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The potential of ohmic heating as an alternative to steam for heat processing shrimps

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ABSTRACT

The potential application of Ohmic Heating as an alternative to the conventional steam cooking for shrimps is examined in this study. Defrosted unpeeled shrimps (*Pandalus borealis*) were cooked either in a steamer or ohmically up to a 72 °C core-temperature. The head, body and tail of steam-heated shrimps cooked at different rates whereas the OH treatment was more uniform and faster. The impact of shrimp size on heating rate was also evaluated, with an overall cooking time of 38 s and 59 s for steam-cooked small and large shrimps, respectively, while only 40 s where needed for OH regardless of shrimp size and measured anatomical location. No differences were found for cook loss and texture (WBSF and Kramer methods) between cooking methods. However, shrimp size seemed to determine the effect of OH on colour differences (ΔE), with greater differences observed in large *vs.* small shrimps, although overall ohmically-cooked shrimps showed less colour differences compared to those cooked conventionally with steam.

Industrial relevance: Traditional heating processes such as boiling or steaming are used in industrial cooking of shrimps. However, the low rate of heat penetration to the thermal centre of shrimps leads to heterogeneous treatments resulting in overcooking which may reduce yield. Ohmic heating technology offers a potential alternative over conventional heat treatments as heat is generated volumetrically inside the food. This form of heat generation results in more uniform temperature distribution which leads to shorter processing times and potentially higher yields while still maintaining the colour and nutritional value of food. This paper hence exploits the potential of Ohmic heating technology as an alternative to conventional steam processing for the cooking of shrimps.

1. Introduction

Shrimp is of considerable commercial significance in terms of global seafood trade. In 2012 shrimp accounted for about 15% of the total value of internationally traded fishery products when the total catch of shrimp species reached 3.4 million tonnes (FAO, 2014). Currently, more than half of the global shrimp catch comes from the Northwest and Western Central Pacific, followed by the Indian Ocean (20%) and Western Atlantic (17%) (FAO, 2014). The cold-water or deep-water shrimp (*Pandalus borealis*) is an important commercial species primarily harvested in northern areas with Canada and Greenland the major producers of this particular species at the moment. Once captured, there are two main ways of processing the shrimps on board: single frozen or double frozen. The single frozen shrimps are caught by smaller boats, where they are covered with ice, brought to a factory on the coast, matured, cooked, peeled and finally frozen. On the contrary, the double frozen shrimps are caught by large trawlers and are frozen on board while still in the shell. Later they are brought to the factory on shore where they are thawed, matured, cooked, peeled and finally re-frozen (Anon., 1972; Johnston, Nicholson, Roger, & Stroud, 1994).

Nowadays seafood processing industries use conventional heating technologies for processing shrimp but one of the difficulties with this method is that heat transfer is limited by internal conduction. Specifically, in the bulk processing of shrimp, the conventional practice involves cooking them in water baths or steam environments with a standardized time-temperature process. This may result in overcooking of small shrimp in relation to the large ones which may have an impact on the quality of the final product and lead into high yield loss. For this reason, Ohmic Heating (OH) technology might be a potential alternative to solve this problem. Ohmic heating is a 'novel' thermal process in which a food which acts as an electrical resistance is placed between two electrodes. An alternating current is passed directly through a conductive food, which in turn leads to internal heat generation (Knirsch, Santos, Vicente, & Penna, 2010; Ruan, Ye, Chen, Doona, & Taub, 2001). Because of the nature of the ohmic process the heat generated is more uniformly and efficiently distributed through the product being cooked, compared to the heating process achieved by either hot water bath or stream. Some previous research has been performed on the application of OH for the processing of shrimp, especially for thawing purposes.

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Roberts, Balaban, and Luzuriaga (2002) studied the potential application of OH to thaw frozen shrimp blocks by comparing the microbial, sensory and quality attributes of ohmically and conventionally thawed shrimps (immersion in warm water). It was observed that total aerobic counts were comparable when shrimps were ohmically or conventionally thawed and no significant differences were found in the taste tests either. Ohmic thawing was demonstrated as being capable of thawing blocks of shrimp in comparable times to conventional thawing method while eliminating local overheating. In addition, small shrimps showed higher moisture content when compared to those conventionally thawed (Roberts et al., 2002). In that study, two pairs of electrodes (23 × 30 cm) were used to simultaneously thaw two 2.3 kg shrimp blocks. For the specific cooking step, Abudagga and Kolbe (2000) studied the effects of conventional cooking (in a water bath at 90 °C) *vs.* ohmic cooking (1200 V/m) of surimi paste (cylindrical samples of 19 mm diameter). OH resulted in a heating rate 11 times faster than the conventionally heated surimi samples. Authors also emphasized the significant effects of the two heating mechanisms upon the time during which the sample centre dwells within the critical enzyme activity range.

Up to date no studies have been published on ohmic heating application for the cooking of shrimps, although it would be expected that many of the findings for meat and meat products would show similar outcomes in fish and seafood (Lyng, 2014). For this reason, the objective of this study was to exploit the potential of OH as an alternative to conventional steam processing for the cooking of shrimps by comparing the effect of both technologies on different shrimp quality attributes.

2. Materials and methods

2.1. Sample preparation

Fresh free-flow frozen shrimps (*Pandalus borealis*) with weights ranging from 1 to 7 g were supplied in 4.5 kg boxes by Royal Greenland A/S (Denmark) and were maintained in frozen state at −20 °C. The day prior to the experiments the shrimps were kept in a fridge at 4 °C to defrost and then grouped by size into small (1–3 g) and large (≥4.5 g) shrimps.

2.2. Cooking of samples

On the day of experiment, shrimps were cooked until the cold-spot reached 72 °C either by steaming in a conventional steamer or ohmically in an ohmic heating cell. This temperature was chosen to meet the FDA specifications for fish and fishery products which indicates that the internal product temperature must be of 72 °C for 1 min to obtain a 6 $\log_{10}$ reduction of *Listeria monocytogenes* (FDA, 2011).

2.2.1. Ohmic heating cooking

A bench scale batch ohmic heater (15 A, 0–250 V, 50 Hz) (C-Tech Ltd., Chester, UK) connected to a 3.5 kW power supply was used for cooking shrimps. The OH cell consisted of two stainless-steel electrodes (55 mm height × 70 mm length) with a distance between them of 7 cm.

Preliminary trials were carried out in order to determine the optimal parameters for the ohmic treatment of shrimps. For this, different volumes of distilled water (120 or 240 mL) containing different concentrations of sodium chloride (0.5, 0.75, 1.0, 1.25 and 1.5% w/v NaCl) were used. Shrimp orientation in the treatment cell (i.e. the longitudinal section of the shrimp parallel or perpendicular to the electrodes) and the number of shrimps cooked in each batch (1, 2, 3 or 4 shrimps cooked at one time) was also evaluated to assess if there was any difference in the cooking time. For this, the shrimps (1, 2, 3 or 4 at a time) were placed inside the OH cell either parallel or perpendicular to the electric field and cooked in 240 mL of 1% w/v NaCl water solution.

During experiments the voltage (V) and current (A) were simultaneously logged at 5 s intervals using a Pico ADC 11 data logger (Model No. R5.06.3, Pico Technology Ltd., UK). Fiber optic probes (Neoptix T1S-02 Fiber Optic Temperature Probe, Neoptix Inc., Canada) were inserted into three locations of the shrimp (head, body and tail) and a further probe was placed in the saline solution to record the rise in temperature during the OH treatments. Temperature was recorded every second using an ADC-24 Data logger (Pico Technology Ltd., Ireland). Experiments were stopped when the three probes reached 72 °C. For these preliminary experiments 24 samples for each shrimp size category (large and small) were used. The electrical conductivity (σ, mS/cm) at 25 °C of the saline solutions used to cook the shrimps in the OH cell was measured before and after cooking. As well, the electrical conductivity in the 5–85 °C range of shrimp mince paste (using an Ultra-turrax T-25 model Janke and Kunkel GmBH, Germany, at 8000 rpm for 10 s) was also measured. Measurements were performed in triplicate using a conductivity meter (Cyberscan PC 300, Eutech Instruments Pte Ltd., Singapore).

2.2.2. Steam cooking

For the steam cooking 1 L of tap water was placed in a conventional stainless-steel steamer (18 cm Essential Stainless Steel Steamer with Tempered Glass Lid, Sabichi, UK) and was brought to the boil on a hot plate. Shrimps were then placed horizontally and randomly distributed in the steamer with a minimum distance of 1 cm between each other. Three T-Type thermocouples (NiCr–Ni sensor class 1, ref. FTA05L0100, Almemo, Ahlborn, Germany) were similarly inserted into the head, body and tail of the shrimps (n = 24 per shrimp size category). The rise in temperature during the treatment was monitored and recorded every second with a Squirrel data logger (Model No. 2040, Grant Instruments Ltd., Cambridge, UK). Cooking was terminated when the three thermocouples reached 72 °C.

2.3. Cooling of samples

Cooked shrimps were first cooled to 5 °C in iced water and, if needed, then kept in a fridge at 5 °C.

2.4. Shrimp quality parameters

For these analysis, only shrimps that were not punctured with either the fiber optics or thermocouples were used. In each experiment, a punctured large shrimp was used as a control to monitor the temperature rise.

2.4.1. Colour

The colour of the body of non-peeled shrimps was measured before and after cooking (either OH or steam cooked) using a Minolta CR-400 colorimeter (Minolta Ltd., Osaka, Japan) with a D_{65} illuminant. Three observations of lightness (L), redness-greenness (a) and yellowness-blueness (b) were recorded for each sample as previously performed by Benjakul, Visessanguan, Kijroongrojana, and Sriket (2008) with steam-cooked shrimps. Also, the parameter ΔE ($\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$) was calculated to determine the colour differences between raw and cooked samples. For this, 45 samples for shrimp size category and cooking method were used.

2.4.2. Cook loss and texture analysis

The loss of juice due to the cooking step (i.e. cook loss, %) was assessed by weighing the samples (n = 24 for shrimp size category and cooking method) before and immediately after cooking, using a digital scale (Model No. TE 313S, Sartorius Mechatronics Ireland Ltd., Dublin, Ireland). To deal with the associated liquid from the outside of processed shrimp, samples were first placed horizontally on a paper towel sheet for 3 s on each side and then weighed. Cook loss was then expressed as a percentage of the original weight. For the texture analysis, cooked shrimps stored in the fridge at 5 °C for 24 h