Thermal penetration study for the purpose of formulating sterilization procedures of yellowfin tuna canning

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Abstract. This study aims to provide the community-based business with simple to follow procedures in the sterilization of canned yellowfin tuna. Two filling mediums, brine and palm oil were used. The thermal treatment process was performed using a small business scale retort of 24L. The process is divided into three stages: heating, holding temperature and cooling stage. The targeted temperature at the holding stage was set at 121.1°C for 50 minutes and measured using a thermocouple gland placed inside the retort. Two more thermocouple glands were placed inside the cans to record the product core temperature. During the heating stage, a time lag of 20 minutes was observed for the palm oil tuna to reach the same holding temperature as the brine tuna. The lethality rate $F_h$ during heating stage was 2.52 and 8.69 minute for brine and palm oil respectively. Lethality rate at the holding temperature stage $F_{121.1}$ was 49.23 for brine and 38.96 for palm oil. The lethality rate $F_{cl}$ of both products were closed at 2.3 and 1.93 minutes respectively for brine and palm oil. The total $F_0$ value were 54.05 and 49.58 minutes respectively for tuna in brine and tuna in palm oil.

1. Introduction
Food preservation practices have been widely adopted for human living since the beginning of nineteenth century, including preservation by canning. Canned food is produced by introducing heat into food or using thermal processing, either in a sealed container or by passing it through heat exchanger and followed by packaging. The heating process can be in a batch or continuous using heating for the most part of the process and cooling the product as quickly as possible to end the process. The heating medium can be saturated steam or hot water which at 100°C both are above atmospheric pressure [1].

The main reason for heating foods is to kill pathogenic and spoilage microorganisms as well as to inactivate enzymes that they produced. Heating also induces physical changes and facilitated chemical reactions which can affect color, flavor, texture and most importantly nutritional value of food. There are two major issues related with thermal processing of food, i.e., food safety and food quality, where the conflicts between these two issues cannot be avoided. The spore of Clostridium botulinum is one of dangerous heat-resistance pathogenic bacteria that most likely to be present in canned fish. However, the most heat-resistance one is actually Bacillus stearothermophilus [2]. These bacteria and their active spores are not allowed to be present in canned food. Therefore, before applying heat
treatment and preserving foods, it is very critical to understand the reaction kinetics and its relation to microbial inactivation, chemical damage, and physical changes of food as well as on how to minimize sensory and nutritional reduction [1]. Significant reduction of essential fatty acids due to different heat treatment on tuna processing had been reported [3].

In order to produce a sterile product, the length of sterilization time at a recommendation temperature (121.1°C) must be calculated carefully [4]. This is related with the destruction of microorganisms that takes place logarithmically during canning process. Therefore, the term “commercial sterility” is crucial to be understood. This means “in practice that the heat processing inactivates substantially all microorganisms and spores which, if present, would be capable of growing in the food under defined storage conditions” [5]. The main concern during canning is to destroy bacteria and their spores completely and in case the spores are still exist in a canned product, they are not able to reproduce new bacteria but remain inactive throughout storage period in room temperature. The rate of survival spoilage microorganism is determined by the type of microorganisms that possibly contaminated the raw fish before canning.

Thermal processing of fish must consider the calculation of $D$ value, $z$ value, $F_0$ value and lethality rate. According to [4] and [5], the $D$ value is known as the decimal reduction time of a specific microorganism. The $z$ value is the temperature change which results in a tenfold change in the decimal reduction time. A reference $F_0$ value is used to describe processes that operate at 121ºC which are based on a microorganism with a $z$ value of 10ºC.

This study was designed to determine the sterilization process through temperature build-up and processing time for canning the yellowfin tuna that are suitable for community-based business in a small scale, particularly in Aceh Province. One of the study related with heat penetration in home canning had been done previously [6] as well as a study that investigated different filling mediums in canned tuna [7]. This investigation used specific retort volume, can dimensions, type of mediums, the volume of medium added and a certain weight of pre-cook tuna. The arrangement of cans inside the retort chamber might be different with other canning practices. Therefore, a heat penetration study was a fundamental step that must be carried out in the beginning of the whole process including determination of lethality rate in canned tuna, calculation of the $F_0$ value and validation of the sterilization process.

2. Materials and methods

2.1. Sterilization equipment and thermal recording process

A large diameter food steamer was used for exhausting prior to seaming. This step allowed oxygen to escape from tuna and filling materials avoiding the product from having air pocket. For the thermal treatment, it was conducted using a 24-liter All American (USA) pressure canner. Two temperatures were measured during sterilization, i.e. the retort interior temperature and the core of the canned tuna temperature. The measurements were taken using Ellab thermocouple gland with built-in logger (TSP Micro, Ellab, Denmark). To measure the retort temperature, the thermocouple was placed right above the water level in the lower part of the retort. While the core product temperature was measured by placing the thermocouple inside the cans before seaming. Thanks to the thermocouple miniature size. This thermocouple was positioning in the base of the can pointing upward to the geometric center and was held in the middle of the can by stuffing tuna meat. The recorded temperatures were converted into data using a docking system (Pro Multi Reader, Ellab, Denmark) and an application software (ValSuite Pro, Ellab).

2.2. Tuna preparation, seaming and thermal processing

Tuna was handling as quickly as possible before canning. All of the canning process was carried out in a laboratory, particularly for tuna preparation (washing, filleting, peeling, cutting), pre-cooking, filling, brining, can-seaming and sterilization process. The laboratory is located within 5 minutes from the nearby fishing port (Lampulo, Banda Aceh) where a 48 kg freshly landed yellowfin tuna (Thunnus
albacares) was purchased. After cleaning the fish which included beheaded, gutted, skinned, tuna was cut into blocks (weighing 0.5 - 1 kg) and frozen. At the day of canning and sterilization process, tuna was thawed first. When it reached the room temperature, the yellowfin tuna was pre-cooked for 15 minutes at 80°C. Pre-cooking process was actually a steaming process, particularly aimed at partially dehydrate the flesh and reduce the strong fishy odor. The pre-cooked tuna was covered and brought to room temperature for red meat removal stage. Only the white meat was selected and used for canning process. Portions of white meat (80 ± 0.01 g), which consist of tuna chunks and flakes, were positioned into a can (7.3 cm in diameter and 5.6 cm in height). Then 80 ml filling medium was added to each can and the necessary headspace (± 1.5 cm) was left to absorb the exerted pressure during thermal treatment. Two kinds of filling mediums were used. Each batch was fills with the same filling medium for consistency and uniformity. The first batch was filled with 5% brine and the second batch was using palm oil. The cans were loaded into the large steamer for exhausting. The steamer was operated to transfer the heat from generated steam into the core of the product to at least 80°C for the duration of 10 minutes. Immediately after exhausting, the cans were covered with the lids and ready for double seaming process using semitro can seamer.

Prepared cans with the same filling medium were loaded into the retort. The sterilization process started when the core temperature of canned tuna reaching 82.2°C. This was called the heating stage which ended when the core reaching 121.1°C (holding temperature). The later stage was the holding temperature stage where the core temperature was kept constant at the holding temperature 121.1°C through maintaining the retort at the same temperature. This was the stage where the lethality was predictable and hence became controllable through regulating the time. The last stage was cooling stage, where the retort was removed from the heat source and cans were cooled under running tab water. The success of the sterilization process was determined by the duration of time where the product core temperature at the slowest heating point (SHP) reached the holding temperature at 121.1°C and it was called the $F_0$ value. $F_0$ value was determined by the heat penetration mechanism from the retort into the core of the product. While the retort temperature can be easily measure, the core temperature cannot be measured without penetrating and thus forfeiting the product. However, if similar equipment, materials (including can dimension and the amount of filling) as well as methods were consistently repeated in every process, the same thermal penetration could be reproduced. Thus ensuring the desired $F_0$ value was obtainable in every sterilization process.

The holding temperature was also introduced to minimize uncertainty. In this study, the holding temperature was set to last for 50 minutes. This would ensure adequate lethality rate was obtained that can be used in controlling the process to obtain the targeted $F_0$ value. Thermocouple glands were used to record the dynamic of temperature changes through the entire process with the resolution of 10 second.

2.3. Bacteria thermal destruction and $F_0$ value
The important factor to consider in this canning process is in obtaining the sufficient heat treatment. This is quantified as $F_0$ value. $F_0$ has a unit in minute to indicate lethality that has been accumulated during heat treatment with regard to bacterial destruction. The $F_0$ value was determined by the product core temperature plot versus time according to the following formula [2].

$$F_0 = \int_0^t 10^{\frac{(T-121.1)}{z}} \, dt$$

where $t =$ time (min), $T =$ core temperature (°C) and $z =$ required temperature addition to accelerate decimal reduction time ($D$) by tenfold (°C). The constant 121.1 is the reference temperature where the controllable rate of destruction is expected. Notice that when $T$ equals 121.1, $F_0$ is simply identical to time $t$ in minute.
3. Results and Discussion

**Characteristic of thermal penetration for different filling mediums**

The recorded temperature versus time in the retort (dashed line) and the core (solid line) of canned yellowfin tuna in brine and palm oil are depicted in Figure 1 and Figure 2 respectively. The recorded retort temperature in both experiments show consistency of the equipment used for sterilization. Which is important in formulating a standard procedure for canning. In addition, both graphs show the canned yellowfin tunas preserved the remaining heat (solid line) acquired from the previous exhausting process. Thus the products temperature were higher initially than the canner chamber.
temperature. It required more than 10 minutes for the canner to take over the product temperature. But the sterilization did not begin until the core temperature reached 82.2°C. This was the temperature where the destruction of bacteria, in particular Clostridium botulinum spores, starts to take place. The minimum $F_0$ value recommended for Clostridium botulinum is 2.52 min [7], which associated to 12 D (see Equation 1) as the minimum process to achieve adequate inactivation of this particular bacteria [8].

The sterilization process started with the heating stage when the products core temperature reached 82.2°C. The thermal penetration into the products continued as the retort temperature increased to reach 121.1°C where it was maintained for the next 50 minutes as the holding temperature. The heating stage still continued and ended when the core temperature matched the holding temperature and the holding temperature stage began. This was occurred around 47 and 59 minutes from the initial process time respectively for brine and palm oil.

\[ L_h = \log^{-1}(\frac{T_h - 121.1}{10}) \]  
\[ L_{cl} = \log^{-1}(\frac{T_{cl} - 121.1}{10}) \]

It can be easily seen from Equation 2 and Equation 3 that when the core temperature equaled the chamber’s (holding temperature stage) the lethality value becomes constant

\[ L_{121.1} = \log^{-1}(\frac{121.1 - 121.1}{10}) = 1 \]
Figure 4. Lethality during heating and cooling for yellowfin tuna in palm oil in accordance with the product core temperature

The lethality during heating and cooling stages were calculated with Equation 2 and Equation 3. The results are charted in Figure 3 for tuna in brine and Figure 4 for tuna in palm oil. The area under the lethality curves can be calculated as $F_0$ value expressed in Equation 1. This value reflects the lethality rate imposed by thermal penetration during heating $F_h$ and cooling stage $F_{cl}$. The results of the calculation of lethality rate are summarized in Table 1. The lethality rate during the holding temperature stage $F_{121.1}$ will be equaled with time in minute and are given in Table 2.

| Table 1. Thermal penetration properties of yellowfin tuna in brine and in palm oil |
|---------------------------------------------|-----------------|---------------------|-----------------|-----------------|
| Product                          | $F_0$ heating stage, $F_h$ (minute) | $F_0$ cooling stage, $F_{cl}$ (minute) | $F_h + F_{cl}$ (minute) | actual process time, $t_h$ and $t_{cl}$ (minute) |
| Yellowfin tuna in brine          | 2.52            | 2.30                | 4.82             | 15 | 6                  |
| Yellowfin tuna in palm oil       | 8.69            | 1.93                | 10.62            | 26 | 4                  |

Table 2. Lethality rate of holding temperature stage for 50 minutes retort holding temperature

| Product                          | $F_{121.1}$ (minute) | actual process time, $t_{121.1}$ (minute) |
|---------------------------------|----------------------|------------------------------------------|
| Yellowfin tuna in brine         | 49.23                | 49.23                                    |
| Yellowfin tuna in palm oil      | 38.96                | 38.96                                    |

The yellowfin in palm oil exhibited slower heat accumulation and required longer time than tuna in brine to reach temperature uniformity in the retort. As the result, its $F_h$ was significantly higher than tuna in brine in the heating stage. While the differences in fillings did not exhibit significant time lag in the cooling stage since the cooling was forced immediately under running tab water hence the
nearby $F_{ct}$. The total $F_0$ value were 54.05 minute and 49.58 minute respectively for tuna in brine and palm oil. As the purposes of thermal process are to meet the safety requirement as well as sensory characteristic and preserving nutrition benefits, a certain $F_0$ value has to be met. Following the results in this section the total $F_0$ value can be easily adjusted at the holding temperature stage providing with knowledge of $F_h$ and $F_{ct}$.

4. Conclusion
The thermal treatment of yellowfin tuna is intended to make the food safe for consumption to a finite period of time while continuously stored in room temperature. $F_0$ value is the standard parameter used for indication of success of a thermal treatment. $F_0$ values were greatly affected by filling material during heating and cooling stage. But when the core reached the holding temperature at 121.1 °C, $F_0$ value was identical with time in minute. In the laboratory experiment, yellowfin tuna in brine showed better heat penetration than yellowfin in palm oil hence it was faster to reach the holding temperature in 15 minutes compared to 26 minutes. But the former only registered about a third $F_0$ value of the latter (2.52 to 8.69 minutes). Despite the differences during heating stage, the rate of cooling was almost similar between the two. The results from this experiment can be reproduced to obtained similar $F_0$ value providing the same equipment and materials are used. In order to obtain a recommended $F_0$ value, which is higher than $F_h + F_{ct}$, can be added through regulating the holding temperature time. However, $F_0$ is not the only parameter to decide the safety of a fish canning product. Further studies in the quality of the material such as assesment in the fish quality is equally important.

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