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A Review of Research Progress of Low-Field Nuclear Magnetic Resonance Technology in the Detection of Aquatic Products

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Abstract. During the processing of aquatic products, the detection of water content is a very important indicator. In this paper, by studying and analyzing the changes of water content in different aquatic products processing by low field nuclear magnetic resonance technology, it is found that it can provide information on the kinetic behavior of water molecules, the content and distribution of components, the storage process and the preservation method. Therefore, low-field nuclear magnetic resonance technology has broad application prospects in the field of aquatic product processing and research, and can provide important scientific basis for the quality control and improvement of aquatic products.

Keywords. Low field nuclear magnetic resonance, Transverse relaxation time, Moisture content

1. Introduction

China has more than 18,000 kilometers of coastline and vast aquaculture waters, so it has become an important fishery country, with more than 1/7 of the world 's annual catches. Aquatic products are rich in protein, which is easy to be digested and absorbed by human body. Aquatic products usually contain 70-80% water, which can be divided into free water and bound water. Due to the high water content in fish meat and less binding tissue, fish meat is more likely to deteriorate than other meats [1]. Therefore, in the process of processing and storage of aquatic products, the technical requirements for rapid detection of their quality are high.

Water is ubiquitous in food processing. Its role in mass and heat transfer is very important, but it is also accompanied by water loss. Previous studies have shown that water content is essential for inhibiting microbial growth, extending storage time and forming a good taste. Although the research on the effect of moisture in food is very extensive, it is difficult to quantitatively explain because of the complexity of typical food systems with multi-component and multi-phase. Especially with the change of food volume shrinkage and internal structure, the interaction between water and

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macromolecules will also change, resulting in the change of drying characteristics of sample materials [2].

In recent years, rapid detection technology has gradually replaced the traditional laboratory or sensory means, including near infrared spectroscopy, Raman spectroscopy, laser-induced breakdown spectroscopy, gene determination technology, mechanical vision, biosensor detection technology and low field nuclear magnetic resonance technology[3].

Low field nuclear magnetic (LF-NMR) resonance generally refers to the nuclear magnetic resonance phenomenon with a constant magnetic field strength of less than 0.5T. At present, it has been gradually applied to food detection, geological exploration, chemical product detection and other fields. LF-NMR technology has the advantages of small equipment size, simple operation, good instrument stability, and can observe the internal material state of the sample without damage[4,5]. Compared with other rapid detection methods, LF-NMR technology is generally not affected by sample shape, color, size, etc., with better detection accuracy and wider application range. At present, it has been widely concerned in the field of food quality and safety detection and plays a role in many food fields[6-10].

This paper mainly analyzes and summarizes the research and application of LF-NMR in different types of aquatic products, and analyzes its advantages and disadvantages in research and application, so as to provide help for the better application of LF-NMR technology in aquatic products.

2. The basic principle of low field nuclear magnetic resonance technology

Under the combined action of an alternating magnetic field and a constant magnetic field, and when the spin quantum number of the nucleon is not zero ($I \neq 0$), the spin energy level undergoes Zeeman splitting under the action of an external magnetic field. The physical process of resonant absorption of a certain frequency of radio frequency radiation is called NMR. LF-NMR refers to the NMR with a constant magnetic field strength of less than 0.5T[11-13]. The LF-NMR technology with hydrogen nucleus (^1H) as the research object is the main and widely used research object at present. It is usually studied according to the information of different states of water in biological materials and their relative contents[14].

In the experiment, by measuring the longitudinal relaxation time T_1 (also known as the spin-lattice relaxation time), the transverse relaxation time T_2 (also known as the spin-spin relaxation time) and the self-diffusion coefficient, the motion properties of the proton can be reflected[15]. LF-NMR is by applying a radio frequency pulse to the sample in a constant magnetic field, the hydrogen proton resonates, part of the hydrogen proton in the low energy level absorbs energy, transitions from the low energy state to the high energy state, after canceling the radio frequency pulse, the proton in the high energy state releases the absorbed energy in a non-radiative manner to the low energy state to achieve Boltzmann equilibrium[16]. In this process, T_1 and T_2 measure the interaction force between spin and environment and spin, respectively. In meat science research, T_2 values can distinguish three different states of water, namely bound water, immobile water and free water, and can also reflect the migration between the three[17]. The variation range of T_2 is large, and it is more sensitive to the existence of various phases than T_1. Therefore, the relaxation time T_2 is mainly

measured in the experiment[16,18]. Therefore, LF-NMR can be well applied to the quality and safety of aquatic products to achieve rapid and accurate detection.

LF-NMR technology can better reflect the quality of aquatic products, such as non-destructive measurement and detection of water distribution and fluidity, composition analysis of protein and fat, protein emulsification and gel properties in aquatic products. Therefore, it can be widely used in the preservation and storage of aquatic products and the gel properties of aquatic products. Compared with conventional aquatic product quality evaluation methods such as sensory evaluation, microbial detection and physical and chemical detection, LF-NMR technology has the advantages of fast, accurate and non-destructive [19], and has a good application prospect in aquatic product quality detection.

3. Application of low field nuclear magnetic resonance in fish products

China is rich in fishery resources. According to statistics, the largest continuous catch in China 's offshore and offshore seas is about 7.5 million tons. The processing methods of fish meat products are mainly frozen preservation and high temperature heating. Therefore, many scholars have systematically studied the changes of water content in different fish processing.

Bian[20], Lin[21],Yang[22], and Zhang[23] used nuclear magnetic resonance technology to study the effect of salt addition on water distribution and migration during surimi processing. They found that the proton density of high relaxation time increased, the proton density of low relaxation time decreased, and the fluidity of water increased after salt mixing and seasoning mixing. The distribution of proton density after heating is opposite to that before. The proton density at high relaxation time becomes less, the proton density at low relaxation time becomes more, and the water holding capacity becomes stronger.

Carla Da Silva Carneiro[24], Sanchez-Alonso[25] and Jepsen[26] used LF-NMR to study the water mobility in the muscle of brasiliensis stored for different days. The transverse relaxation (T_2) data were fitted exponentially, and three T_2 peaks were obtained. There was a close correlation between the quality indicators obtained by analyzing the physical and chemical parameters and the relaxation data of NMR. At the same time, the change of water mobility caused by degradation during the storage of salted fish led to the change of component values observed by transverse relaxation nuclear magnetic resonance. These results are mainly related to the protein degradation of the product during storage, which changes the kinetics and tissue composition of water molecules.

By analyzing the research and application of LF-NMR technology in different fish products, it can be concluded that LF-NMR technology can achieve rapid and non-destructive detection of water content changes in fish products, so this technology can be widely promoted in such research.

4. The application of low-field nuclear magnetic resonance in shrimp products

Since 2020, China 's annual shrimp production has exceeded 2 million tons, and some scholars predict that it will reach 4-5 million tons in the future. Among them, the

production of Penaeus vannamei has exceeded 1/2, so the production and processing of Penaeus vannamei has attracted more and more attention.

Yu[27] used low-field NMR to study the effect of ultra-high pressure treatment on the water state in fresh Penaeus vannamei, and compared it with the heat treatment sample. It was concluded that both ultra-high pressure treatment and heat treatment changed the relative content and transverse relaxation time of different water states in the sample to varying degrees. When the treatment pressure was above 100MPa or the temperature was above 60℃, it was found that the sample moisture induced a strong bound water with stronger binding force (relaxation time was 0.1-1ms). The content of immobile water, which is closely related to the water holding capacity of the sample, is less affected by pressure, but decreases significantly with the increase of heat treatment temperature, indicating that ultra-high pressure treatment can better maintain the water holding capacity of the sample than heat treatment.

It can be seen that LF-NMR technology can also be applied to the detection of water content in shrimp meat, which provides a feasible technology for rapid detection of water content in shrimp meat.

5. The application of low field nuclear magnetic resonance in sea cucumber abalone products

Sea cucumber (Stichopus japonicus) is considered to be a high-priced delicacy in Japan and China due to its unique flexibility and palatability. The important step to obtain the required texture of sea cucumber is heating and drying. Therefore, it is particularly important to monitor the change of water content in sea cucumber during heating and drying. Therefore, many scholars have done a lot of research in this area.

Many scholars have used LF-NMR to study high-end aquatic products such as sea cucumber and abalone. For example, Zang [28] studied the hydrodynamics during the drying process of sea cucumber (Apostichopus japonicus), Bi[29] studied the changes of body wall during the heating process of sea cucumber, and Gao[30] studied the moisture and fat content of abalone. Through their research, it's found that the changes of T_1 and T_2 parameters of LF-NMR can clearly show the changes of water content in sea cucumber or abalone, which is reflected in the changes of meat quality.

As a high-end food material, the water content of sea cucumber has a great influence on the taste and texture. Through the above research, it is found that LF-NMR technology can efficiently and non-destructively detect the change of water content of sea cucumbers, and then better taste and nutritional sea cucumber products can be obtained by controlling the water content.

6. Summary and prospect

In the study of different aquatic products, LF-NMR detection parameters are mainly concentrated in T_1 and T_2. Therefore, special T_1 and T_2 databases can be established for different types of aquatic products to correspond to different meat quality. For example, by analyzing T_1 and T_2 data, the freshness and quality changes of aquatic products can be obtained, and then how to store and preserve aquatic products can be explored. Therefore, it can be used to evaluate the effects of different storage conditions on the quality of aquatic products, and to optimize the storage and preservation methods.

Therefore, LF-NMR is a very practical new science and technology, which can be used to study the quality and quality of aquatic products. It can provide information about the dynamic behavior of water molecules, composition content and distribution, storage process and preservation methods. LF-NMR has broad application prospects in the field of aquatic products research, which can provide important scientific basis for the quality control and improvement of aquatic products.

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