The use of ohmic heating in processing of food industry

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Abstract: - The aim of this work was to identify optimal pre-treatment conditions for cannellini beans in order to improve heating uniformity and, thus, the quality of product, during the subsequent sterilization process. Dry beans were blanched for different length of times (35 and 50 s) in a water bath set at 90°C after soaking (12 h) in tap water. Heating curves of solid-liquid mixtures (53g of beans/100g of mixture) of pre-treated beans and salt solution (1 g/100mL) were determined in a static ohmic heating device by applying a constant voltage of 100V. Results showed that the ohmic heating rate of beans increased with increasing the blanching time as a direct result of the increase of electrical conductivity. Optimal pre-treatment conditions, which allowed the ohmic heating of both phases of solid-liquid mixture at comparable rate, were found when beans were blanched for 50 s at 90°C. Beans pre-treated under optimal blanching conditions and sodium chloride solution (1g/100ml) (53g of beans/100g of mixture) were then subjected to both ohmic and in-container sterilization process. The solid-liquid mixture was sterilized at 121 °C for 10, 15 and 20 min. The parameters measured immediately before and after thermal treatments were: total microbial count, yeasts and molds, split degree, and proteins content. The experimental results have shown that, regardless the thermal method and treatment conditions the initial microbial spoilage was reduced up to below the detection limit of the method (<10 cfu/ml). When compared to the beans sterilized by conventional treatment, the samples treated by the ohmic method appeared of attractive appearance, with a lower split degree. The analyses of the chemical composition revealed a higher proteins concentration in sample processed by ohmic heating than those treated by conventional method.

Key-Words: - Ohmic heating, In-container sterilization, Cannellini beans, Heating uniformity Microbiological stability, Quality parameters.

1 Introduction

Traditional thermal preservation processes such as in-container sterilization or continuous flow aseptic processing of food products, are widely used in food industry to deliver shelf-stable food at ambient temperature [1]. However, because this methods rely on indirect mechanisms of heat transfer to food products, the overall quality of stabilized foods is typically poor, especially when fluids containing large particulates and fluids of high viscosity are processed [2].

Due to these drawbacks, the use of direct heating through a Joule effect, such as ohmic heating, has gained increased attention in the food industry.

Ohmic heating is distinguished from other electrical heating methods either by the presence of electrodes in direct contact with the food (as opposed to microwave and inductive heating, where electrodes are absent) or by the frequencies and waveforms used. In an ohmic heating processing, the food material (liquid, solid or particulate-liquid mixture) placed between the two electrodes of a ohmic heater acts as part of the electric circuit through which electric current (usually alternating) fed by a power supply flows. The heating occurs in the form of internal energy transformation (from electric to thermal) within the material as a result of its inherent electrical resistance [2].

Interestingly, in liquid-particulate food mixtures, ohmic processing enables, under certain circumstances, large particulate and carrier fluids to heat at comparable rates, increasing the final product quality and adding value to products [3]. This very desirable scenario, which is hardly achieved during conventional heating of solid-liquid mixture, depends on the relative conductivities of the system’s phases and the volume fractions of the respective phases [2]. Solids of low conductivity compared to liquid will lag behind if they are in low
concentration, but under high-concentration conditions, particles may heat faster than fluid [2]. In addition, vegetable and other food particles show a lower electrical conductivity than liquids. Therefore, adjustment of the heating pattern of solid-liquid systems by adjusting the overall influence of particles’ resistance in the system are required in order to ensure uniform heating of the solid-liquid suspension with reduced processing time and without any overheating.

The objectives of this work were i) to study the effect of different blanching conditions on the ohmic heating uniformity of a solid-liquid mixture composed by cannellini beans in salt solution; ii) to evaluate the impact of ohmic and conventional in container sterilization methods on safety, quality parameters, and nutritional value of pre-treated beans.

2 Problem Formulation

2.1 Raw material and pretreatments

Dried cannellini beans (Phaseolus vulgaris) were purchased from local market and used for the experiments.

The electrical conductivity of the beans after soaking (12 h) in tap water, estimated according to the method suggested by Kim et al. [7], was 1.4 mS/cm at 25°C. This value was well below to that of sodium chloride solution (1 g/100mL, 9 mS/cm) typically used as liquid phase during the in-container sterilization process of beans-liquid mixture. Therefore, in order to adjust the electrical conductivity of beans to that of sodium chloride solution, prior to ohmic processing of solid-liquid mixture, the beans were subjected to blanching pretreatments.

During blanching pretreatment, beans previously hydrated by soaking (12 h) in tap water at 25 °C were kept immersed into a water bath set at 90°C for either 35 or 50 s in order to increase the temperature of the core of the beans up to 70°C. The pretreated beans were then mixed with sodium chloride solution (1 g/100ml) in order to obtain beans/salt solution mixture containing 53 g of beans/100g of mixture. After the temperatures of both the solid and liquid phases were equilibrated to an initial value of about 25°C, the solid/liquid mixtures were subjected to ohmic heating from room temperature up to about 90°C by applying a constant voltage of 100V.

The experimental apparatus used to both measure the electrical conductivity of beans and test the heating uniformity of beans-liquid mixtures, consisted of a static ohmic heater of own construction made of a cylindrical polycarbonate tube closed at the ends with two plated stainless steel electrodes. The test cell diameter and the electrode gap used in this study were 3.5 and 5 cm, respectively. The electrodes were connected to a 15 kW power supply unit (model GR1520, Micropi Elettronica, Saviano, Italy) able to deliver up to a maximum a.c. voltage of 1500 V at 25 kHz. T-type Teflon coated thermocouples (1 mm in diameter) were used to measure the temperature of both the liquid phase and the geometric centre of the solid particle. Voltage and current transducers were used to measure the voltage across the samples and the current flowing through them.

A data logger linked to a computer was used to obtain the voltage, current, and temperature data at constant time intervals. The electrical conductivity (σ, in S/m) of the samples was evaluated by the following formula:

$$\sigma = \frac{L \cdot I}{A \cdot V}$$

where, L is the length of the sample (m), A is the cross sectional area of the sample (m2), I is the current flowing through the sample (A), and V is the voltage across the sample (V).

Three replicate experiments were conducted. Heating curves of solid and liquid phases of the mixture were obtained and compared. In deciding on the optimal pretreatment conditions, we chose those able to minimize the differences in heating rates between the solid and liquid phases.

2.2 Sterilization process

In order to prepare the samples for the sterilization process, the beans were first soaked and then subjected to blanching under the optimal processing conditions selected as described above. This practice is typically adopted at industrial level in order to induce softening of beans tissue and enhance the efficiency of the subsequent in-container sterilization process [2]. For each experimental run, the pretreated beans were mixed with sodium chloride solution (1 g/100ml) and the resulting beans/salt solution mixture (53 g of beans/100g of mixture) was subjected to sterilization process by either ohmic or in container sterilization treatment.

Ohmic process was carried out in the same laboratory scale batch unit described above, but with a different ohmic heater. The latter was made of a cylindrical polyether ether ketone (PEEK) tube (7.6 cm in diameter, 20 cm in length) with two inox
(AISI 316) electrodes isolated at each edge with Teflon pressure caps. The electrodes were provided with an internal cavity in which, during the cooling phase, water-ethylene glycol solution was recirculated from an external refrigerated bath. The shell of the plastic tube was provided with openings for temperature probe, pressure gauge, safety valve and pressurization system. A data-logger was employed to record continuously and simultaneously current intensity, voltage and product temperature, while a control system automatically adjusted the power required to heat the product up to the processing temperature as well as to maintain this temperature during all the holding phase.

During ohmic treatment, a batch of 661 g of beans/salt solution mixture (53 g of beans/100g of mixture) was loaded into the ohmic heater. Then, the solid/liquid mixture was heated by applying a constant peak to peak voltage of 1000 V in order to reach, within the selected heating time of 90 s, the processing temperature of 121±2°C °C and then maintained at this temperature for the following holding times: 10, 15, and 20 min. At the end of each holding phase, the power supply was turned off and the product was immediately cooled. Afterwards the product was rapidly removed from the ohmic heater under an aseptic laminar flow hood and filled into aseptic glass containers before the analysis.

For in-container sterilization process, batches of 283 g of beans/salt solution mixture (53 g of beans/100g of mixture) were introduced in glass containers. Then the containers were loaded in the autoclave (FVA-HT, Fedegari, Italy) and subjected to sterilization process at 121°C for three different holding time: 10, 15, and 20 min. At the end of the holding phase, the containers were cooled and stored at room temperature until analysis.

The microbiological stability of the raw and processed product was assessed by the total aerobic microorganisms count and yeasts and molds. The extent of splitting in the pretreated and sterilized beans was evaluate according to the method of Taiwo et al. [4].

Protein content (%Nx6.25) of raw, and processed beans was determined as described by Official Methods of Analysis of AOAC [5].

All the treatments and analyses, unless otherwise stated, were performed in triplicate, and the results were expressed as the average ± standard deviation. From the results it may be observed that more uniform ohmic heating of the product may be achieved by increasing the blanching time of solid component.

3 Problem Solution

3.1 Ohmic heating after blanching pre-treatment

The heating curves of beans-salt solution mixture (53 g of beans/100g of mixture) obtained after blanching of hydrated beans at 90°C in tap water for different lengths of time are shown in Fig. 1. In the same graphs also the heating curve obtained during the ohmic hating of the salt solution alone (L) is shown for the sake of comparison.

![Fig. 1. Heating curves of salt solution (1g/100mL) alone (L) and of salt solution (1g/100mL) (LM) mixed with beans (BM) (53 g of beans/100g of mixture) previously blanched at 90°C in tap water for (a) 35 and (b) 50 s.](image)
heated, structural changes like cell wall breakdown, tissue damage, increase of mobile moisture, starch gelatinization and softening may occur, affecting the electrical conductivity [6].

It is possible to further improve the above blanching protocols by either increasing blanching time, using different balnching medium or using different solid-liquid concentration if the composition and other properties of the food are not greatly affected.

In the following of this work, before of the sterilization process of beans, the latter were first subjected to blanching pre-treatment as described by the results of Fig. 1b.

3.2 Sterilization process

Data not shown revleal that, as expected, the ohmic treatment yielded a higher heating rate than during conventional method. The time required by the product to reach the processing temperature (121°C) was about 25 min during conventional method, while it was only 90 s during ohmic heating. After the heating phase, the processing temperature was maintained fixed for three different holding times (10, 15, and 20 min) for both ohmic and conventional method. At the end of the holding phase, cooling of the product was immediately start for both thermal treatments. Results revleal that, also during this phase, ohmic unit allowed to cool the product faster than the conventional one. The time required to cool the product from 121°C to about 60 °C was 8 min in the ohmic unit and approximately 40 min in the autoclave.

Overall, the sterilization process of beans in liquid using ohmic technology made it possible to reduce the processing time up to 75% when compared with the conventional method, with significant benefits in terms of lower thermal stress for the final product.

The microbiological examination revleal a low contamination load of raw beans both in terms of total microbial count (150 CFU/mL) and yeast and molds (<10 CFU/mL), which certifies the good quality of raw materials. During sterilization process of beans in liquid, the microbial load was always reduced to values below the detection limit of the experimental procedure used for the microbiological assay (<10 cfu/mL). These results confirmed the stability of the product regardless of the sterilization technology and holding time used.

According to previous study [3], due to both the thermally lethal conditions and high alternating current frequency (25 kHz) utilized in our experiments, we attributed the microbial reduction to thermal effects since heating is the dominant mechanism.

Heat treatment is particularly important in the preparation of legumes for consumption from the point of view of acceptability. Differences in the thermal treatments employed may have a negative impact on appearance of legumes. Fig. 2 presents the results for the extent of splitting of beans after pre-treatment stages and sterilization process at different holding times.

Soaked beans showed an initial percentage of splitting of 18%, which was slightly increased up to 22 % during the subsequent preheating stage. In addition, the splitting degree induced in beans sterilized by ohmic heating was always significantly lower than that of autoclaved beans. However, for both thermal methods, splitting of seeds increased with holding time according to the results of Taiwo et al. [4] which found an increase of splitting degree with cooking time of two variety of cowpea beans.

![Split degree of beans after soaking, preheating, and sterilization process by conventional and ohmic heating method.](image)

Legumes such as beans (Phaseolus vulgaris), considered as poor man’s meat, are an important and inexpensive source of protein for a large part of the world’s population, mainly in developing countries.

Raw beans presented an initial content of proteins of 26.1±0.8 g/100 g dry weight product. Data not shown, revleal that sterilization processes significantly reduced the proteins content of beans, regardless of the thermal method. However, it was noted that, the composition of the final product was dependent on thermal treatment and only slightly affected by the holding time.
Interestingly, the samples treated by ohmic heating revealed a significant higher concentration of proteins (14 g/100 g dry weight, on average) than that of autoclaved beans (6 g/100 g dry weight, on average). This is a very important result since beans is generally considered a product able to replace meat in daily diet.

4 Conclusion
The present work showed that, between the components of the biphasic system composed by beans in salt solution, the beans were less conductive than the liquid phase. The electrolytic content within beans as well as ionic mobility can be increased by blanching them in tap water for a given length of time in order to level the heating rate of both phases during the subsequent ohmic heating process. The adoption of the optimized pretreatment protocols developed in this work led to stabilized beans product of higher quality when compared with autoclaved product.

References: