Food Processing & Nutritional Science

Research Article | Vol 3 Iss 1

Changes in Umami Components of Scallops after Microwave and Oven Cooking

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Received: February 25, 2022; Accepted: March 12, 2022; Published: March 19, 2022

ABSTRACT

Scallops taste very good because they contain umami components, such as glycogen, inosinic acid (IMP), adenosine monophosphate (AMP), and glutamic acid (Glu). These umami components are produced and decomposed by certain enzymes in scallops. The activity of these enzymes varies greatly depending on temperature; therefore, amount of the umami components varies depending on the cooking method. Currently, microwave ovens and ovens capable of automatic cooking are used as cooking devices in households. In recent years, the need for automatic cooking of meat and vegetables using an oven range that combines microwave and oven functions (rapid and slow cooking, respectively) has increased. Therefore, in this study, I focused on microwave and oven cooking, which are commonly used in households, and compared the contents of the umami components in scallops. I set the following cooking conditions to achieve a central temperature of 80°C in scallops: microwave oven for 30 seconds, microwave oven for 20 seconds + oven for 4 minutes, microwave oven for 10 seconds + oven for 8 minutes, and oven for 8 minutes. No significant difference was observed in the contents of glycogen, AMP, IMP, inosine, and hypoxanthine under various cooking conditions, whereas Glu content tended to increase during oven cooking. In addition, results on the synergistic effect of umami revealed that oven cooking increased the content of umami taste components. Therefore, the results indicate that oven cooking is better than microwave cooking as a cooking method for scallops as far as umami is concerned, and oven cooking time should be increased when both oven and microwave cooking are used.

KEYWORDS

Scallops; Umami; Oven heating; Microwave heating

INTRODUCTION

Scallops are taste very good because of the presence of many umami components [1] and are popular and widely consumed worldwide. The umami components of scallops are reported to be glycogen, inosinic acid (IMP), adenosine monophosphate (AMP), and glutamic acid (Glu) [2]. Compared with common fishes, which contain only IMP, scallops contain more umami components. A synergistic effect of umami is known, and it has been reported that Glu exhibits 4 times - 8 times more umami in the presence of IMP than that exhibited by each of them alone [3-8]. Since it has been reported that the synergistic effect of umami varies depending on the ratio of each ingredient [4], umami intensity in scallops may also vary depending on the ratio of each ingredient. Although changes in the ratio of umami components occur during storage of raw scallops, the ratio is expected to change significantly during cooking.

Citation: Hiroko Seki, Changes in Umami Components of Scallops after Microwave and Oven Cooking. Food Proc Nutr Sci 3(1): 1-9.

Glycogen is produced in scallops as a metabolite during metabolism, whereas Glu is produced by protease degradation of proteins. AMP and IMP are produced by the enzymatic degradation of adenosine triphosphate (ATP)-related compounds in the muscles. The conversion pathway of compounds is given as follows:

ATP→Adenosine diphosphate (ADP)→AMP→IMP→ inosine (HxR)→hypoxanthine (Hx)

It has been reported that enzymes in muscles play a major role in the production of umami components in scallops [5]. During the cooking of poultry meat and fishes, IMP is degraded by phosphatase and amino acids are produced from proteins by proteases [6]. In scallops, phenylalanyl aminopeptidase in the closed-shell muscle is heat sensitive [7] and the activities of enzymes degrading AMP and adenosine, which are ATP-related compounds, are changed depending on the cooking time [5]. This suggests that the ratio of umami components may change depending on the cooking time and method.

Currently, microwave ovens and ovens capable of automatic cooking are used as cooking devices in households. A microwave oven heats food from the inside by dielectric heating, whereas an oven is a cooking device that heats food from the outside by radiation from the wall heated by the heater and convection from the air [8]. In recent years, the need for automatic cooking of meat and vegetables using an oven range that combines these two functions has increased. In this study, I measured glycogen, IMP, AMP, and Glu contents in scallops cooked in a combination of microwave and oven functions and determined the cooking conditions for scallops that can provide high umami content. First, the heating conditions of an oven range with both oven and microwave functions were assessed and different cooking conditions, including the combination of these functions, were determined. Next, I performed cooking under the determined conditions and compared the contents of the umami components. Based on these results, I proposed a cooking method that produced high umami level.

MATERIALS AND METHODS

Sample Collection

Ezo giant scallops (*Mizuhopecten yessoensis*) were obtained from Hokkaido, Japan. The scallops were frozen and stored at -20°C in a freezer in the laboratory. Three scallop samples were used in each test group.

Investigation of Cooking Conditions for Scallops using Microwave and Oven Functions

The samples were heated in an oven range (Panasonic) with microwave heating (500 W output) used for rapid cooking, oven heating (210°C) used for slow cooking, or a combination of the two. The temperature of the center of the sample was measured using a digital thermometer (CUSTOM). The time required for the temperature of the center of the sample to reach 80°C was measured.

Measurement of Glycogen

The glycogen content was evaluated according to the method described by Seki et al. [9]. Approximately 0.1 gram of scallop adductor muscle was placed in a 15 mL centrifuge tube, and 2 mL of 10 % perchloric acid was added to it for glycogen extraction. The solid matter was removed by centrifugation (12,000 gram, 5 minutes, 5°C), and the supernatant was transferred to another tube. Thereafter, 5 mL of ethanol (Fujifilm Wako Pure Chemical Corporation) was added to the supernatant; the mixture was stirred and centrifuged (12,000 gram, 5 minutes, 5°C) to obtain precipitated glycogen. The supernatant was removed, and the precipitate was resuspended in 50 mL purified water. Overall, 200 µL of this solution, 12 µL phenol (Fujifilm Wako Pure Chemical Corporation), and 500 µL sulfuric acid (Fujifilm Wako Pure Chemical Corporation) were mixed in a new tube. The solution was

incubated at 25°C for 10 minutes and further shaken briefly. After incubation for 20 minutes, the absorbance was measured at 490 nm using a plate reader (iMark; Bio-Rad Laboratories, Inc.), and glycogen content was calculated from standard dose response curve of glycogen (Fujifilm Wako Pure Chemical Corporation).

Measurement of ATP-related Compounds

The contents of ATP-related compound were evaluated according to the method described by Seki et al [9]. As HxR and Hx are the decomposition products of IMP, they were measured along with AMP and IMP. Approximately 2.5 gram of scallop adductor muscle was placed in a 15 mL centrifuge tube, and 4 mL of 10% perchloric acid (Fujifilm Wako Pure Chemical Corporation) was added to extract ATP-related compounds. The solids were removed by centrifugation (11,000 gram, 10 minutes, 5°C) (MX 201; Tomy Seiko Co., Ltd.), and the supernatant volume was adjusted to 10 mL with 10% perchloric acid. Overall, 1 mL of this solution was neutralized with KOH (Kanto Chemical Co., Inc.). The precipitate was removed by centrifugation (12,000 gram, 5 minutes, 5°C), and the volume of the supernatant was adjusted to 5 mL with purified water. This solution was filtered through a 0.22 μm filter (Shanghai Fenghan Industrial Co., Ltd.), and the levels of ATP-related compounds were measured using high-performance liquid chromatography [HPLC); column: Cosmosil Packed Column 5C18-PAQ, 4.6 mm I.D. × 150 mm, mobile phase: 20 mM KH_2PO_4 (Fujifilm Wako Pure Chemical Corporation) solution (pH 7), flow velocity: 1.0 mL/min, temperature: 40°C, detector: U.V., wavelength: 260 nm, and injection volume: 20 μL] (10A series; Shimadzu Corporation).

Measurement of Glu

The Glu content was evaluated according to the method described by Seki (2021), which is the same as that used for the determination of ATP-related compound levels described previously (**Measurement of ATP-related compounds**). Labeled Glu in the sample solution was obtained by mixing 40 μL of the sample solution with 70 μL ethanol, 20 μL triethylamine (Fujifilm Wako Pure Chemical Corporation), and 20 μL phenyl isothiocyanate (Kanto Chemical Co., Inc.). Further, the mixture was incubated at 25°C for 30 minutes. Subsequently, 500 μL of acetate sodium acetate (Fujifilm Wako Pure Chemical Corporation) buffer (50 mM, pH 6.0) and acetonitrile (Fujifilm Wako Pure Chemical Corporation) (97:3, v/v) were added to the sample mixture. The mixture was filtered through a 0.22 μm filter, and the Glu content was measured using HPLC. The HPLC column (Cosmosil Packed Column 5C18-MS-II, 4.6 mm I.D. × 150 mm) was injected with 20 μL of the sample at a 1.0 mL/min flow velocity. HPLC detection was at a wavelength of 254 nm at 40°C. The mobile phase conditions were as follows: eluent A composed of 50 mM acetate–sodium acetate buffer (pH 6.0):acetonitrile (97:3); eluent B composed of acetonitrile : Water (6:4); gradient: Eluent B was increased from 5% to 100% between 0 and 16 min, decreased from 100% to 5% for 4 minutes, and was kept steady for another 5 minutes. Glu content was calculated using the standard dose response curve of Glu (Fujifilm Wako Pure Chemical Corporation).

Establishing Conditions for Cooking Scallops with High Umami Content

It has been reported that umami has a synergistic effect, and the simultaneous presence of IMP (a nucleic acid) and Glu (an amino acid) results in an umami flavor approximately 4 times - 8 times higher than normal [3]. The following equation has been reported as an expression of the synergistic effect [10]. The amounts of IMP and Glu in scallops cooked under each condition were substituted into the following equation and compared to determine the most appropriate cooking conditions.

$Y = u + \gamma uv$ [u: Glu concentration; v: IMP concentration; γ: 1200 (constant)]

Statistical Analyses

Data were obtained using Fisher's three principles. t-test was performed to determine the difference between the mean values using Microsoft Excel. $p < 0.05$ was considered statistically significant.

RESULTS

Investigation of Cooking Conditions for Scallops using Microwave and Oven Functions

Figure 1 shows the relationship between the central temperatures of scallops heated using a microwave and/or oven and time. In the case of only microwave cooking, the temperature was -8°C at 0 second (frozen), 4°C for 10 seconds, 60°C for 20 seconds, and 78°C for 30 seconds. In the case of only oven cooking, the temperature was -6°C at 0 second (frozen), 52°C for 5 minutes, 63°C for 7 minutes, and 79°C for 8 minutes. Based on these results, it was decided that microwave heating for 30 seconds for rapid cooking and oven heating at 210°C for 8 minutes for slow cooking would be used. For the combination of rapid and slow cooking, based on the above results, it was decided that rapid cooking would be done in the microwave for 10 seconds and 20 seconds, followed by slow cooking in the oven. The time for the central temperature to reach 80°C was measured. For microwave cooking for 10 seconds, the central temperature of the samples was -4°C at 0 second (frozen), followed by 8°C after microwave cooking for 10 seconds, and 80°C after oven cooking for 8 minutes. For microwave cooking for 20 seconds, the central temperature of the samples was -6°C at 0 second (frozen), followed by 47°C after microwave cooking for 20 seconds, and 80°C after oven cooking for 4 minutes. Therefore, two rapid and slow cooking combinations were analyzed in this study: 1. cooking in the microwave oven for 10 seconds followed by cooking in the oven for 8 minutes, and 2 minutes cooking in the microwave oven for 20 seconds followed by cooking in the oven for 4 minutes.

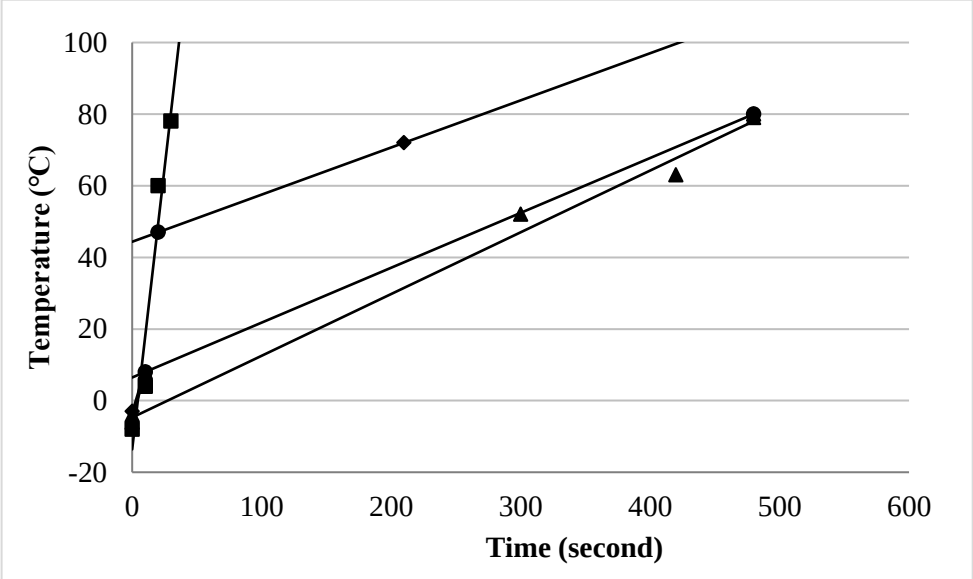

Figure 1: Relationship between cooking time and central temperature of scallops.
■ microwave (500 W) 30 s, ◆ microwave 20 s + oven 4 min, ● microwave 10 s + oven 8 min, ▲ oven 8 min

Measurement of Glycogen

Table 1 shows the glycogen content in scallops cooked under the various conditions. The highest value of glycogen content (2%) was obtained after scallops were oven cooked for 8 minutes only; however, no significant difference was observed among the cooking conditions ($p > 0.05$).

Cooking condition	Glycogen (%)	Standard Deviation
Microwave 30 seconds	1.8	(0.8)
Microwave 20 seconds + oven 4 minutes	1.2	(0.5)
Microwave 10 seconds + oven 8 minutes	1.7	(0.8)
Oven 8 minutes	2.0	(0.8)
The tests were conducted with n = 3.		

Table 1: Comparison of glycogen content in scallops under various cooking conditions.

Measurement of ATP-related Compounds

Table 2 shows the contents of AMP, IMP, HxR, and Hx in scallops heated under various cooking conditions. For cooking conditions, AMP content was 1.4 µmol/g, 1.8 µmol/g, 1.6 µmol/g, and 1.8 µmol/g, respectively; IMP content was 0.097 µmol/g, 0.090 µmol/g, 0.11 µmol/g, and 0.097 µmol/g, respectively; HxR content was 2.7 µmol/g, 3.1 µmol/g, 3.2 µmol/g, and 3.2 µmol/g, respectively; and Hx content was 2.8 µmol/g, 2.8 µmol/g, 3.0 µmol/g, 4.0 µmol/g, and 3.0 µmol/g, respectively. No significant differences were observed in AMP, IMP, HxR, or Hx contents among all the cooking conditions ($p > 0.05$).

Cooking Condition	AMP (µmol/g)	Standard Deviation	IMP (µmol/g)	Standard Deviation	HxR (µmol/g)	Standard Deviation	Hx (µmol/g)	Standard Deviation
Microwave 30 seconds	1.4	(0.27)	0.097	(0.037)	2.7	(0.37)	2.8	(0.19)
Microwave 20 seconds + oven 4 minutes	1.8	(0.43)	0.090	(0.027)	3.1	(0.38)	3.0	(0.59)
Microwave 10 seconds + oven 8 minutes	1.6	(0.12)	0.11	(0.016)	3.2	(0.32)	4.0	(0.39)
Oven 8 minutes	1.8	(0.29)	0.097	(0.016)	3.2	(0.28)	3.0	(0.28)
The tests were conducted with n = 9.								

Table 2: Comparison of AMP, IMP, HxR, and Hx contents of scallops under various cooking conditions.

Measurement of Glu

Table 3 shows the Glu content in scallops under various cooking conditions. For cooking conditions, the Glu content was 1.5 mg/g, 2.5 mg/g, 2.5 mg/g, and 2.5 mg/g. No significant difference was observed between Glu content in microwave 20 secs + oven 4 min ($p > 0.05$); however, Glu content in 30 secs microwave was significantly lower than that in methods microwave 10 secs + oven 8 min ($p < 0.05$).

Cooking condition	Glutamic acid (mg/g)	Standard deviation
Microwave 30 s	1.5	(0.50)
Microwave 20 s+ oven 4 min	2.5	(0.63)
Microwave 10 s + oven 8 min	2.5	(0.50)
Oven 8 min	2.5	(0.51)
The tests were conducted with n = 9.		

Table 3: Comparison of glutamic acid content scallops under various cooking conditions.

Establishing Conditions for Cooking Scallops with High Umami Content

Table 4 shows values of the synergistic effect calculation for umami in scallops heated under various cooking conditions. For cooking methods, the values were 176.1, 272.5, 332.5, and 293.5, respectively. Microwave 30 seconds showed value significantly different from other conditions ($p < 0.05$). There were no significant differences

among the values of conditions. Microwave 20 seconds + oven 4 minutes, microwave 10 seconds + oven 8 minutes and oven 8 minutes ($p > 0.05$).

Cooking Conditions	Calculated Value	Standard Deviation
Microwave 30 seconds	176.1	(71)
Microwave 20 seconds + oven 4 minutes	272.5	(85)
Microwave 10 seconds + oven 8 minutes	332.5	(101)
Oven 8 minutes	293.5	(55)
The tests were conducted with n = 9.		

Table 4: Synergistic effect of umami in various cooking conditions.

DISCUSSION

Measurement of Glycogen

No significant difference was observed in glycogen contents in scallops cooked under various conditions. Since the glycogen content of raw scallops has been reported to be 2.0% - 3.0% [9], the value was observed to be lower in cooked scallops. Glycogen is maintained in the body as a storage sugar and is used as energy during exercise. Glycogen is utilized through the glycolysis system, where it is degraded to glucose-1-phosphate by phosphorylase [11]. Scallop phosphorylase exists in scallops as a b-type enzyme as it does in mammals [12]. Additionally, carp and rabbit glycogen phosphorylase are b-type enzymes, and their optimal temperatures are 35°C for carp and 40°C for rabbit [11]. In this study, it is possible that cooking the scallop activated phosphorylase b, resulting in a decrease in glycogen content.

Measurement of ATP-related Compounds

No significant differences were observed in AMP, IMP, HxR, and Hx contents in scallops cooked under various conditions. The activity of AMP-degrading enzyme in scallops after cooking at 40°C, 60°C, and 80°C for 5 minutes was reported to be 77%, 16%, and almost 0% of that in unheated scallops, respectively [13]. In this study, the time required for the central temperature of scallops to reach 80°C was less after 30 seconds of microwave heating, which is a rapid cooking method. However, 8 minutes in the oven, takes a long time to reach 80°C. This indicates that the AMP-degrading enzyme is most likely more active during 8 minutes of oven cooking. Table 2 shows that 30 seconds of microwave cooking resulted in low AMP, HxR, and Hx contents, confirming the overall trend of degradation. In a study, during the reaction between trypsin and casein in pig pancreas, L-tyrosine equivalents released from casein per min were measured by applying 10 W microwave at 22°C. The amount of tyrosine increased in the microwave irradiated area, indicating that weak microwave irradiation promoted the enzyme activity [14]. On the other hand, the activity of radish peroxidase decreased with time after microwave irradiation at 1000 W. However, approximately 80% of its activity was maintained even after microwave cooking at 1000 W for 40 seconds [15]. Since the enzyme was heated at 500 W for 30 seconds in this study, the activity of the enzyme was hardly decreased; it is possible that the activity was accelerated by microwave irradiation. In the bovine semimembranosus muscle, lactate dehydrogenase and its isozyme activity were reported to be decreased by oven cooking at 57°C - 66°C in a temperature-dependent manner [16]. However, proteolytic enzyme in bovine semitransparent membrane exhibited lower enzyme activity after microwave cooking than that after oven cooking [17].

Measurement of Glu

Table 4 shows that the Glu content was low in the after 30 seconds of microwave cooking and high after the conditions that included oven cooking. The content of many amino acids increased with cooking time; in bouillon at 80°C - 95°C, Glu content is also reported to increase with cooking

time [18]. In addition, in beef, the amount of free amino acids was measured when the beef was heated from 40°C to 80°C for 10 minutes - 360 minutes; the highest amount of free amino acids was obtained when the beef was heated at 40°C for 360 minutes, and the highest amount of Glu was obtained when the beef was heated at 40°C for 180 minutes and 360 minutes [19]. Furthermore, in abalone, it was reported that the umami taste and taste desirability increased more after 180 minutes of cooking than after 30 minutes of cooking [20], suggesting that cooking time has a significant effect on umami taste. Similarly, in this study, the Glu content was affected by the cooking time; it increased under slow cooking rather than under rapid cooking.

Establishing Conditions for Cooking Scallops with High Umami Content

Table 5 shows that the synergistic effect of umami was highest after 10 seconds of microwave cooking followed by 8 min of oven cooking; however, this result largely reflects the result of Glu content, which had lower values for microwave cooking and higher values for oven cooking. The equation for umami synergistic effect reported by Yamaguchi (1991) was studied for three line grunt, pork, and red sea bream, and the calculated umami intensity was reported to be in good agreement with the results of sensory tests [21]. Therefore, the formula can be considered to reflect the effect of umami. Slow cooking resulted in high umami in this study. From the above results, oven cooking was observed to be better than microwave cooking as a cooking condition as far as high umami content is concerned. In the case of combination cooking using both microwave and oven functions, the results of this study suggest that to enhance umami content, it is better to increase the oven cooking time rather than the microwave cooking time. However, this study has a limitation in that only microwave and oven cooking methods were considered in this study. Other cooking methods should be considered in future studies.

CONCLUSION

In this study, I identify a cooking method that can produce scallops with numerous umami components. No significant difference was observed in glycogen, AMP, IMP, HxR, or Hx contents among the various cooking conditions. In contrast, Glu tended to increase in oven cooking. The calculation of the synergistic effect of umami indicates that oven cooking increased umami taste. Therefore, oven cooking is observed to be better than microwave cooking as it produces more umami. I conclude that it is better to increase the oven cooking time in case of cooking using the combination of oven and microwave methods.

AVAILABILITY OF DATA

Conflict of Interest

The author declares no conflict of interest.

Funding

This research was supported by the Society for Research on Umami Taste.

Acknowledgments

The author would like to thank Ebisawa, S. for assistance with the numerical simulations.

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