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Study on heat and mass transfer, protein denaturation and physicochemical changes in kuruma prawn Marsupenaeus japonicus during thermal processing

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博士学位論文内容要約
Summary

専　攻 Major	応用生命科学専攻 Course of applied marine Bioscience	氏　名 Name	李 暁龍 LI XIAOLONG
論文題目 Title	Study on heat and mass transfer, protein denaturation and physicochemical changes in kuruma prawn *Marsupenaeus japonicus* during thermal processing （クルマエビ加熱プロセスにおける、熱・物質移動、タンパク質変性および物理化学的変化に関する研究）		

Prawn or shrimp is a rich source of nutritious substance and has good taste and flavor. Water and protein were the main components of prawn muscle. Quality attributes including water release and protein denaturation were occurred in prawn muscle during thermal treatment.

In Chapter 1, the current research on prawn muscle was reviewed. Various factors including heating method, temperature and processing time will impact on the products quality. Quality attributes are commonly evaluation indicators. Moreover, quantitative analysis and prediction of protein denaturation has been studied by DSC-dynamic method. Mathematical models are expected to improve our understanding of physics behind the thermal treatment.

In Chapter 2, in order to analyze the kinetics of protein denaturation and the relationship between the degree of denaturation and chemical changes, changes in Ca^{2+}-ATPase activity, protein solubility, and total sulfhydryl content of whole prawn meat during heating were investigated. TPD was described by a first-order reaction. Approximately 15 mg of raw material was placed in aluminum pans and the pans were sealed, samples were heated from 20 to 100 °C at different heating rates. The temperature at each endothermic peak was measured and recorded using a DSC analysis. The thermogram obtained by non-isothermal differential scanning calorimetry analysis displayed three endothermic peaks corresponding to myosin, sarcoplasmic-collagen, and actin. Enthalpy values of individual protein were calculated using the area of each endothermic peak divided by the dry matter weight of each DSC samples. The results revealed an uneven distribution of the protein denaturation in prawns that was dependent on the heating conditions. Ca^{2+}-ATPase was detected by quantifying phosphorus according to the instructions of ATPase kit. Ca^{2+}-ATPase activity decreased with increasing heating times at 51 or 85°C and was strongly related to the average degree of total non-denaturation ratio. The results of protein solubility analysis suggested that hydrogen bonds, hydrophobic interactions, and ionic bonds changed with protein denaturation. The number of ionic bonds was reduced, while hydrogen content was enhanced at both temperatures. Hydrophobic interactions increased gradually at 51°C ($p < 0.05$). At 85°C, hydrophobic interactions increased notably at first ($p < 0.05$); however, as heating continued, no significant changes were observed ($p > 0.05$). Our results indicate that the extent of protein solubility is significantly correlated with the average degree of protein denaturation during the heating process.

In Chapter 3, excessive shrinkage of processed food lowers its perceived quality by consumers, and therefore should be avoided. This chapter aimed to clarify the Multiphysics involved in the shrinkage of prawn during heating, a model that describes changes in moisture content of prawn due to pressure-driven water transport was reported. The transport model for the heating process included a stress-strain analysis coupled to a virtual work principle. Simultaneous calculation of changes in internal pressure and TPD, was used to describe the physics behind

shrinkage. Temperature, moisture, pressure, as well as TPD profiles and distributions were calculated, and were validated with measured results. Results indicated that shrinkage was delayed due to slow rate of water release, which promoted the increment in internal pressure. This phenomenon, in combination with actin denaturation, resulted in dramatic water release and volumetric shrinkage. By the proposed model, the understanding of the shrinkage phenomena of prawn during heating was improved. The proposed structural mechanics model combined with the pressure driven transport of water allowed calculation of the time evolution of many different variables. Similar approach can also be applied for different samples treated using other heating methods. In addition, the employed TPD approach not only have application to simulate the denaturation, but also, they can be used for the analysis of additional thermal treatments, making possible the evaluation of the changes in other quality attributes besides texture and water retention.

In Chapter 4, for kuruma prawn, the presence or absence of shell is also a factor that should be considered. Several factors including heat penetration, moisture content, color distribution, microstructure, and texture changes of peeled and unpeeled samples were tested at several thermal schedules. Heat penetration was slower in unpeeled than peeled prawns at the initial stage at all evaluated heating temperatures, unpeeled prawns were required one more minute to get equilibrium state compared to peeled prawn. Slower heat penetration was correlated well with the predicted lower denatured rate observed for each protein. The denatured rate of myosin, sarcoplasmic-collagen, and actin in unpeeled prawns at 85 °C decreased by 9.36%, 5.88% and 15.30% compared to peeled prawns. The tissue connection between shell and muscle apparently protects the prawn meat from shrinkage, resulting in a reduction of the water release. L^* values of prawn muscle showed a closed correlation with X_{tot} at 65, 75 and 85 °C. Color values regardless of L^*, a^*, and b^* between unpeeled and peeled prawns in any were not significant different ($p > 0.05$). However, color values of peeled samples showed a slightly higher than unpeeled prawns, which was probably caused by denser structure. Maximum stress of unpeeled prawns at 50, 65 and 75°C were significantly higher than peeled prawns. Moreover, the absence of shell lead to a denser microstructure and slightly higher color profiles in peeled prawns. However, the maximum stress showed no significantly different regardless of the presence or absence of prawn shell underwent 75 or 85 °C for 20min. These results will be helpful in optimizing the thermal treatment conditions of peeled and unpeeled prawns and contributing to provide technical support in the design of high-quality prawn products.

In general, thermal protein denaturation kinetic model made it possible to predict protein denaturation at an arbitrary temperature. Experimental measuring and mathematical modeling were combined to forecast and control products quality. Effect of heating temperature and time on peeled and unpeeled prawns were investigated. These results will be as the basis theory of the heating for widely application in food industry and improve the level of automation management of the food industry.