Research on Quality Evaluation Methods and Quality Improvement Techniques for Aquatic Products

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Abstract With the improvement of living standards and the shift in societal consumption attitudes, consumers' demand for the quality of aquatic products is increasingly stringent. Freshness and quality have become primary factors determining consumers' purchasing decisions. However, due to the high moisture content, active endogenous enzymes, and rich nutrients in aquatic products, both fresh and processed products are highly susceptible to quality deterioration during procurement, distribution, and storage, which leads to a significant decline in sensory quality and nutritional value, while also compromising safety. Today, the consumption of high-quality aquatic products has become a prevailing trend. This paper reviewed the methods for freshness evaluation and quality grading of aquatic products in terms of sensory and nutritional aspects, aiming to support the market circulation principle of "higher price for better quality" and "price based on quality", and better meeting consumer demands. Therefore, it is imperative to enhance the analysis and evaluation of aquatic product quality and to continuously refine assessment systems and methods, which is crucial for promoting industry transformation and fostering a healthy market-consumer economic cycle.

Key words Aquatic product quality; Sensory evaluation; Physical evaluation; Chemical evaluation; Microbiological evaluation

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China is a major producer and consumer of aquatic products. According to statistics, in 2020, the total national output of aquatic products reached 73.575 9 million t, representing a year-on-year increase of 4.1%. It reaffirms China's position as the world's largest producer of aquatic products, with the aquaculture industry continuing to lead globally, and export volumes returning to the pre-epidemic level[1 – 2]. However, during post-harvest stages such as transportation, storage, and processing, aquatic products are highly susceptible to quality deterioration due to external environmental factors and intrinsic elements (microorganisms and endogenous enzymes). The quality of aquatic products is directly linked to consumer safety, market demand, and processing value[3 – 4]. Therefore, evaluating the quality of aquatic products through sensory, physical, chemical, and microbiological methods and establishing a standardized quality control system can provide a scientific basis for aquaculture and processing enterprises, and guide them in optimizing production processes, improving preservation technologies, and enhancing product added value. Such measures can effectively reduce resource waste, improve the overall competitiveness of the industry, and contribute to the sustainable development of fisheries.

Sensory Evaluation Methods

When purchasing aquatic products and their processed goods in the consumer market, buyers often assess factors such as odor, color, defects, and taste to determine whether the product meets their quality expectations. Sensory evaluation is a scientific method that comprehensively assesses parameters and distinct characteristics of aquatic products, including color, flavor, texture, and mouthfeel. It involves trained evaluators using the five senses, sight, smell, touch, taste, and hearing, to appraise the sensory attributes of the product[5]. For aquatic products, the European Union (EU) method and the Quality Index Method (QIM) are the most widely used sensory evaluation approaches today. The EU method classifies freshness into grades E (extra), A (acceptable), B (poor), and C (unacceptable) and is widely applied to various fish products. It assesses fish quality based on skin condition, surface mucus, eyes, gills, abdominal cavity, odor, and texture. However, this method only provides a rough classification of freshness and overlooks the specific differences among various aquatic species. Compared with the EU method, QIM specifically differentiates between various species of aquatic products. It is based on detailed descriptions of different sensory attributes, such as general appearance, color, eye turbidity, and gill color, and develops targeted evaluation protocols. Using a demerit scoring system, it enables evaluators to objectively score different sensory attribute parameters of aquatic products. Typically, each parameter is scored on a scale of 0 – 3, where 0 indicates the best condition and 3 the worst. Finally, the sensory scores provide direct information on the external quality of the product.

Physical Evaluation Methods

Rigor index

The rigor index is primarily used to assess the freshness of fish. The measurement procedure begins by identifying the midpoint of the fish's body length. The fish is then placed on a horizontal plate, with the front half of its body resting on the plate and the rear half hanging freely. The vertical distance from the

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horizontal extension line of the plate surface to the base of the tail (excluding the caudal fin) is measured immediately after the fish dies, denoted as L. At a specific time after death of the fish, the same vertical distance is measured again, denoted as L'. The rigor index (R) is then calculated using the formula: $R = L - L'L \times 100\%$. The method is convenient, fast, and suitable for on-site testing. However, the variation in rigor index differs significantly among fish species. For example, Pacific herring exhibits obvious appearance and disappearance of rigor, resulting in a wide range of R values, while goosefish shows minimal rigor all the time, with an R value close to zero. Additionally, this method is highly influenced by storage temperature, which imposes certain limitations in practical applications.

Color difference analysis

During the storage of aquatic products, as spoilage progresses, the surface color changes, primarily in terms of brightness and chromaticity. The alteration in surface color of aquatic products correlates well with sensory evaluation results. Therefore, using a colorimeter to detect the color status of aquatic products can effectively assess their freshness. Wang *et al.* [6] used a colorimeter to rapidly measure the L*, a*, and b* values of the body color of South America white shrimp (*Litopenaeus vannamei*). They fitted the colorimeter results with the total volatile basic nitrogen (TVB-N) content of the shrimp meat. The results showed that using the color difference model to assess the freshness of whiteleg shrimp achieved an accuracy of 86.7%. Although color difference analysis offers a relatively convenient means for rapid freshness detection of aquatic products, this method is relatively simplistic and susceptible to errors influenced by storage conditions such as temperature, humidity, and pH.

Texture analysis

Fresh fish and shrimp typically exhibit firm and elastic flesh, whereas spoiled ones tend to become soft and loose. Therefore, the freshness of aquatic products during storage can be assessed using a texture analyzer to measure parameters such as hardness, elasticity, resilience, and cohesiveness of the samples. The study of Wang *et al.* demonstrated that during shrimp storage, changes in hardness and resilience follow clear patterns and correlate well with shrimp freshness quality. Similarly, the study of Zhang *et al.* [7] showed that under 25 ℃ storage conditions, the hardness of golden pompano decreased over time, while its adhesiveness increased.

Electrical properties

As aquatic products spoil, microbial proliferation breaks down proteins and fats into amino acids and organic acids, increasing the number of charges within the product and thus raising its electrical conductivity. Zhang *et al.* [8] assessed the freshness of grass carp by measuring the conductivity of the dorsal muscle extract. The results showed a strong correlation between conductivity and sensory analysis. By analyzing the capacitance changes in shrimp, it was observed that as storage time extended and bacterial proliferation increased, capacitance also rose. Its microbial content and capacitance showed a positive correlation, enabling this method to rapidly estimate the microbial load in shrimp. To further meet the demands for sensitive, rapid, and non-destructive detection of aquatic product freshness, various modern techniques such as spectroscopy, mass spectrometry, and other emerging techniques have been progressively developed. These methods enable fast analysis, high repeatability, and accurate qualitative detection.

Chemical Evaluation Methods

K-value

After fish death, adenosine triphosphate (ATP) in the body is degraded stepwise by endogenous enzymes into adenosine diphosphate (ADP), adenosine monophosphate (AMP), inosine monophosphate (IMP), inosine (HxR), and hypoxanthine (Hx). As this conversion proceeds, the proportions of HxR and Hx gradually increase, leading to a decline in freshness. The K-value is defined as the percentage of the sum of ATP degradation products (HxR and Hx) relative to the total ATP-related compounds (ATP + ADP + AMP + IMP + HxR + Hx)[9]. In China's aquatic industry standard SC/T 3048, high-performance liquid chromatography can be applied to determine the K-value as an indicator of fish freshness. Since this method measures the enzymatic degradation process of ATP, it is generally applicable only to the initial stage of freshness assessment in aquatic products.

Total volatile basic nitrogen (TVB-N)

During the spoilage of aquatic products, proteins decompose under the action of enzymes and bacteria, producing alkaline nitrogenous substances such as ammonia and amines. These compounds are collectively referred to as total volatile basic nitrogen, serving as an objective indicator of the freshness of aquatic products. The national food safety standard GB 2733 for fresh and frozen animal aquatic products specifies the following limits for TVB-N content: no more than 30 mg/100 g in marine fish and shrimp, no more than 25 mg/100 g in marine crabs, no more than 20 mg/100 g in freshwater fish and shrimp, and no more than 15 mg/100 g in frozen shellfish. The determination of TVB-N in aquatic products can be carried out according to GB 5009.228. However, this method involves cumbersome steps, and is time-consuming. Therefore, it is difficult to be used for rapid detection on site.

Trimethylamine (TMA)

During the storage of aquatic products, trimethylamine oxide degrades under the action of bacteria and enzymes to produce trimethylamine, dimethylamine, and ammonia. Trimethylamine is one of the key indicators for assessing the freshness of aquatic products, and its content increases as freshness declines[10]. The determination of trimethylamine content in aquatic products can be performed according to the national standard GB 5009.179 using headspace gas chromatography-mass spectrometry or headspace gas chromatography. While this method provides accurate measurements, it involves complex sample pretreatment, is time-consuming, and requires costly instruments.

Indole

Indole is an important spoilage metabolite in shrimp products, primarily generated during the autolysis stage. Proteins in shrimp are broken down into a series of intermediate products by endogenous enzymes, which are then further decomposed into spoilage substances by exogenous enzymes, leading to the onset of spoilage in shrimp. The U. S. FDA stipulates that shrimp with an indole content of ≤250 g/kg is classified as first-grade freshness, while ≥500 g/kg indicates third-grade freshness. In China, the indole content in shrimp can be measured according to the import-export inspection and quarantine standard SN/T 0944 using a colorimetric method. However, this method involves steps such as distillation, extraction, color development, and separation, making the procedure cumbersome and requiring highly toxic reagents such as chloroform.

pH value

The pH of live aquatic products is generally neutral. After death, circulation stops, and glycogen stored in the muscles undergoes anaerobic glycolysis to produce lactic acid, causing the pH to drop. Subsequently, due to the action of spoilage microorganisms, amino acids are broken down into alkaline substances such as ammonia and amines, leading to a rise in pH. The pH of oysters in aquatic products can be determined according to the national standard GB 5009. 237. The method is convenient, fast, and low-cost. However, since the pH decreases initially and then increases during the spoilage of aquatic products, it cannot accurately determine the freshness level. Additionally, the initial pH and the rate of pH change vary among different aquatic species, so pH measurement is generally used as an auxiliary method in combination with other techniques for freshness assessment.

Microbiological Evaluation Methods

Due to their high moisture content, delicate muscle tissue, and active endogenous enzymes, aquatic products provide an ideal environment for microbial survival and proliferation. Consequently, microbial contamination can easily lead to spoilage and affect shelf life. Microbiological methods primarily involve counting the number of colonies during biological metabolic processes, using colony counts to reflect the freshness of the product. Microbiological testing methods can determine the total plate count and total coliform count in samples according to China's national standard GB 4789. However, both total plate count and total coliform count methods require at least 48 h of incubation and must be performed by trained professionals. Consequently, these methods are not suitable for the procurement, transportation, sales, or processing stages of aquatic products. Improving the accuracy and specificity of test results would enable broader application.

The assessment of the quality of aquatic products typically refers to the extent to which their appearance characteristics and edible performance comply with relevant regulations and meet consumer requirements. Currently, the detection of freshness and quality in aquatic products still relies predominantly on traditional methods, including sensory evaluation, physicochemical indicator measurement, and microbiological testing. However, relying on only one or two technical methods may lead to significant errors and relatively low reliability in the evaluation results. Therefore, selecting appropriate indicators and detection methods from different requirement perspectives, while ensuring accuracy and achieving efficient, high-precision, and low-destructive quality evaluation of aquatic products, will facilitate accurate and efficient product grading. This approach supports the principle of "higher price for better quality", and enhances public trust and international competitiveness of products. This study provides a foundation for exploring novel preservation methods and high-value utilization of aquatic products.

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