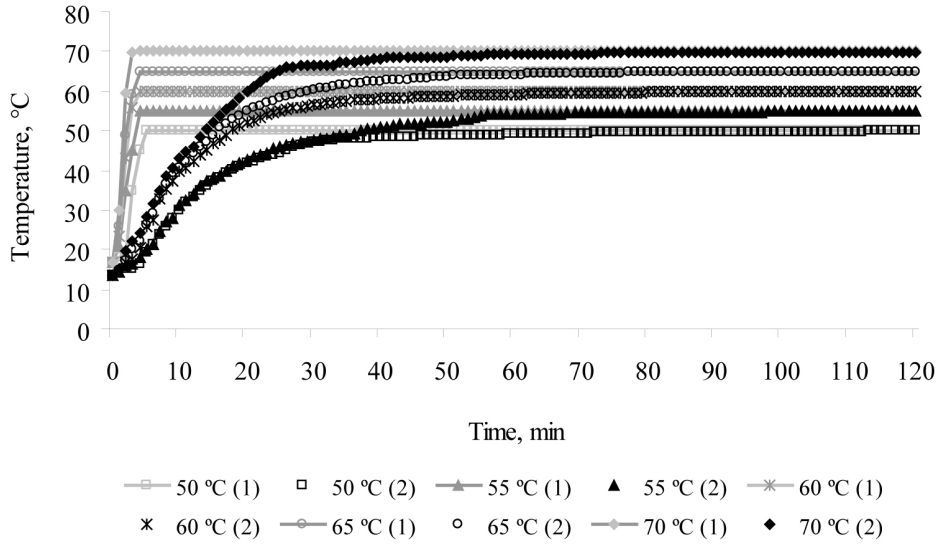

Fig. 7. Heat penetration curves for sample B (pasteurization in a convection steam oven) showing ambient temperature (1) and temperature of food (2) in the core of the pouch.

$$\log D = -0.0120t + 2.2702, \quad (7)$$

$$D = 10^{-0.0120t+2.2702}, \quad (8)$$

where

t – ambient temperature in the convection steam oven, °C.

For sample B, the calculated D-values were from 46.08 to 27.62 (Table 2), therefore also the Z-value could be related to the reduction of D-value by 0.1 factors and the process could be characterized by Z-value of 8.3 ºC, which is similar to that in sample A. Significant differences for Z-values between sample A and sample B were not found (p>0.05). The straight lines shown in Figs 4 and 5 are known as the thermal death time (TDT) curves. The slope of those curves reflects the temperature dependency of D-value and is used to derive the temperature dependency factor Z, which is expressed as the temperature difference required for the curve to traverse one log cycle.

Once the TDT curve has been established for the given microorganisms, it can be used to calculate

the time–temperature requirements for any idealized thermal process. Using equations 6 and 8 we can calculate the corresponding D-value responding to any ambient temperature in the heating retort. For example, assuming a process is required that would achieve one log cycle reduction in the population of microorganisms in a mayonnaise-based salad with meat, whose kinetics is described by a TDT curve (Z-value) in Fig. 5, and that the temperature in the heating retort is chosen 67.0 ºC for thermal treatment of sample A (pasteurization in a water bath), the calculated D-value will be D_{67}=29.3 minutes.

The temperature of the mayonnaise-based salad with meat (T) developed in the pouch during pasteurization is a function of the ambient temperature (t_a) in the retort, initial temperature (T_1) of the product, location of the product within the pouch (x), thermal diffusivity of the product (α), and the time (τ) in the case of the conductive heating method: $T=f(t_a, T_1, x, \alpha, \tau)$ (Teixeira, 1992).

The temperature/time plot of the experimental data for heating of a mayonnaise-based salad with meat in polymer pouches for samples A and B is shown in Figs 6 and 7. The degree to which the core centre temperature of the product can lag behind the ambient temperature during heating is illustrated. It is seen that increase in temperature in the core of pouches and warming-up time depend on the ambient temperature in the heating retort. The warming-up time for sample A decreases from 48.31 minutes (t_a=50.0 ºC) to 27.78 minutes (t_a=70.0 ºC), but for sample B – from 46.08 minutes (t_a=50.0 ºC) to 27.62 minutes (t_a=70.0 ºC) depending on the temperature in the water bath and the convection steam oven. The duration of pasteurization for sample A (pasteurization in the water bath) is from 48.31 to 27.78 minutes, but for sample B (pasteurization in the convection steam oven) – from 46.08 to 27.62 minutes. During that time the total count of bacteria in both cases decreased by 90% compared with the initial count of bacteria in the salad with meat in mayonnaise.

The difference in the initial points of ambient temperatures in the water bath and the convection air/steam oven could be explained by the accepted constant temperature t_a=+(50.0, 55.0, 60.0, 65.0, and 70.0)±0.5 ºC at which the samples were placed in the water bath; whereas in the convection air/steam oven the samples were inserted at 16.8 ºC and approximately 5 minutes passed to reach the accepted ambient temperature similar to that in the water bath.

The total count of microorganisms in the mayonnaise-based salad with meat during pasteurization in the water bath decreased from 4.0 log cfu g^{-1} to 2.8 log cfu g^{-1}, and in the convection air/steam oven – from 4.0 log cfu g^{-1} to 2.9 log cfu g^{-1} (Levkane, Muizniece-Brasava, 2009). No growth of microorganisms in *sous vide* packaged mayonnaise-based salad with meat was observed during the chilled storage within 52 days after pasteurization, and good quality and sensory properties were maintained (Levkane, Muizniece-Brasava et al., 2009).

Conclusion

The experiments proved that D-values, required for tenfold reduction of the total ACC in mayonnaise-based salad with meat thermally treated in a water bath and in a convection air/steam oven, are equivalent.

The graphically calculated Z-values can be used to determine the pasteurization time of mayonnaise-based salad with meat at any ambient temperature in a water bath and in a convection steam oven. The thermal treatment time for pasteurization in a water bath and in a convection steam oven at one and the same temperature is equivalent.

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Anotācija

Lietošanai gatavi ēdieni, tajā skaitā salāti ar majonēzi, tiek uzskatīti par ātrbojīgiem pārtikas produktiem, kuriem praksē ļoti bieži ir palielināts mikrobioloģiskais piesārņojums. Eksperimenti veikti Latvijas Lauksaimniecības Universitātes Pārtikas tehnoloģijas fakultātē. Pētījumu mērķis – izstrādāt termiskās apstrādes matemātisko modeli (D vērtības un Z vērtības) izdzīvojušo mikroorganismu skaita noteikšanai salātos ar gaļu un majonēzi *sous vide* iepakojumā atšķirīgā sildošās vides temperatūrā. Paraugus *sous vide* iepakojumā pasterizēja, izmantojot dažādas termiskās apstrādes metodes: ūdens vannā un konvekcijas krāsnī gaisa/tvaika vidē. Apkārtējā vides temperatūra ūdens vannā un konvekcijas krāsnī bija: t_a=+(50.0, 55.0, 60.0, 65.0 un 70.0)±0.5 °C. Produkta temperatūru termiskās apstrādes procesā mērīja iepakojuma centrā katru minūti, un kopējo mikroorganismu skaitu ar standarta procedūrām noteica svaigi sagatavotiem salātiem pirms iepakošanas 0 minūtē un pēc tam ik pēc 10, 20, 30 40, 50, 60, 70, 80, 90, 100, 110 un 120 termiskās apstrādes minūtēm. Eksperimentāli noteikts, ka D vērtība, kas nepieciešama kopējo mikroorganismu skaita samazināšanai par vienu lg ciklu, paraugus termiski apstrādājot gan ūdens vannā, gan gaisa/tvaika konvekcijas krāsnī, ir līdzvērtīga. Grafiski aprēķināto Z vērtību var lietot pasterizācijas laika (min) aprēķināšanai jebkurā sildošās vides temperatūrā gan ūdens vannā, gan gaisa/tvaika konvekcijas krāsnī. Pasterizācijas ilgums abos termiskās apstrādes procesos vienā un tajā pašā sildošās vides temperatūrā bija līdzvērtīgs.