Aquaculture and Seafood Processing in Japan

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Introduction

A number of marine products have been utilized as a major protein resource in Japan since ancient times. Despite the current diversified diet, around 20% of the total protein supply for a Japanese per day is derived from seafood, accounting for 40% of animal protein supply (Institution of Statistics in Agriculture and Forest, 2002). Furthermore, the beneficial functions of seafood for human health, such as preventive effects of polyunsaturated fatty acids against atherosclerosis, have been successively revealed (Dyerberg, 1986) so that the advantage of seafood intake is now appreciated.

However, Japanese fisheries production has considerably decreased in the past two decades. For example, over 11 million tons of catch in 1990 was lowered to around 6 million tons in 2000 (Institution of Statistics in Agriculture and Forest, 2002). The decline of sardine resources, which largely contributed to the catch in 1980s, is mainly a cause of the recent decrease in fisheries production. The changes in the costal environment and over-fishing are also of concern. To increase fisheries production in coastal areas in Japan, various attempts have been made. One of the typical projects is seed (juveniles) production of fish and release. On the other hand, the decrease in catch has promoted imports of seafood from abroad. Nowadays, Japanese imports of seafood are the largest in the world, accounting for over 15 billion dollars (Institution of Statistics in Agriculture and Forest, 2002).

The production of seafood through aquaculture, which includes both mariculture and freshwater culture is about 1.3 million tons a year, corresponding to 20% of total fisheries production. The aquaculture in Japan now contributes 6 billion dollars revenue (Institution of Statistics in Agriculture and Forest, 2002). Principal species produced by aquaculture are yellow tail, sea bream, trout, scallop, and oyster; edible seaweed is also included in the production.

There are numerous cuisines and processed seafoods prepared from varied species of marine products. In particular, *sashimi*, a sliced raw fish flesh, is a typical cuisine in Japanese food culture. As to processed seafoods, surimi based products such as *kamaboko*, as well as salted/dried fish, frozen food, and canned food, are produced in large quantities. Among them, surimi based products have the largest production, accounting for over 700,000 tons per year (Institution of Statistics in Agriculture and Forest, 2002).

The post-mortem biochemistry of fish muscle is different from that of land animal muscles, such as beef, pork, and poultry. Fish muscle tissue is characterized by a rapid progress of post-mortem changes in comparison with those of livestock animals. For instance, rigor mortis and resolution of fish take place rapidly after catch (Iwamoto *et al.* , 1987). Furthermore, muscle proteins of fish are extremely unstable and are readily denatured by storage and processing (Hashimoto *et al.* ,1982), resulting in loss in food functionality, such as water-holding capacity and gel-forming ability. In addition, fish lipids are also more susceptible than mammalian species to oxidation because of a higher content of polyunsaturated fatty acids (Bilinski *et al.* ,1978; Cho *et al.* ,1987). Therefore, controlling the post-mortem changes is essential for efficient utilization of marine products.

This paper addresses several current research topics in Japan about the delay of rigor mortis and control of protein denaturation in fish muscle. The former is related to the quality of raw fish for *sashimi*, and the latter, which includes some data from our laboratory, is concerned with the quality of processed seafood, especially the influence of long-term storage on functionality of fish fillet.

Freshness and Rigor Mortis

Freshness of muscle is an important criterion to the determination of how a fish is to be utilized in the manufacture of marine products. As depicted in Figure 1, only fresh fish, generally in a couple of days after catch, is served as a raw material like *sashimi*, and cooking or processing is predominant with lowering freshness because of changes in texture and flavor of fish meat. This is somewhat similar to

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the common practice in the red meat retail and processing industry where high-quality meat is normally consumed fresh as steaks or chops while less fresh meat is always used for further processing. Apart from bacterial spoilage, to evaluate acceptability of fish as raw material, K value is available, which stands for the ratio of the amount of inosine and hypoxantine to that of total degradation products of ATP related compounds (Saito *et al.* ,1959). When the K value is less than 20%, the fish is supposed to be served as *sashimi*.

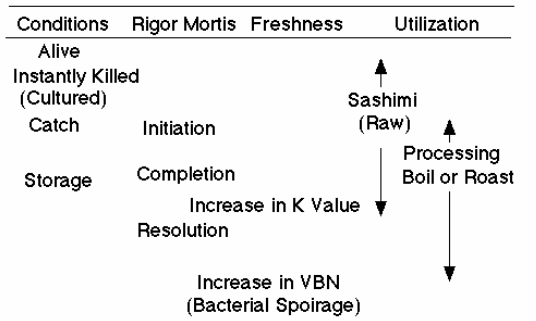

Figure 1. Schematic diagram of fish utilization depending on freshness.

The progress of rigor mortis also influences the value of raw fish in the market. In fact, fish before rigor mortis is traded at higher price than that in post-rigor in the market. The rigor mortis of fish is initiated in several hours after death and completion can take just a few hours or up to 20-30 hours, (Iwamoto *et al.* , 1987). These processes are varied depending on not only the species and size, but also physiological, killing, or storage conditions. Therefore, numerous efforts have been made to delay the onset of rigor mortis of fish, especially cultured one. Thus, the perspective to the rigor mortis of fish is opposite to that of land animals, where softening of meat though resolution of rigor mortis is desirable.

As well known, the progress of rigor mortis strongly depends on ATP degradation, and the decay of ATP in post-mortem muscle is influenced by physiological, killing or storage conditions. According to early studies (Amano *et al.* , 1953; Fujimaki and Kojo, 1953), fish should be killed instantly after enough rest to delay rigor mortis avoiding excessive loss of ATP. Iwamoto *et al.* (1985; 1987) investigated the effect of storage temperature on the progress of rigor mortis of sea bream as well as flat fish, and reported that rigor mortis occurred rapidly at 0ºC in comparison with that at 10ºC. This abrupt rigor mortis at 0ºC was explained due to activation of Mg-ATPase activity by rising of Ca ion concentration in muscle cell as a result of lowering Ca intake of sarcoplasmic reticulum. This phenomenon is similar to cold shortening, which has been found in livestock animals. Accordingly, cultured fish instantly killed should be transported around at 10ºC to avoid abrupt rigor mortis.

The softening of fish meat has been considered to be in connection with resolution of rigor mortis. However, Toyohara and Shimizu (1988) indicated post-mortem softening of fish meat proceeded earlier than rigor mortis. Ando *et al.* (1991; 1999) and Sato *et al.* (1997) suggested that degradation of pericellular collagen fiber was involved in this phenomenon and bleeding was effective to suppress the disintegration of pericellular matrix in pelagic fish. Furthermore, Terayama *et al.* (2002) reported spiking and bleeding of skipjack tuna suppressed softening and discoloration. Subsequently, they developed the automatic system to spike and bleed of skipjack tuna on ship.

Denaturation of Myofibrilar Protein during Storage and Processing

It is generally accepted that fish myofibrillar protein are structurally much unstable in comparison with those of livestock land animals (Hashimoto *et al.* , 1982; Hasnain *et al.* , 1976; Arai *et al.* 1976). In addition, the structural stability of fish myofibrillar protein is species-specific, depending on the temperature of the habitat. For instance, protein of cold-water fish like walleye, pollack, and main materials of frozen surimi, is more susceptible to heat or freezing than that of warm water fish. Denaturation of myofibrillar proteins caused by storage and processing affects the food functionality of fish meat, such as gel forming ability and water holding capacity (Numakura *et al.* , 1987; Seki *et al.* , 1985), resulting in quality changes in processed seafoods like surimi-based products (Katoh *et al.* , 1979). Moreover, due to unstable structure, fish myofibrillar protein is more readily degraded by endogenous protease during storage than that of livestock land animals. Thus, stabilization of myofibrillar protein during storage and processing is essential and must be done through quality control of processed seafoods. For instance, myofibrillar protein in frozen surimi is protected from freeze denaturation using sugar compounds such as sorbitol as cryoprotectants.

To confirm the kind and the amount of sugars added to frozen surimi to suppress freeze denaturation of myofibrillar protein, quantitative aspect for the protective effect of sugar compounds against denaturation was established from the relation between inactivation rate constant of myofibrillar Ca-ATPase and molarity of sugars (Ooizumi *et al.* , 1981). The results of a series of studies indicated that sugars with more OH groups had a stronger protective effect (Figure 2). Furthermore, it was confirmed that 8% of sorbitol was sufficient for long-time storage of frozen surimi with good food functionality (Matsumoto *et al.* , 1985; Matsumoto and Arai, 1987).

In the process of surimi production, sugars as cryoprotectants are mixed with minced meat uniformly and their concentrations are constant in any part of surimi. On the other hand, adjustment of the concentration of food additives including sugars in fish fillet is not easy as is in surimi. Injection or massaging of meat, which is a common method used in the meat industry, is not necessarily suitable for the processing of fish meat because of weakness of muscle tissue. A conventional practice to adjust the concentration of additives is to soak fish fillet in a solution containing additives at an appropriate concentration. However, there was

no scientific information available to regulate the concentration of additives in fish fillet. Thus, we have investigated permeability of various sugar compounds into fish meat as a function of osmotic pressure of soaking solution and suggested that permeability of sugars depends on the molecular weight, the smaller the more permeable (Ooizumi *et al.* , 2000; Ooizumi *et al.* 2004) (Table 1).

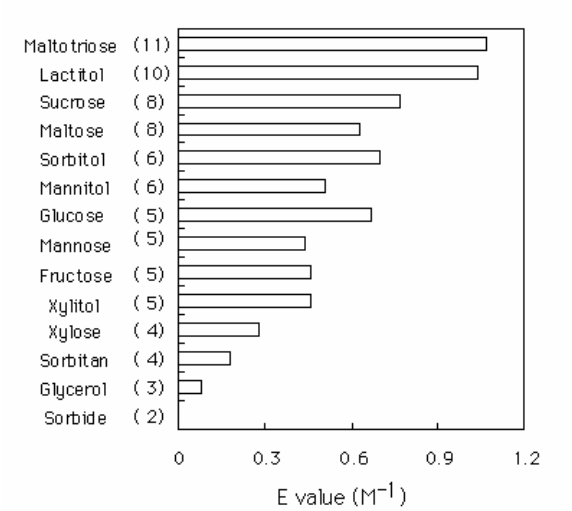

Figure 2. Relationships between the number of OH groups of sugar compounds and their protective effects against heat-denaturation of myofibrils. Protective effects (E value) were defined as decrease of logarithm of inactivation rate for myofibrillar Ca-ATPase caused by 1 molar of sugars. The numbers of OH groups are shown in the parentheses.

Table 1. Comparison of permeation rates of several sugars. Permeation rates were defined as the amount of permeation of sugars (mol/kg) caused by 1 atm of osmotic pressure of the soaking solution.

Sugars	M.W.	Permeation rate x 10^3 (mol/kg atm)
Glycerol	92	23.8
Xylose	150	19.5
Xylitol	152	20.2
Glucose	180	17.7
Fructose	180	19.1
Sorbitol	182	16.7
Mannitol	182	18.1
Sucrose	342	14.7
Lactitol	344	14.7

Sugar compounds in soaked fish meat are largely distributed in the superficial part regardless of soaking duration, while less amounts of them are found in the internal deep part, suggesting their sluggish migration in the meat during soaking (Ooizumi *et al.* , 2003). This is somewhat similar to salt/phosphate brine diffusion into marinated chicken meat where a sharp gradient of brine was found between the surface and the interior of the chicken breast muscle filet (Xiong and Kupski, 2000). The heterogeneous distribution of sugars in soaked meat raises a concern that denaturation of myofibrillar protein in the internal part of fish meat proceeds during frozen storage. Successfully, the migration of sugar compounds from the outside to the interior of the meat was promoted by subsequent cold preservation of the soaked meat (Tsuruhashi *et al.* , 2003) (Figure 3). Consequently, sugar concentrations in the internal part of the meat were raised to the level required to prevent protein denaturation by soaking and subsequent cold preservation. Actually, the measurement of myofibrillar Ca-ATPase activity confirmed that the protein denaturation of the internal deep part of walleye pollack meat barely proceeded in two months of frozen storage by adjustment of sugar concentration using soaking and cold preservation. On the other hand, a marked decrease in Ca-ATPase activity was observed in the internal part of soaked meat without cold preservation. Hence, cold preservation is essential for homogeneous distribution of sugar compound in soaked fish meat at the level required to suppress denaturation of myofibrillar protein during freeze-storage. Furthermore, cold preservation of soaked meat has another merit, i.e., shortening the duration of soaking, resulting in a reduction of loss of water-soluble components of meat such as free amino acids.

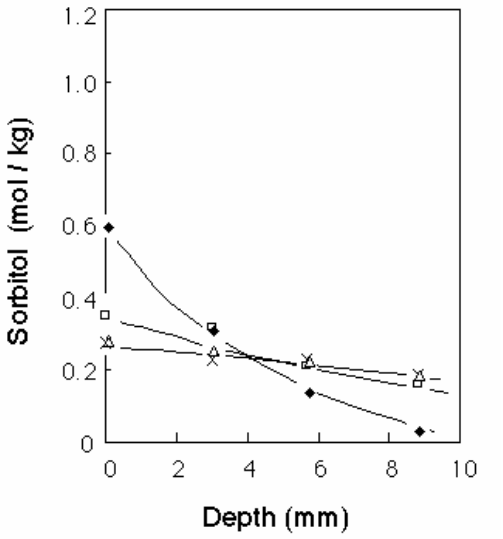

Figure 3. Changes in the distribution of sorbitol in soaked meat by cold preservation. The meat strips soaked in 1.0 M sorbitol solution were subjected to cold preservation for 0 (♦), 24 (□), 48 (△) or 84 (×) h. Sorbitol contents at the different depth from the surface of the meat were determined.

Conclusion

Fish meat is characterized by rapid post-mortem changes in comparison with meat of land livestock animals. Therefore, control of these changes is essential for effective utilization of marine bioresources. Furthermore, due to the opposite perspective on rigor mortis of fish to that of land animals, much effort has been made to delay rigor mortis. On the other hand, for efficient utilization of marine products whose protein is inherently unstable, regulation of protein denaturation is critical at every step of storage and processing. Thus, adjustment of the concentration of sugars as cryoprotectant in meat is needed to control quality of processed seafoods. Moreover, because of the huge variety of fish species, the progress of further investigation is expected to control species-specific post-mortem changes.

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