Electric paralyzation and reduction of weight loss in the processing of round-cooked spiny lobsters

Paralisação elétrica da lagosta e redução da perda de peso no processamento de lagosta inteira-cozida

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Abstract

This study proposes alternatives to the current methods of processing round-cooked lobster. The paralyzation of lobsters with direct electric shock consumes 10.526 x 10^{-3} kWh, which is significantly less than the 11 kWh required by the traditional thermal-shock method (based on 60 kg of lobsters). A better weight gain was obtained by immersion of paralyzed lobsters in brine before cooking. Systematic trials combining 3, 6, or 9% brine concentrations with immersion periods of 15, 30, or 45 minutes were performed in order to determine the best combinations. A mathematical model was designed to predict the weight gain of lobsters of different sizes in any combination of treatments. For small lobsters, a 45 minutes immersion in 6% brine gave the best response in terms of weight gain (4.7%) and cooking produced a weight loss of only 1.34% in relation to fresh lobster weight. For medium-sized lobsters, a 45 minutes immersion in 9% brine produced a weight gain of 2.64%, and cooking a weight gain of 1.08%. For large lobsters, a 45 minutes immersion in 6% brine produced a weight gain of 3.87%, and cooking a weight gain of 1.62%.
Keywords: spiny lobster; electric stunning; cooking; weight gain; weight loss.

Resumo

O presente estudo propõe alternativas aos métodos convencionais de processamento da lagosta inteira-cozida. Para a paralisação de 60 kg de lagosta com aplicação de choque elétrico, foram consumidos 10,526 x 10^{-3} kWh, valor significativamente inferior aos 11 kWh requeridos pelo método tradicional de choque térmico. Um maior ganho de peso foi obtido pela imersão de lagostas paralisadas em salmoura antes do cozimento. Experimentos combinando as concentrações de salmoura a 3, 6 e 9% com os tempos de imersão de 15, 30 ou 45 minutos foram realizados. Um modelo matemático foi ajustado para predizer o rendimento de peso de lagostas de diferentes tamanhos para as combinações de tratamentos testadas. Para lagostas pequenas, um tempo de imersão de 45 minutos em salmoura a 6% apresentou a melhor resposta em termos de ganho de peso (4,7%) e o cozimento produziu uma perda de peso de somente 1,34% em relação ao peso da lagosta fresca. Para lagostas de tamanho médio, um tempo de imersão em salmoura a 9% produziu um ganho de peso de 2,64%, e o cozimento, um ganho de peso de 1,08%. Para lagostas grandes, uma imersão de 45 minutos em salmoura a 6% produziu um ganho de peso de 3,87%, e o cozimento, um ganho de peso de 1,62%.
Palavras-chave: lagosta; choque elétrico; cozimento; ganho de peso; perda de peso.

1 Introduction

Spiny lobster represent one of the most important fishing resources in northeastern Brazil, and the country has exported lobsters to the USA, mainly in the form of frozen tails, since the early 1960s. In the past few years, however, the Brazilian lobster industry has experienced a severe crisis due to overfishing and predatory fishing. The Brazilian record for lobster production was set in 1979 with 11,119 metric tons. In 1996, the lobster production of Ceará – the state which by far produces the most lobsters – reached 6,024 metric tons, but only two years later, in 1998, it had plummeted to 2,238 metric tons. Estimates suggest lobster production in 2000 will, at best, reach the level registered for 1998.

There is, therefore, presently a need for diversification of both products and markets. Some of these new markets, especially Japan, require that the lobsters be cooked alive and whole, so processing plants in exporting countries must paralyze live animals – most frequently by thermal shock with ice, a very energy-consuming practice – and then cook the cooled-down lobsters while coping with an inevitable weight loss. If the lobsters are not cooked alive, the legs and antennae sometimes detach from the cephalothorax. In addition, the cooking step assures the complete inactivation of polyphenol oxydase, thus preventing the darkening (melanosis) of the hepatopancreas and meat during storage. This enzyme, responsible for much of the melanosis observed in crustaceans[7-9], is naturally present in the hemolymph and viscera of the spiny lobster.

There has been little need for studies using electrical stimulation of marine animals for the purpose of stunning since both the onset and cessation of rigor mortis occur very early for these animals. The only case of such a study involves paralyzing live eels with the aim of making filleting easier. On the other hand, post-mortem electrical stimulation (as opposed to ante-mortem electrical stunning), has been widely studied and used in the red meat industry for accelerating conditioning and preventing cold shortening[3,5,10,11]. Also, electric discharges have been studied as a method for accelerating post-mortem reactions in poultry meat, making earlier deboning of breast muscles possible without toughening the meat[12].

According to OGAWA et al.[7], the cooking of spiny lobsters produces a weight loss that increases with cooking time,

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reaching as much as 15 ± 3%. It is therefore preferable not to cook lobsters beyond the minimum time required (taking into account the size of the specimen) for the complete inactivation of polyphenol oxydase. However, immersion in brines of appropriate concentration prior to cooking seems not only to counteract this loss in weight but effectively to produce a slight weight gain in the cooked meat.

2 Materials and methods

The spiny lobsters of this study belonged to the species *Panulirus argus* and *P. laevicauda* and were collected alive from the coastal waters off Fortaleza (CE, Brazil). They were subsequently kept in 2000 L saltwater tanks until processing. The specimens were divided into three weight groups: small, 150-300 g; middle-sized, 351-600 g; and large 601-900 g. Most of the smaller specimens were *P. laevicauda*. Only the most active specimens were used.

A plastic box containing selected lobsters was placed inside a 150 L plastic container (stunning machine) and then covered with 100 L of seawater at 26 °C (Figure 1). The electrical current was supplied by either a transformer and electrodes or a pair of electrical plates. In the first arrangement, two positive electrodes and one negative were placed in the box, forming a row along the center line. The second arrangement tested two bottom plates along the sides of the box. The electrode arrangement that achieved the best electrical field distribution was used to test varying voltages, from 10 to 220 V, with the same experimental setup.

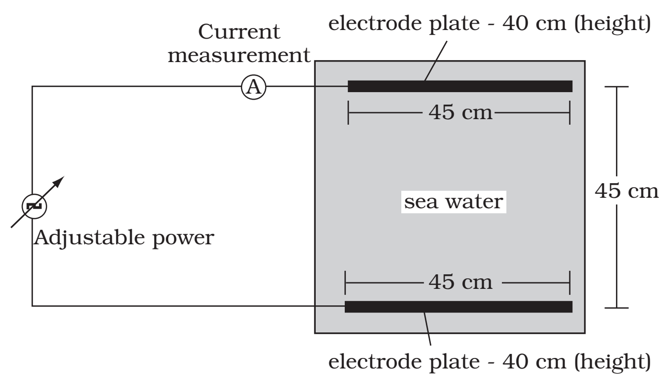

Figure 1. Schematic diagram of the experimental setup.

The electrical pulse treatment consisted of a 30 second train of 15 one-second square pulses stunning groups of 50 lobsters each. Thus, each 1 second electrical pulse was followed by a 1 second interval. The resistance of the seawater established the voltage amplitude for a maximum current operation. The maximum effective current was 10 A, for an electrical resistance of approximately 1.30 Ω. In order to test the resulting paralysis, once the electrical current had been disconnected, the eye globes of each specimen were compressed, which is a treatment that will almost always produce a response in a live lobster.

The stunned lobsters previously classified into small, medium and large size were immersed in 3, 6 and 9% brine during 15, 30 or 45 minutes in order to test the weight gain hypothesis. Lobsters from all treatments were reexamined, and all weight changes were registered.

The undersides of the lobster tails were injected at various points with about 0.1 mL of 1.0 M catechol in order to verify whether the cooking time had been long enough to inactivate the polyphenol oxydase enzyme system and thereby prevent the meat from darkening[8]. In a second-phase set of tests, the lobsters were beheaded and given similar catechol injections.

During cooking, the temperature inside the cephalothorax was kept at 80 °C, thus reducing both cooking time and the weight loss, which occurs through dehydration while maintaining the quality of the final product. The cooking temperature was also sufficiently high to inactivate the enzyme, which causes melanosis in crustaceans. The increase in water temperature was registered at 1 minutes intervals during a 20 minutes cooking period.

Moisture and NaCl contents were measured, according to the A.O.A.C.[1] method, to determine whether the observed weight changes could be associated with variations in these two factors.

The experiments in weight gain were designed using Response Surface Methodology (RSM). A Box-Behnken factorial design with brine concentration and immersion time as independent variables was applied[4]. This methodology allows for the modeling of a second-order equation, which describes this process. The data were submitted from the factorial design to multiple regression analysis using the least-squares regression method to obtain the parameters for the mathematical model. A canonical analysis was also performed in order to predict the shape of the curve generated by the model[17]. These analyses were conducted by a RSREG (Response Surface Regression) procedure using the STATISTICAL ANALYSIS SYSTEM[15]. The 3D response surface graphs and 2D contour graphs were plotted with Microsoft® Office Excel.

3 Results and discussion

3.1 Electrical paralyzation

At 110 V, a 20 seconds exposure was necessary to paralyze the lobsters fully. At 220 V, only a 5 seconds exposure was required, even when both the size and number of specimens were increased (Table 1). In contrast, the conventional paralyzation technique, using immersion in ice water, takes up to 15 minutes[14]. Therefore as much as 14 minutes 55 seconds can be saved by applying an electrical shock at 220 V. Also, paralyzation of lobsters with direct electric shock consumes only 10.526 x 10^{-3} kWh, which is far less than the 11 kWh

Table 1. Paralyzation exposure time of spiny lobsters when an electric current was applied to a container with 60 L of sea water at 26 ± 1 °C.

Applied voltage (V)	Sample size (n)	Size of lobsters	Exposure time (seconds)
110	50	medium, large	20
220	50	small, medium, large	5

required by the traditional thermal-shock method (based on 60 kg of lobsters).

Two positive electrodes and a negative one were found that forming a row along the center line of the box did not provide an even distribution of electricity in the medium. Two lateral bottom plates along the sides of the box provided a much more uniform electrical field (Figure 1). This arrangement can also be extended lengthwise into adjacent boxes as far as one wishes. Lobsters closer to the electrodes were paralyzed faster.

Although a constant electrical current also paralyzes lobsters efficiently, it exposes operators to serious operational risks through accidental shock, so the square-pulse method is safer as the electrodes are only activated during 1 second intervals. Figure 2 shows the power input as a function of the current supplied. The applied power for a current of 10 A corresponds to 1.4 kW for one electrical pulse train treatment. This power was sufficient for the complete paralyzation of the lobsters in a 30 seconds electrical pulse treatment. We also observed that during the electrical square pulse treatment, the lobsters' muscles became contracted. Further research might reveal whether such paralyzation treatment will prevent the antenna muscle from toughening when frozen raw.

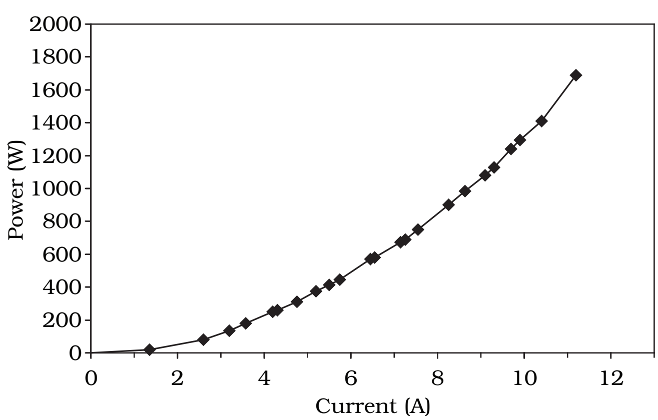

Figure 2. Power input as a function of the current supplied.

Electrical paralyzation also reduced cooking time, since the stunned lobsters were available for processing while still at room temperature, rather than at 8 °C like conventionally cold-paralyzed lobsters (Figure 3). Boiling the electrically stunned lobsters in seawater required 5 minutes, as compared to 8 minutes for those paralyzed with ice. The entire cooking process took 17 minutes for the former and 20 minutes for the latter. The accompanying reduction in energy consumption was very large. Chilling and cooking 50 spiny lobsters paralyzed by the conventional chilling treatment required 6,456 kcal. Stunning and cooking 50 lobsters required 166.7 kcal, that is, only 2.58% as much (Table 2). Further advantages of the electrical stunning technique are that the procedure described herein, using seawater for the purpose of paralyzation, can be done in large or small scale on fishing vessels at open sea, it requires little investment and entails a near 97% reduction in energy consumption. Currently a safer and more efficient electrical-pulse treatment method is being developed for the paralyzation

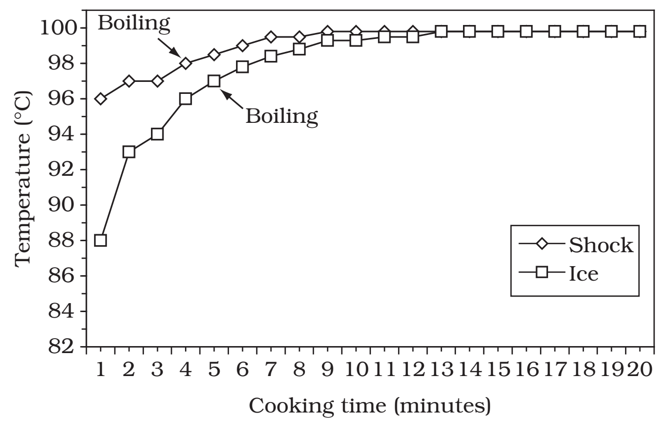

Figure 3. Internal temperature variation as a function of cooking time in lobsters (n = 50) submitted to paralyzation with either ice or electric shock.

Table 2. Energy consumption when spiny lobsters are paralyzed electrically and by conventional chilling treatments.

Method of paralyzation	Exposure time (minutes)	Total cooking time (minutes)	Consumption of ice (kg)	Energy consumption (kcal)[a]
Ice	15	20	60	6456.0
Electric shock	5	17	-	166.7

[a]Estimate based on the following assumptions: 1) A power plant consumes 2,000 kcal to produce 1 kWh; 2) it takes 107.6 kcal to produce 1 kg of ice at -4 °C; and 3) the strength of the transformer was 1000 W.

of mangrove crabs (the demand for which reaches 60,000 units per week in Fortaleza).

3.2 Immersion in brine

In general, brine is used to hydrate meat and thereby partly make up for the weight loss caused by cooking, and white fish fillets and oyster meat (which are usually treated by immersion in brine before freezing and cold storage so as to reduce drip during thawing) have been shown to benefit from the same process. According NONAKA et al.[6], wet-salted herring produced in brine at a concentration below 9% show a weight gain, but, curiously enough, at a concentration between 18 and 25%, the fish initially loses weight, then gains it back.

In this study, we found combinations of brine concentration and immersion time capable of producing a substantial weight gain for lobsters from all three size groups. For the small lobsters, the treatment with 6% brine concentration and a 45 minutes immersion time gave the best weight gain (4.7%), but after the cooking step a weight loss of 1.34% was observed (for the medium-sized lobsters treated with a 9% brine concentration and immersed for 45 minutes, the weight gain was 2.64% and after the cooking step a further weight gain of 1.08% was achieved; for the large-sized lobsters treated with 6% brine and a 45 minutes immersion, the weight gain was 3.87%; after the cooking step the weight increased by 1.62%). When the lobsters (all sizes) were immersed in water, a weight loss of about 10% was observed (Figure 4).

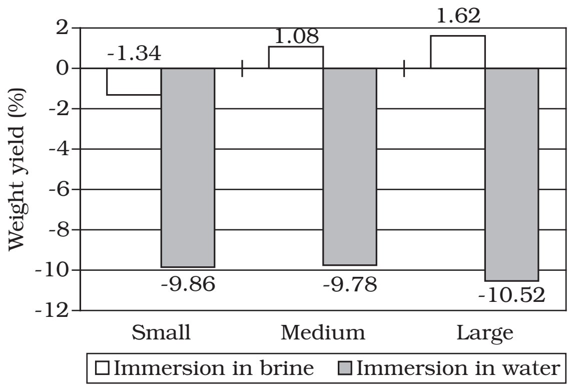

Figure 4. Weight yield after cooking.

The increase in moisture content was not significant (F test, $p > 0.05$). The F test for the whole block (small, medium and large lobsters) was significant ($p < 0.01$). A comparison of the average results of the treatments through the Tukey test (at $\alpha = 5\%$) showed no differences in the moisture percentages; therefore the difference in weight gain after cooking must be explained by other factors. The coefficient of variation (CV) obtained was 0.68%, indicating that the experiment was adequately carried out.

The statistical F test values obtained for the percentages of NaCl in the lobster tails, both for the treatment and for the block, could not be considered significant at a level of 5%. A comparison of the average results by means of the Tukey test indicated no difference at a level of 5%. The CV for the NaCl analysis was 19.76%.

The three-dimensional representations of the combined factors indicate a weight gain over time for lobsters immersed in brine. The great variation in weight gain response in different weight groups is due to the influence of size (Figures 5, 6, and 7). Although the graphs produced with the mathematical models show an increasing weight gain as a function of immersion time, an external limiting factor must be considered, namely the detachment of the tail from the cephalothorax after a certain amount of immersion and the resulting depreciation the product will suffer on the market.

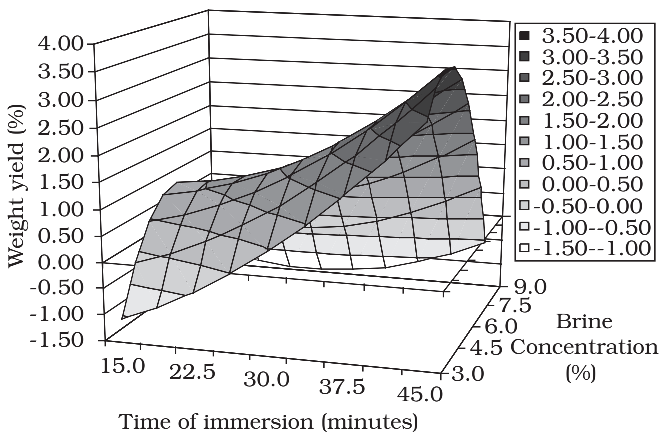

Figure 5. Graphic representation of weight gain for small lobsters.

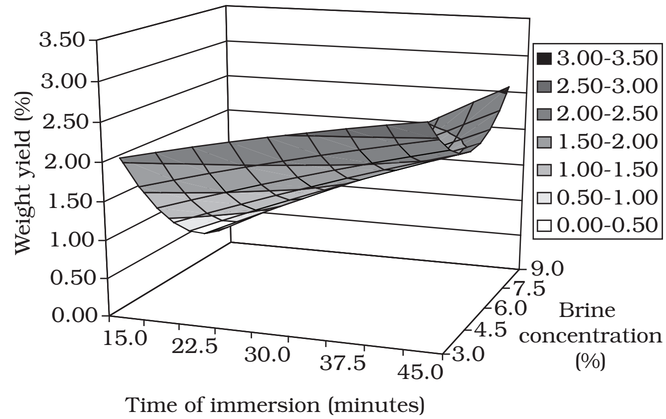

Figure 6. Graphic representation of weight loss for medium-sized lobsters.

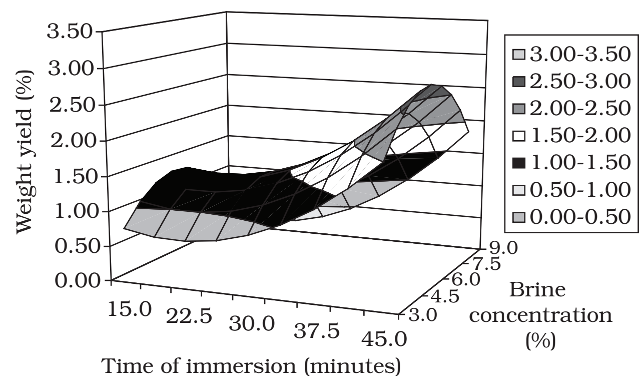

Figure 7. Graphic representation of weight gain for large lobsters.

Statistical analysis of the factorial design, expressed by the coefficients of determination (R2), indicated that the variations in the experimental data may be explained by the adjusted mathematical model, and the nonsignificant F value at 10% of the "lack-of-fit" test, which measures the fitness of the model obtained, indicated that the model is sufficiently accurate for predicting the weight gain for any combination of independent variable values within the ranges studied. The canonical analysis produced a stationary point in a saddle-shaped curve whose estimated surface determines a response in regions or areas of graphical representation.

It is not yet clear why during cooking some of our brined spiny lobsters gained weight while others lost it. The in- and outflow of water during the salting process is quite complex and is not yet clearly understood (REAY, 1936, as quoted by NONAKA et al.[6]). According to VOSKRESENSKY[16], the increase in salt content of the cellular body fluids of fish releases the muscle-bound water and brings about a decrease in the salt concentration of the muscle. Thus, the muscle absorbs more salt from the brine and gains extra weight.

BERHIMPON et al.[2] studied the behavior of wet-salted yellowtails at several brine concentrations (5, 10, 15, 21, and 26.5%). At concentrations of 5 and 10%, the fish absorbed water, and the salt content increased, reaching 4.2 and 8.2%, respectively. A similar process may be at large in the case of the spiny lobsters in this study. Moreover, it should be remembered that with more expensive commodities such as spiny lobster, even a slight increase in weight is of economic importance.

When animal tissue is immersed in NaCl solutions, the ions bind to regions in electrically charged protein molecules. The Cl^- ion is much more influential than the Na^+ ion because of its larger atomic volume and a tendency to form complexes with amino groups. The Cl^- ion layer gathers water and keeps it bound through electrostatic attraction and Na^+ ions are relatively small, so a high ionic power can be attained at low concentrations[13].

4 Conclusion

The direct use of electricity for the stunning of live spiny lobsters allows for a decrease in cost and in processing time with no apparent loss in product quality. It therefore represents a feasible alternative to the conventional chilling paralyzation process commonly used by the round-cooked lobster-processing industry.

The analysis of the response surface methodology shown in the graphs shows that lobsters in the upper weight groups tend to gain weight when immersed in brine. The best results for the small and large lobsters were obtained in the region where the brine concentration is 6% and immersion lasted for 45 minutes. For expensive commodities such as spiny lobster, even a slight alteration in weight is of considerable economic importance.

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