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Utilization of steam heat generated via microwave energy in seafood cooking

Abstract

Most restaurants and retail food stores rely upon conventional steamers to cook seafood to the required internal temperature of 145°F (62.8°C) as specified in the FDA Food Code. The problems associated with conventional steamers include high costs of the units, energy expenses, complicated plumbing hookups and difficulty of cleaning and sanitizing. The Food Code requires that seafood heated via microwave energy must attain an internal temperature of 165°F (73.9°C). The purpose of this study is to evaluate the effectiveness of steam cooking of seafood in a covered microwave pan containing water using microwaves as the energy source to produce steam. Three different cooking methods, including covered pan with water, covered pan without water and uncovered pan without water, were compared to optimize the cooking condition using a commercial microwave steamer. The internal temperature of lobsters (determined at 7 locations) cooked in a covered microwave pan with 45 ml water were all above 145°F (62.8°C), while the other two methods resulted in uneven heating or not well cooked products. Furthermore, three widely used models of microwave oven were evaluated for their effectiveness in cooking lobsters and shrimp using microwave-generated steam. All the microwave ovens studied produced consistent results, with internal temperatures of lobsters and shrimp all above 145°F (62.8°C), regardless of the standing time. Even heating and high sensory quality were observed in all cooked seafood. This study has shown that cooking seafood using microwaves as the energy source to generate steam was effective and efficient. This method provides the additional advantages of faster cooking, lower energy costs, easy setup and ease of cleaning and sanitizing. The next step is to petition FDA for an amendment within the Food Code to allow for the steam heating of seafood products to aminimum internal temperature of 145°F (62.8°C) using microwave as the energy source.

Keywords: seafood cooking, steam, microwave, internal temperature, food code

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Introduction

Conventional steamers are widely used to cook seafood products. However, there are several drawbacks in using them to cook seafood products, such as high costs of the units, energy expenses, complicated hookups and difficulty of cleaning and sanitizing the interior. A solution to these issues is the use of microwave-generated energy to steam-cook seafood. Advantages of steam-cooking using microwave-generated energy include quick and complete heating of food and elimination of problems associated with the loss of moisture.[1,2]

There is a substantial difference in the methodology of steam-cooking foods using microwave-generated energy as opposed to traditional microwave cooking. Traditional microwave cooking does not produce high sensory quality due to a drying phenomenon caused by moisture evaporation from the food during cooking.[3] A microwave steam cooking apparatus is used in Tsai's study cooked food in the microwave oven using a combination of steam and microwave heat.[2]

The government regulation has a significant impact on the use of microwave-generated steam to cook seafood. Section 3-401.12 of the 2013 edition of the FDA Food Code requires that raw animal foods, including seafood, heated via microwave energy must attain an internal temperature of at least 165°F (73.9°C).[4] However, traditional steam heating of seafood products is only required to reach an internal temperature of 145°F (62.8°C).[4] Therefore, this study was designed to determine whether cooking seafood in covered microwave-approved pans with added water and using microwaves as the energy source to produce steam was effective in reaching internal temperatures greater than 145°F (62.8°C). If this premise is proven true, then it could suggest that the FDA Food Code be amended to allow for the steam heating of seafood products to aminimum internal temperature of 145°F (62.8°C) using microwave energy as the source.

Materials and methods

Four microwave ovens were used in this study, including a commercial microwave steamer (Sonic steamer, NE-3280, 3200 watts, 4-magnetron, Panasonic Corporation of North America, NJ, USA), Panasonic Inverter microwave oven (NN-SE982S, 1250 watts, 1-magnetron, Panasonic Corporation of North America, NJ, USA), Panasonic compact commercial microwave oven (NE-12521, 1200 watts, 1-magnetron,Panasonic Corporation of North America, NJ, USA) and GE microwave oven (GE-JES1451DN1BB, 1100 watts, 1-magnetron, General Electric, Connecticut, USA).

The medium-size microwave-approved pan (30cmx51cmx10cm), composed of high density polyethylene, was used for all the cooking. Lobsters weighing 567 to 680g each and large shrimp (283g/12) were used as the examples of seafood typically steamed by traditional methods in food establishments. All temperatures were taken utilizing 3 standard Comark KM28 Thermocouples (Comark Instruments, OR, USA) with 15cm needle probes, temperature range -40°C to 537.8°C, and accuracy ±1.1°C. The thermocouples were calibrated before use on each day.

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Determination of temperature of steam generated by microwave energy

The steam temperature was monitored in all the four microwave ovens over 5min. Cold water (45 ml) was added into a medium-size microwave-approved pan, which was then covered. The pan was put in a microwave oven and heated at full power for 0, 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5min. The steam temperature was measured with a thermocouple.

Cooking seafood in microwave steamer with three different methods

A lobster (567 to 680g was cooked in the commercial microwave steamer (sonic steamer) in three different ways:

a. microwave-approved pan with 45ml water added and with cover;

b. microwave-approved pan without water added and with cover; and

c. microwave-approved pan without water and without cover.

The first method utilized the steam generated by microwave energy to cook the lobsters, where water served as a catalyst to create steam. The second and third methods simulated the traditional microwave cooking. The lobster was cooked in a sonic steamer at full power for 2min. followed by 2min. standing to obtain temperature equilibrium. The internal temperature of lobster was measured at multiple locations, including head (point 1), cervical groove (point 2), cephalothorax (point 3), abdomen (point 4), tail (point 5), left claw (point 6), and right claw (point 7) with a thermocouple.

Cooking seafood using steam generated by four different microwave ovens

In addition to the commercial microwave steamer, three widely used models of microwave oven (Panasonic Inverter, Panasonic-1200, and GE) were evaluated for their effectiveness in cooking seafood using microwave-generated steam.

A lobster (567 to 680g) was cooked in a covered microwave-approved pan with 45ml water for 2min. in sonic steamer and for 4min. in the other three microwave ovens at full power. The cooked lobsters stood for another 2min. before temperature measurement or were measured immediately after cooking.

Twelve large shrimp (283g/12) were cooked in a covered microwave-approved pan with 45ml water for 1min in sonic steamer and for 3min. in the other three microwave ovens at full power. The internal temperature of each shrimp was taken immediately after cooking.

Statistical analysis

One-way ANOVA model was used to examine the mean temperatures of the lobsters cooked by three different methods in the microwave steamer. Multiple comparisons with Tukey adjustment were conducted to compare each pair of cooking methods. Graphs were generated to visually see the mean and standard error (SE) of the temperature at each point for the lobster and shrimp. All the experiments were conducted in triplicates. All the statistical analysis were performed using SAS 9.3 Windows version (Gary, NC).

Results

Generation of steam via microwave energy

In order to evaluate the effectiveness of cooking seafood using microwave-generated steam and determine the proper cooking time, we first observed the generation of steam via microwave energy and monitored the temperature change of steam over time. A small amount of water (45ml) was added into covered microwave approved pan to serve as a catalyst to create steam upon heating in microwave oven.

As shown in Figure 1, the steam temperature reached 200°F (93.3°C) within 1min. in sonic steamer and remained higher than 200°F (93.3°C) over 5min. The steam temperature changes in GE and Panasonic Inverter microwave ovens share the similar pattern, climbing to 200°F (93.3°C) within 3min. and remaining high over 5min. The steam produced by Panasonic-1200 hit 180°F (82.2°C) before becoming stable. Above all, all the four microwave ovens were able to generate steam well above 170°F (76.7°C). This indicated that microwave energy can effectively and consistently be utilized to generate steam within the covered microwave pan, which allowed us to further evaluate the cooking effectiveness of the steam. Based on these results, we decided to cook lobsters for 2min. in sonic steamer and 4min. in the other three microwave ovens.

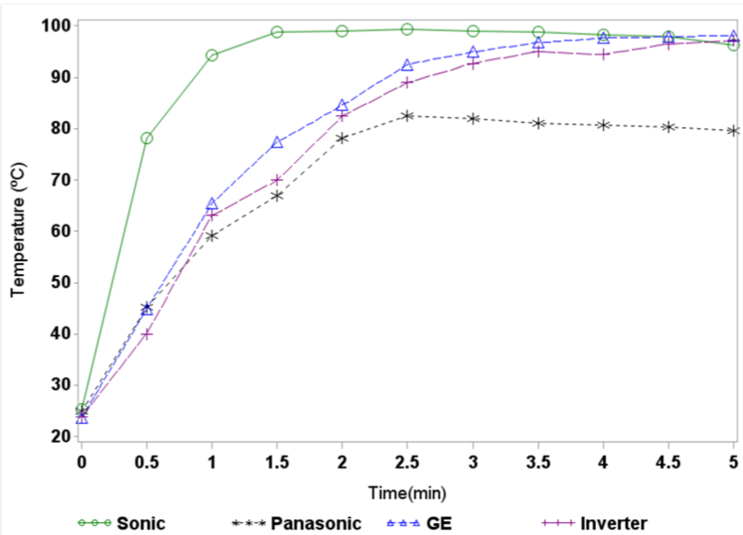

Figure 1 Inhibition of *in vitro* growth of LNCaP cells by mono- and bispecific oligos.

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Effectiveness of three different methods to cook seafood in microwave steamer

In an effort to determine the effectiveness of microwave steamer cooking and optimize the cooking condition, we compared three different methods using a sonic steamer, including

a. covered pan with water

b. covered pan without water

c. uncovered pan without water

The second and third methods simulate the traditional microwave cooking. After 2min. standing, the internal temperature of lobster was then determined at 7 locations, from head to tail and both claws (Figure 2A).

As shown in Figure 2A & 2B, the three cooking methods produced significantly different results with p-value <0.001 from the ANOVA model. The internal temperature readings of the lobster cooked by the first method (covered pan with water) were all well above 145°F (62.8°C) (as required by FDA for steamed seafood) and very close to each other, with the average of 153.2°F (67.3°C) and standard deviation of 3.6 (Figure 2B). The combination of microwave energy with the covered microwave-approved pan containing water generated a "steam environment" similar to conventional steaming. By contrast, both of the other two cooking methods resulted in uneven heating, with the standard deviation approximately 7.8 (Figure 2B) (Table 1). As shown by the multiple comparisons with Tukey adjustment, the third cooking method (uncovered pan without water), which is the traditional microwave cooking, was significantly different from cooking methods 1 and 2 (Table 2). More important, we also observed that the third cooking method was the least effective one. In this condition, the internal temperatures taken at multiple locations of the lobster were well below 145°F (62.8°C) (Figure 2A) (Figure 2B), the FDA standard for steamed seafood, and the lobster was not well cooked (Figure 2C). On the other hand, although the second cooking method (covered pan without water) resulted in higher than 145°F (62.8°C) internal temperatures, the uneven heating produced low quality, e.g. rubbery texture. As shown in Figure 2C, the lobster split into two parts due to the difference between high pressure inside and lack of steam outside. Therefore, we decided to focus on the first method, which utilized the steam generated by microwave energy to cook the lobsters, for the rest of the study.

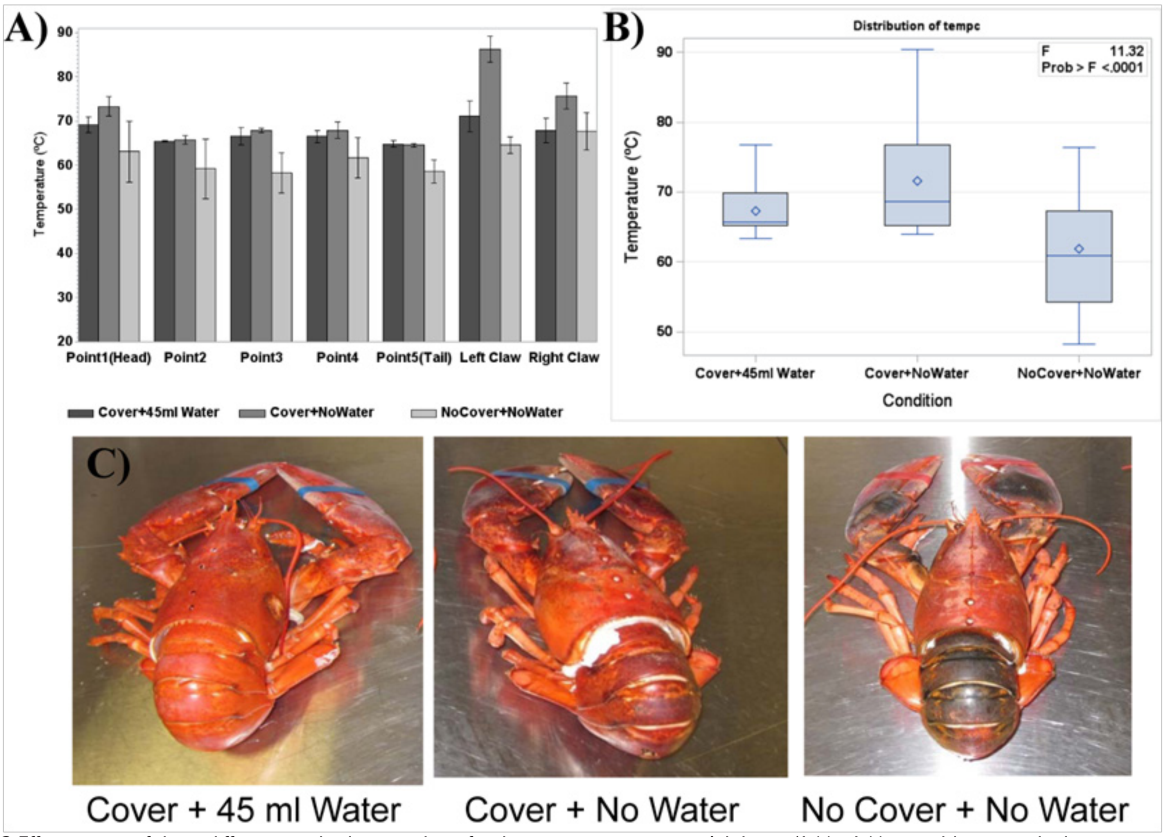

Figure 2 Effectiveness of three different methods to cook seafood in microwave steamer. A lobster (1 ¼ - 1 ½ pounds) was cooked in microwave steamer at full power for 2min. followed by 2min. standing in three different ways: covered pan with 45ml water, covered pan without water, and uncovered pan without water.

A. The internal temperature of lobster was determined at 7 locations, including head (point 1), cervical groove (point 2), cephalothorax (point 3), abdomen (point 4), tail (point 5), left claw (point 6), and right claw (point 7) after cooking. Data are presented as mean±SE (n=3).

B. The internal temperatures at the 7 locations were combined for the comparison of three different methods.

C. Pictures of lobsters cooked with the three different methods.

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Table 1 Descriptive statistics for three cooking methods using microwave steamer to prepare lobsters

Cooking method	Mean temperature(°C)	Standard deviation	Minimum temperature(°C)	Maximum temperature(°C)
Cover+45ml Water	67.3	3.6	63.3	76.7
Cover+No Water	71.6	7.8	64.0	90.4
No Cover+No Water	61.8	7.8	48.2	76.4

Table 2 Comparison of three cooking methods in microwave steamer using multiple comparisons with Tukey adjustment

Cooking method	Mean temperature(°C)	Tukey grouping[a]
Cover + 45ml Water	67.3	A
Cover + No Water	71.6	A
No Cover + No Water	61.8	B

aThe same letter for Tukey grouping indicates that the mean temperatures are not significantly different.

Effectiveness of steam cooking of seafood in different microwave ovens

Since we had demonstrated that commercial microwave steamer was effective in cooking lobster when a covered microwave-approved pan with a small amount of water was used, we then investigated other microwave ovens as well as optimized cooking condition. The three models we used well represented the microwave ovens widely used by food establishments and homes.

All the microwave ovens under study produced consistent results, with internal temperature readings of lobsters all well above 145°F (62.8°C), regardless of the standing time (Figure 3A) (Figure 3B). Even heating and high sensory quality were observed in all the cooked lobsters.

Next, we expanded the food products to shrimp. We cooked twelve large shrimp in a covered microwave-approved pan with a small amount of water. Because traditional steaming usually does not require standing time and our results in lobsters had shown that standing time is not necessary, we measured the internal temperature of shrimp immediately after cooking. As shown in Figure 4, all the shrimp reached internal temperature well above 145°F (62.8°C), as required by FDA for steamed seafood.

Taken together, all these results indicate that utilizing microwave energy to generate steam for seafood cooking is highly feasible and effective. The internal temperatures of lobsters and shrimp all reached FDA requirement for steamed seafood.

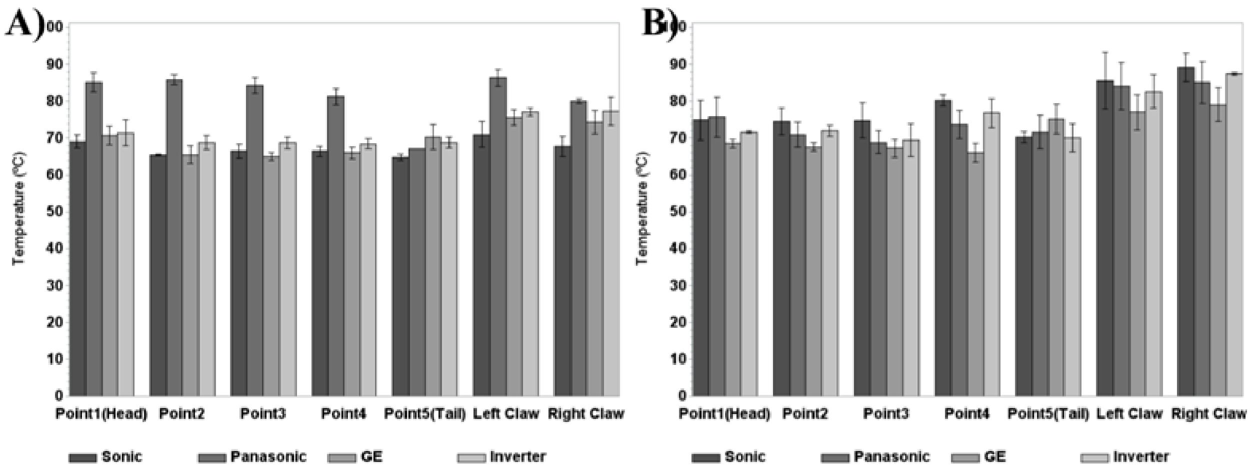

Figure 3 Effectiveness of steam cooking of lobsters in four different microwave ovens. A lobster (1¼ - 1½ pounds) was cooked in a covered microwave-approved pan with 45ml water for 2min. in the microwave steamer and for 4min. in the other three microwave ovens (Panasonic Inverter, Panasonic-1200, and GE) at full power. The internal temperature of lobster was determined at 7 locations, including head (point 1), cervical groove (point 2), cephalothorax (point 3), abdomen (point 4), tail (point 5), left claw (point 6), and right claw (point 7) after 2 min. cooking plus 2min. standing (A) or immediately after 2 min. cooking (B). Data are presented as mean±SE (n=3). Sonic, commercial Sonic steamer microwave oven. Panasonic, Panasonic compact commercial microwave oven. GE, GE microwave oven. Inverter, Panasonic Inverter microwave oven.

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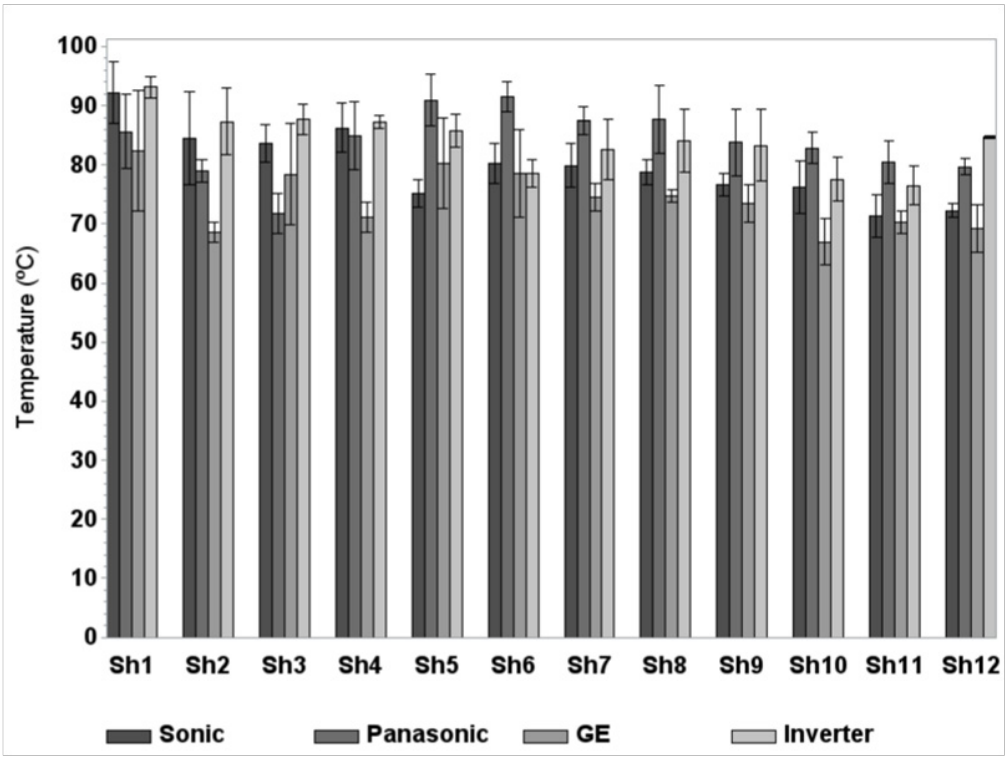

Figure 4 Effectiveness of steam cooking of shrimp in four different microwave ovens. Twelve large shrimp (10oz/12) were cooked in a covered microwave-approved pan with 45ml water for 1min. in microwave steamer and for 3 min. in the other three microwave ovens (Panasonic Inverter, Panasonic-1200 and GE) at full power. The internal temperature of each shrimp was taken immediately after cooking. Data are presented as mean±SE (n=3). Sonic, commercial Sonic steamer microwave oven. Panasonic, Panasonic compact commercial microwave oven. GE, GE microwave oven. Inverter, Panasonic Inverter microwave oven.

Discussion

Steaming is a common practice in food processing; however, the process of heat transfer during microwave steaming has not been fully explored.[5] In our present study, steam generated via microwave energy that consider coupled energy, water and vapor transport were developed and were utilized using microwave energy and covered microwave pans with water for cooking lobster and shrimp. The validity of our results is corroborated by our experimental work of the steaming of lobster and shrimp samples with and without a covered microwave pan with and without water. It shows a good agreement with the experimental results in terms of temperature and increased moisture. The implications of these results can provide a basis for future elucidation of more complicated microwave food steaming processes for seafood.

This study was conducted to evaluate the heat transfer within seafood products via microwave-generated steam in covered microwave-approved pans with added water placed within a commercial microwave steamer (3200 watt, 4-magnetron microwave unit) as well as three other widely used microwave ovens (ranging from 1100 to 1250 watt, 1-magnetron unit). We tried to simulate steaming seafood in both a high watt microwave steamer for use in retail establishments and lower wattage home/commercial microwave ovens.

The technology of microwave steaming is not new and in fact has been used in research studies and patent applications and approvals over the last 25years.[2,3,6–9] The patents are varied in ways of producing steam but all utilize microwave energy to produce steam with various apparatus and containers. Steam heating of food can surround or be injected into the product being heated. It can fill any space at a uniform temperature and will supply heat by condensing at a constant temperature; this eliminates temperature gradients which may be found along any heat transfer surface-a problem which is often a feature of high temperature foods or hot water heating and may result in quality problems, such as distortion of materials being heated.[5]

Our study used the principles of microwave energy and heat transfer to produce steam by a simple combination of a covered microwave containers and a small amount of water just to cover the bottom of the pan. When the steam is generated and reaches the food in the covered microwave pan, the condensation process efficiently transfers the heat to the product being heated.[5] Not only is steam an excellent carrier of heat transfer, it is also sterile and thus popular for processing use in the food, pharmaceutical and health industries, as well as sterilization in hospitals.[5]

Our results showed that microwave energy can effectively and consistently be utilized to generate sufficient steam heat to reach temperatures above 145°F (62.8°C) within all the microwave ovens utilized using a covered microwave-approved pan. Furthermore, in all the microwave ovens tested, the combination of the covered microwave pan with the added water along with the microwave energy generated a "steam environment" similar to conventional steamers. Our study indicated that the added water is necessary for the development of steam and the heat was generated unevenly via traditional microwave energy.[1] The evenness of heating was quite evident when the lobsters and shrimp were cook by steam generated by microwave energy using covered microwave containers. In all microwave steaming experiments, the sensory qualities (including the appearance, texture, color, flavor and overall eating quality) of the

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seafood which was cooked in the covered microwave pan with water was excellent.

Because the heat transfer properties of steam are so high, the required heat transfer area is relatively small. This enables the use of more compact space, such as a microwave oven, which is easier to use and takes up less space. A modern microwave unit for steam heated hot water, rated to 1200 Wand incorporating a covered microwave pan as a heat exchanger and all the controls, requires only a microwave cavity space. In comparison, a packaged unit incorporating a shell and tube heat exchanger would typically cover an area of two to three times that size.

There are many advantages to using microwave steaming compared to conventional steamers.[1,3] First, the microwave units are portable and do not require expensive and complicated steam and waste water plumbing hookups. Second, the covered microwave-approved plans are available in different sizes to economically accommodate the volume of food items being prepared. Third, the stainless steel microwave units as well as the microwave pans can be easily cleaned and sanitized. Fourth, cooking time is reduced significantly in that a traditional 1.5-pound lobster can be steamed to aminimal internal temperature of 145°F (62.8°C) in a total of 4minutes (2minutes cooking and 2minutes holding). Fifth, there is a large savings in energy costs using microwaves to generate steam as opposed to using conventional steamers.

Conclusion

This study has shown that cooking seafood in covered microwave pans with added water and using microwaves as the energy source to produce steam is a viable alternative to conventional steamers. Section 3-401.12 of the 2009 edition of the FDA Food Code requires that raw animal foods, including seafood, heated via microwave energy must attain an internal temperature of at least 165°F (73.9°C),[4] while traditional steam heating of seafood products need only attain an internal temperature of 145°F (62.8°C).[4] In keeping with the scientific evidence provided by this study, the next logical step is to petition FDA for an amendment within the Food Code to allow for the steam heating of seafood products to aminimum internal temperature of 145°F (62.8°C) using microwave as the energy source.

Acknowledgments

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Conflict of interest

Author declares that there is no conflict of interest.

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