Seafood Processing

Adding Value Through Quick Freezing, Retortable Packaging, and Cook-Chilling

V. Venugopal

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To My Parents

Foreword

The international seafood industry is faced with interesting complexities and many contradictions, such as the following:

Seafood is among the most internationally traded food product categories, but it is also among the most perishable and requires flawless distribution chain management.

Value addition through processing is the key to success, but often the least prepared seafood — fresh or even live from the sea — fetches the highest price.

Seafood is a valuable part of a healthy diet but consumers lack the skills and confidence to prepare it.

Health authorities advise increased fish consumption but production is constrained by sustainability issues in the capture fisheries and environmental concerns in aquaculture.

How does the seafood industry operate within these apparent contradictions and constraints? There is no simple answer, except to say that it is driven by the market pull that is created by increasingly health conscious consumers, sound technology in processing, modern logistics, and not the least by across-the-world cooperation of production and marketing people who face the everyday challenges of the business with enthusiasm and expertise.

Value addition is an important term for the modern food business. Traditionally, it has been thought of as a processing term, that is, adding value to basic foods by means of coating, combination of ingredients, processing, and convenient presentation. The driving force for value is, however, created in the market by the consumer who finds the product to have added value as per his or her circumstances. It is therefore appropriate to think of value primarily as a marketing term and in each instance based on consumer perception.

Worldwide, marketing people agree that the trends driving the demand for seafood in years to come and in the major markets are closely tied to trends in lifestyles, which seem remarkably similar in many areas of the world. Across the globe, these driving forces originate in the need and desire of the human race when it is presented with a wide choice of food and a reasonable income, and they are manifested in the quest for convenience in preparation, product quality, and the healthy image that seafood has gained in terms of nutritive value, and even special health benefits.

This book brings together a wealth of information on seafood processing and consumption. It provides an overview for the global fisheries production and consumption pattern, highlights the nutritional importance of fishery products, and also discusses perishability and the biohazards associated with seafood as well. It gives a thorough description of processing technologies for quick freezing, cook-chilling, and retort pouch packaging, among others with a briefer look at smoking and canning.

In short, this book will greatly help to explain how the seafood industry operates quite successfully in spite of the contradictions mentioned above, but primarily it will serve as an expert source on modern processing technology for seafood.

Alda B. Möller
Food Scientist
Seafood Industry Consultant, Iceland

The Author

Dr. V. Venugopal received his M.Sc. (Chemistry) from the University of Kerala and Ph.D. (Biochemistry) from the University of Bombay. He began his career at the Central Institute of Fisheries Technology, Cochin, India, and later moved to the Bhabha Atomic Research Center, Mumbai, where he was head of the Seafood Technology Section of the Food Technology Division. He has been a postdoctoral research fellow at the National Institutes of Health, Bethesda, Maryland, U.S. and a Visiting Scientist at the Memorial University of Newfoundland, St. John's, Newfoundland, Canada. His main interests were value addition of fishery products, radiation processing of fishery products, role of bacterial proteases in fish spoilage, and gelation of fish muscle proteins. He has published more than 120 publications in these areas, which included research papers, review articles, and book chapters. He is a Fellow of the National Academy of Agricultural Sciences, New Delhi, India.

Preface

With changes in life styles, consumers' perception of processed food is also changing. As a consequence there is an increasing demand for convenient, nutritive, and safe foods all over the world. In addition, consumers are aware of the nutritive value of food and the effects of processing on it. These changes have caused more and more agricultural products to enter international trade in processed form rather than as raw commodities. This scenario indicates prospects for novel techniques of value addition that can add convenience, novelty, and marketability to products without causing significant losses in their nutritive value. Minimal processing techniques including nonthermal methods and techniques that are less harsh in their thermal effects are gaining importance to satisfy the needs of modern consumers.

Seafoods, which traditionally were traded in bulk consignments without much serious processing, can attract novel processing techniques. The time has arrived for the fishery sector to take advantage of the outlook of the modern consumer to capture wider markets through process-diversification techniques. The 1980s saw seafood items getting increasing media attention as a source of valuable nutrients. Greater demands for fishery products, diminishing marine landings, and depletion of certain fish stocks have resulted in rapid rise in fish production by farming techniques. However, currently most farmed items are marketed with negligible levels of value addition. As observed recently by Prof. J.M. Regenstein, Cornell University (*Food Technol.*, 58, 28, 2004), if the fishery industry is to compete with other food industries more creativity will be needed in their processing and marketing. Because of its diversity in composition, seafood offers scope for a wide range of product forms having diverse flavors. Success of the seafood industry in the coming years lies in the judicious application of value addition methodologies to develop products that are nutritive, tasty, appealing, and stable for extended storage, supported by marketing strategies. Developments in minimal processing, nonthermal methods, or methods that are less harsh allow processing of seafood without much adverse impact on their flavors and contents of essential nutrients. These methods, which rely heavily on principles of physics, chemistry, and microbiology, include irradiation, high hydrostatic pressure, antimicrobials, ultrasound, pulsed electric light, and oscillatory magnetic fields. In this book, an attempt has been made to focus the upcoming technologies for value addition of marine and aquacultured fishery products. The introductory chapter is devoted to briefly discuss the current global status of seafoods, consumption pattern, and to highlight prospects for value addition. This is followed by two chapters, one that discusses perishability and biohazards associated with the commodity, and the other discusses the bulk handling and chilling of fishery products. The remaining part of the book discusses different process technologies for value addition. Conventional techniques such as smoking and canning have not been discussed separately; but briefly dwelt upon in relevant chapters. At the end, a chapter is devoted to highlighting the nutritional importance of fishery products including the influence of processing on its nutritive value. An appendix provides some information related to seafood processing.

This book would not have been possible without the initial guidance and support I received from a number of my former esteemed colleagues, the late Dr. A.N. Bose, the late Prof. A. Sreenivasan, the late Dr. U.S. Kumta, and the late Dr. V.K. Pillai. Drs. S. Ayyappan and K. Gopakumar have extended encouragement in writing this book. Dr. K. Devadasan, Director, Central Institute of Fisheries Technology (CIFT), India, was generous in extending his valuable library facilities. Ms. V. Muralidharan, J. Joseph, T.K. Sreenivas Gopal, P.K. Surendran, S.P. Garg, Ms. Sailaja of CIFT; D.R. Bongirwar, S.B. Warrier and S.V. Ghadhi of BARC; Dr. A.K. Bhargava, Fishery Survey of India, and S. Mathew have shared with me useful information that is included in this book. I also thank the library authorities of Bhabha Atomic Research Centre and University Institute of Chemical Technology, Mumbai. I am obliged to K.K. Balachandran, former principal scientist, CIFT, for going through the manuscript critically and offering suggestions. I am thankful to many individuals outside India who have provided valuable information, which were included in specific chapters. These persons include Drs. Paw Dalgaard and K.N. Jensen of the Danish Institute of Fisheries Research, Denmark; Phil Bremer from University of Otago, Dunedin, New Zealand, Dr. S. Rodgers, University of Western Sydney, Australia; Dr. N. Hedges of Unilever Research, Sharnbrook, U.K.; and Dr. N. Krishnasamy, Infofish, Kuala Lumpur, Malaysia. My former student, Dr. R. Lakshmanan, University of Glasgow, Scotland, U.K., deserves special mention for his continued interest and support during the preparation of the book. I appreciate the interesting pictures on impingement freezing system and *surimi* products sent by Ms. Rikard Jevinger, Frigoscandia, Sweden and Peter Lammertyn, *Viciunai*, Lithuania. I am also grateful to my family members—my wife, Rema for her patience and support, Prakash and Laxmi for their help at various stages of the work, and Hari, Shyamsundar, and Srikant for their excellent computer support. My special thanks are due to Ms. Susan B. Lee and Ms. Randy Brehm of CRC Press and Mr. K. Mohankumar, Newgenimaging Systems, Chennai, India for their valuable editorial support. I welcome suggestions from readers to improve the contents of the book and correct any inadvertent errors.

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Contents

1 Availability, Consumption Pattern, Trade, and Need for Value Addition

1.1 Introduction

The term "seafood" generally refers to a variety of groups of biologically divergent animals consisting not only of fish, whether of freshwater, estuarine, or marine habitats, but also of shellfish which include crustacea and mollusks. The crustacea comprises of crayfish, crab, shrimp, and lobster, while the mollusks could be bivalves such as mussel, oyster, and scallop, univalve creatures such as abalone, snail, and conch, and cephalopods which include squid, cuttlefish, and octopus. Fisheries provide a vital source of food, employment, trade, and economic well-being for people throughout the world. In the early 1970s fish was considered as a resource against hunger in the world. Presently, fish has gained importance as a health food, because several species have been identified as rich in easily digestible proteins containing all the essential amino acids, therapeutically important polyunsaturated fatty acids, in addition to calcium, iodine, vitamins, and many other nutrients. Fishery products constitute a major portion of international trade, which is a valuable source of foreign exchange to many developing countries. Fisheries sector enjoys some advantages over other animal production systems. First, fish is the cheapest source of animal protein and a health food. Second, high fecundity (up to 1 million eggs) and fast growth rate of fishes have no parallel among other animal protein sources, like livestock including poultry. These biological advantages offer considerable benefits to fish as a tool to achieve nutritional and social security. While contribution of agriculture to gross domestic product (GDP) is decreasing all over the world, that of fisheries is increasing in most countries.

1.2 Availability of Fishery Products

Fish makes a very significant contribution to the diets of many communities in both the developed and developing worlds. According to the State of World Fisheries and Aquaculture, 2002, published by the Food and Agriculture Organization (FAO) of the United Nations, more than one billion people worldwide rely on fish as an important source of animal proteins, deriving at least 20% of protein from fish.[1] This share could exceed 25% in poor countries and could be much higher in isolated

TABLE 1.1
Capture Production (in tons) by Some Major Groups of Species During the Years 2000 and 2002

Species group	2000	2002
Carps, barbels, and other cyprinids	570,965	592,962
Tilapia and other cichlids	680,066	682,639
Salmons, trouts, smelts	805,139	806,998
Flounders, halibuts, soles	1,008,471	918,840
Cods, hakes, haddocks	8,673,042	8,392,479
Miscellaneous coastal fishes	6,039,972	6,471,124
Herring, sardines, anchovies	20,628,706	22,472,563
Tunas, bonitos, billifishes	5,828,375	6,088,337
Sharks, rays, chimaeras	857,749	818,542
Freshwater crustaceans	568,469	818,993
Lobsters, spiny-rock lobsters	222,052	222,132
Shrimps, prawns	2,949,714	2,979,336
Oysters	249,647	186,699
Mussels	276,276	264,101
Scallops	660,700	747,516
Clams	798,339	825,651
Squids, cuttlefish, octopuses	3,660,404	3,173,272
Freshwater mollusks	595,286	633,561
Miscellaneous marine mollusks	1,497,351	1,491,849

Source: Adapted from FAO, *FAO Yearbook, Fishery Statistics, Capture Production*, Vol. 94/1. Food and Agriculture Organization, United Nations, Rome, Italy, 2002. With permission.

parts of coastal or inland areas in some countries. For example, the proportion of animal protein derived from marine products in the diet of the population in West Africa is as high as 63% in Ghana, 62% in Gambia, and 47% in Senegal.[2] However, in the course of the last four decades, the share of fish proteins to animal proteins has exhibited a slight negative trend due to a faster growth in consumption of other animal products.[1]

1.2.1 Capture Fisheries

The fish landings in the world has increased from 39.2 mt in 1961 to 122.1 mt in 1997 (at an annual growth rate of 3.6%), while food fish supply has grown from 27.6 mt to nearly 94 mt during the same period.[1] The landings were 130.9 mt and 132.9 mt in 2000 and 2002, respectively.[1] World fish production of finfish remained relatively stagnant at around 130 mt for the last few years.[1] Table 1.1 indicates world landings of major groups of fishery products in recent years. Two thirds of the total food fish supply is from marine and inland water fisheries.[1] The irregular and dwindling supply of capture fish is adversely affecting seafood industries in several countries. Decline in capture fisheries is likely to have a serious impact on food security, nutrition, and income levels for people in the developing countries in the coming years. Unlike processors of other food commodities, the seafood processor is limited in his choice of raw materials to what is available with respect to species, size, and quality at a given time. In order to meet the protein requirements of the world population, which is likely to increase to 8.5 billion in the next 25 years, fish production has to double during this period. While efforts are needed to maintain sustainable fish production to satisfy the demand, growth in capture fisheries has not been promising. The FAO has estimated that 19% of the world's major fishing grounds have either reached or exceeded their natural limits and that at least nine fishing areas, about 69% of the world's fisheries, are either fully exploited, overexploited, depleted, or slowly recovering from the effects of overfishing.[1] Major reasons for overfishing are use of sophisticated techniques, which adversely affect breeding of the species and large government subsidies in this sector facilitating overexploitation and limitation of resources. Furthermore, pollution and overfishing have severely depleted fish population affecting several maritime countries. It has been estimated that approximately only 100 mt of conventional species can be fished from the ocean on a sustainable basis.[3]

There are specific examples for diminishing fish stocks. Several years ago, Canada had to close down many processing plants that depended on a few selected species such as cod and salmon.[3,4] The recent decline in salmon stocks in that country has led to conservation measures, which included selective harvesting, improvements in handling, augmentation through aquaculture, and development of value-added products.[4] Another example is that of white pomfret, a highly preferred fish in the Indian subcontinent. According to the Central Marine Fisheries Research Institute, Mumbai, India, the landing of the fish in the western coast of India has fallen alarmingly, from 19,000 t in 1983 to 4,500 t in 1995. Similarly, the landing of Bombay duck, the third largest fish resource in India after sardines and mackerel, has declined from 3,500 in 1981 to 700 t in 1993. Sand lobster has almost completely disappeared in the waters near Mumbai, India.

Introduction of mechanized bottom trawling in the late 1950s resulted in a 2.7-fold increase in the catch of demersal fish from the Indian Ocean. However, as a result of intensive trawling and introduction of gears such as purse seines, resources in the 0 to 50 m depth zone were significantly exploited. Some of the exploited species were sciaenids, silver bellies, elasmobranchs, pink perch, lizardfish, goatfish, threadfins, and eels, while resources such as catfish, the whitefish, ghol, and flatheads declined in production. This was chiefly due to overfishing, which caused destruction of juveniles as well as the trampling of the bottom habitat.[5] Another example is of tuna stocks in the Indian Ocean, which provides over 1.5 mt, or a nearly a third of world total, dominated by yellowfin and skipjack tuna. Of these, while skipjack stocks appear to be unaffected, yellowfin and big eye tuna stocks are fully exploited.[6]

Depletion of fish stocks has been felt in other parts of the world too. In the United States, most capture-fishery stocks are fully exploited, or, in the case of

TABLE 1.2
U.S. Supply of Fishery Products

	Domestic commercial landings (1000 t)		
Year	Edible fishery products	Industrial fishery products	Total
1992	7,618	2,019	9,637
1993	8,214	2,253	10,467
1994	7,936	2,525	19,461
1995	7,667	2,121	9,788
1996	7,474	2,091	9,565
1998	7,173	2,021	9,194
1999	6,832	2,507	9,339
2000	6,912	2,157	9,069
2001	7,314	2,178	9,492

Source: MPEDA Newsletter, 7, 7, 2000, Marine Products Export Development Authority (India). With permission.

Atlantic cod, it is even overexploited. The availability of edible and industrial fishery products in the United States is given in Table 1.2. It can be seen that the availability of fish was almost stagnant during the last decade. Diminishing catches in countries belonging to the European Union have also resulted in heavy seafood imports. In Australia, out of a total of 67 target species, 11 species are classified as overfished. These species include southern blue fin tuna, brown tiger shrimp, grooved tiger shrimp, southern scallop, tropical rock lobster, and orange roughy among others.[7] India ranks third in fish production, after China and Japan, where production has increased more than 10 times in recent years, reaching a value of 6.39 mt during 2003, a growth arguably one of the highest in the food-production sector in the country. Nevertheless, marine fisheries may not be in a position to meet the projected demand of 10% annual increase.[8] The 2004 Tsunami disaster has dealt a severe blow to capture fisheries in India and some other Asian countries.

Growing concerns on overfishing and environmental impact of fishery activities has led to a series of international initiatives such as identification of maximum sustainable yields and introduction of quota systems for several species.[9] The United Nations Agreement on Straddling Fish Stocks, the Agreement to Promote Compliance with International Conservation and Management Measures by Fishing Vessels on the High Seas, and the Code of Conduct for Responsible Fisheries are three such measures. The Kyoto Declaration for "Sustainable Contribution of Fisheries to Food Security" set an *Action Plan* either directly or in cooperation with other states or through the FAO, which set ten major goals.[10] These include assessment and monitoring the present and future levels of fish production, enhancement of cooperation among countries for straddling fish stocks, promotion of aquaculture, control of postharvest losses, and optimum use of unexploited or underexploited resources.[10] Since the most important environmental impact of capture fisheries is overfishing and by-catches, a need has been felt for the production methods to be able to protect the environment. Labeling in general, and es pecially environmental labeling, is increasingly becoming an important marketing tool.

An analysis by the Malaysia based World Fish Center (WFC) and the International Food Policy Research Institute cautioned that within the next 20 years, fish, which currently accounts for about 7% of global food supplies, will deprive one billion people in developing countries of their source of protein.[11] The Center fears that some fish species will disappear from markets and the quality of seafood will decline. Almost three-quarters of the 130 mt landed in 2000 came from fish stocks already depleted, overfished, or fully exploited. The situation is alarming particularly due to the annual increase of about 90 million in world population as well as increasing consumer interests in fishery products. It was observed that only appreciable growth in fish farming could save the world from a critical situation of shortage of fishery products.[11]

Although supply of several commercially important fish species is dwindling, a significant amount of the available fish remains underutilized. These fish species consist mostly of the by-catch of fishing operations of targeted species such as shrimp. In addition, several varieties of pelagic, demersal, and unconventional fish species are not fully utilized for human food. Out of a total production of 22.5 mt of demersal and 37.6 mt of pelagic fish, only 13.7 and 18.8 mt, respectively, are used for human consumption. The rest are reduced to fish meal or discarded in the ocean.[12] Many of the currently underutilized fish having potential as human food, and therefore, have been arranged roughly in the order of their possible food value. These fish include anchovy, barracuda, Bombay duck, catfish, croaker, flying fish, garfish, grey mullet, hake, herring, horse mackerel, jewfish, leatherjacket, mackerel, pony fish, ray, rock cod, sardine, scad, Spanish mackerel, spotted bat, and tilapia, among others.[13] The underutilized bottom-water species include blue ling, roundnose, grenadier, black scabbard, and various small sharks. The global trend in low-cost fish catch and need for their better utilization for human consumption have been discussed extensively.[13–19]

1.2.2 Aquaculture

The interest in aquaculture stemmed from stagnating capture fisheries, which failed to meet the rising demand for fish. Fish farming is being considered the best option to make preferred fish species available to the consumers. Fish production by this method has reached 38 mt worth US$55.7 billion in 2001.[20,21] Thus, while capture fisheries remained more or less the same from 91.6 mt in 1995 to 89.0 mt in 2000, aquaculture production increased from 24.5 to 33.3 mt during the same period. In 1999, Asia produced about 91% of the world's total cultured fish, with China, India, Japan, Republic of Korea, Philippines, Indonesia, and Thailand topping the list.[1] As many as 39 and 52 species are cultured in China and Korea, respectively.

Freshwater aquaculture is a major source of growth in world fisheries. In general, freshwater fish is cheaper and is an indispensable source of animal protein, as it is preferred among the lower income groups in the Asian countries. Among the Asian countries, China ranks first in fish farming, producing 26 mt (worth US$26 billion) of fish and shellfish in 2001. Other major producing countries in 2001 were India (2.2 mt), Indonesia (864,000 t), Japan (802,000 t), Indonesia (864,000 t), and Thailand 724,000 t).[21]

Finfish, with a share of 23 mt, ranked first in the total aquaculture output in 2000, and accounted for about 65% of the total production. The major share was carps (68%), consumed mostly in the producing countries, mainly, China and India. Because of its diminishing wild stock, Atlantic salmon (*Salmo salar)* is important among various species cultured worldwide, with a contribution 1 mt or 2.39% to the total aquaculture production.[4,20] Norway, Chile, the United Kingdom, and the United States are the major producers of farmed salmon. Consumer demand for white, easy-to-prepare fillets was the reason for rapid rise in farming of catfish and tilapia in the United States.

Shrimp farming is one of the most rapidly developing areas of the international seafood industries. Since 1990, black tiger (*Penaeus monodon*) is the main shrimp farmed. The shellfish can grow up to 13 inches, but the average harvest size is between 9 and 11 inches in length. Farmed black tiger has a mild or almost bland flavor, compared with the prominent taste of its marine counterpart. Important suppliers include Thailand, Bangladesh, India, Indonesia, and Malaysia. Thailand farmed about 300,000 t of this shellfish, out of a total world production close to 570,000 t, in 2000. There is a large variety of black tiger shrimp products in the world markets, predominated by individually quick-frozen (IQF) or block-frozen headless shrimp. The shellfish is often an ingredient in combination dishes with fish, and is often used in pasta dishes with vegetables. During the last decade, the white spot virus caused dramatic drop in production of shrimp making significant financial losses to Asian farmers.[1] Table 1.3 shows world production of some major aquacultured fishery items in 2000.

1.3 Trade in Fishery Products

Depletion of fish stocks and diminishing catch of preferred species have contributed to an imbalance in supply and demand for fishery products in several countries, which has promoted international trade in seafood. More than one third of global fisheries production moves into international markets. World exports of fish and fishery products were 5.6 mt in 1967, which grew to 24.7 mt in 1997. The present value of globally traded fishery products is approximately US$57.[21] For many developing countries in Asia, Africa, and Latin America fishery products have become an important foreign exchange earner and their market share in terms of value is just over 50%.[22]

Shrimp accounts for only about 3% by weight of internationally traded seafood, but in monetary terms, the shellfish trade is worth approximately 20%. About 80% of shrimp consumed in the United States are being met through imports.[1]

TABLE 1.3
Production of Some Major Fishery Items through Aquaculture in the Year 2000

Species	Production (1000 t)
Freshwater fish	19,801
Salmon	1,000
Catfish	280
Trout	140
Mollusks	10,732
Aquatic plants	10,130
Diadromous fishes	2,257
Crustacea	1,648
Marine fishes	1,010

Source: Adapted from *State of World Fisheries and Aquaculture*, 2002, Food and Agriculture Organization of the United Nations, Rome, Italy, With permission.

Japan, Spain, France, and the United Kingdom are other major shrimp importing countries.[22,23] The international shrimp suppliers annually serve the United States, Japan, and Europe with more than 600,000 t of the shellfish from aquaculture operations. Over the past years, increasing environmental awareness all over the world has resulted in demand for quality products and services. The farmed shrimp has received a negative image in Europe because of occasional presence of antibiotic residues and other hazardous substances. As a consequence, exporters to Europe have been required to comply with environmental legislation and regulations in order to be able to export to Europe.

Some of the other major internationally traded seafood items include Alaska pollock, cod, dogfish, haddock, hake, tuna, salmon, sea bass, sea bream, shark, tilapia, trout, cephalopods, and mollusks. During the last few years, prices of aquatic products have increased in all the countries. Developed countries accounted for more than 80% of total fish imports with Japan accounting for 26% of global total import.[1] Notwithstanding huge imports, developed countries also process substantial amounts of seafood. The United States, in addition to being the world's fourth largest exporting country, is the second largest importer, particularly of shrimp. Southern bluefin tuna, orange roughy, rock lobster, swimming crabs, squid, oysters, and scallops are the major seafood of trade in New Zealand, whereas, frozen fish and other value-added products are the important items traded in the United Kingdom.[24,25] The sea bream and sea bass industry has grown strongly in Europe, with a 120,000 t production of these species in 2001.[25] In France, where per capita fish consumption is approximately 28 kg, 700,000 to 750,000 t, worth about US$5 billion, raw, chilled, delicatessen, canned, and frozen seafood were processed in 2000.[26]

Fish production in China has reached about 30% world production, which exported seafood and aquacultured products worth US$3.7 billion in the year 2000. The aqucultured products exported consisted of eel, shrimp and other shellfish, oysters, crabs, and tilapia.[25,26] China also reprocesses imported raw material for export, creating a strong value addition in the process. The main thrust in Chinese seafood industry in recent years has been export of live fish species, individual quick-freezing and retail packaging, and downstream processing. Thailand is another major exporting country, which exported products worth US$4.4 billion in 2000. The disadvantages faced by developing countries in increasing the exports to European countries include tariffs for value-added products, and the necessity to prove their ability to deliver quality products on time and at stable prices.

Seafood industry is showing signs of some development in other countries of the world too. Cephalopods are utilized as an important food item in various countries, especially in Asia. The Japanese consumes some of the species raw. There is a huge potential for processing and marketing of cephalopod products in Asia.[27] In the Arab countries, at present the industry is limited to employing simple and traditional methods, despite developments in some fish canning and processing projects. Most Arab countries depend on fish imports, especially canned products.[28] Fisheries development issues and their impact on the livelihood of fishing communities in West Africa have been discussed recently.[2] Latin American countries have an abundant source of unexploited or underexploited aquatic resources, where there is also an urgent need to increase the consumption of aquatic protein in order to alleviate the problem of malnutrition. India is a major exporter of fishery products, worth above one billion US$ per year. The share of seafood exports in India is about 16% of the total exports of agriculture products.[29–31]

Most international trade in fishery products is limited to items as bulk frozen or chilled forms. Trade in consumer friendly, value-added products is very limited, except a few items, according to the Yearbook of Fishery Statistics, published by the FAO, Rome, Italy.[1] In the year 2002, the major traded value-added products were canned shrimp (276,282 t), imitation crabsticks (20,102 t), marinated and spiced fish (7,809 t), small amounts of fish pastes (3,201 t), fish cakes (5,590 t), and fish sausages (49 t). The Southeast Asian Fisheries Development Center has compiled data on several value-added products developed in seven ASEAN countries, which have potential for export to destinations throughout the world including the United States and the European Union.[32] Lack of sufficient raw material and concerns about the quality of processed products are some of the problems facing the current international seafood industry. Other related issues include environmental concerns regarding aquaculture, changes in quality and safety control measures particularly adoption of Hazard Analysis Critical Control Point (HACCP)-based strategy, the concepts of risk assessment, traceability in major markets, third-country processing, and eco-labeling.[1] The subcommittee on Fish Trade of the Food and Agriculture Organization, in its ninth Session in Bremen, Germany, identified major requirements for a healthy future in global trade in fishery products. These included need for science-based safety-monitoring and eco-labelling systems for seafood products, improving the accuracy of catch reporting by the fishing sector, and measures to help developing countries and small-scale fishermen increase their access to international markets.[21]

1.4 Per Capita Availability and Consumption Pattern

The per capita availability of fish and fishery products has nearly doubled in the last 40 years. The share of animal protein intake of human population derived from fish, crustaceans, and mollusks increased from 13.7% in 1961 to 16.1% in 1996 and then showed a decline to 15.8% in 1999.[1] The value is higher against per capita consumption of 11 kg recommended by the World Health Organization for nutritional security. The quantity of fish consumed and the composition of the species vary with respect to countries and regions. The values for various regions were as follows: Oceania (22.5 kg), Europe (19.1 kg), Asia (excluding China) (13.7 kg), China (25.1 kg), North and Central America (16.8 kg), South America (8.5 kg), and Africa (8.0 kg).[1] The reasons behind wide variations in consumption level include movement of people to urban area away from the coastal zones, disparity in income level, and religious beliefs.[29] Per capita consumption by continents and economic groupings in 1999 is given in Table 1.4. The world average per capita fish consumption is expected to rise between 19 and 21 kg by the year 2030.[33]

A survey of human fish consumption pattern showed that fresh fish (53.7%) was the most preferred item, followed by frozen (25.7%), canned (11.0%), and cured fish (9%).[1] An amount of 45 mt of marine finfish accounted for 75% of the per capita fish consumed in 1997. Shellfish (crustaceans, mollusks, and cephalopods) shared the remaining 25%. Demersal fish are highly preferred in North Europe and North America. In these countries, as much as 60% of all fish consumed is either fillet or value-added product. Cephalopods are consumed in certain Mediterranean and Asian countries, and to a much lesser extent in other continents. Crustaceans are highly priced commodities and their consumption is mostly in the affluent countries.[32]

1.4.1 Changing Consumer Trends Toward Processed Foods

Modern consumers prefer processed foods that are more convenient to handle, store, and prepare. The consumers insist that such products also possess high quality, freshness, nutrition, and health. They would also appreciate flavorsome food items produced by more ethical methods, including environmentally friendly processes and economically acceptable behavior.[27,33] The changes in consumer lifestyles have resulted in increased demands for two distinct types of seafood products. The first type includes *fresh*, *chilled* products that are conveniently

TABLE 1.4
Total Fish and Shellfish Supply and Annual Per Capita Consumption by Continents and Economic Groupings in 1999

Location	Total supply (mt, live weight)	Annual per capita consumption (kg)
World	95.5	16.1
World excluding China	64.3	13.6
Africa	6.2	8.0
North and Central America	8.1	16.8
United States	—	21.3
South America	2.9	8.5
China	31.2	25.1
Asia (excluding China)	32.5	13.7
Europe	13.9	19.1
United Kingdom	—	20.2
Germany	—	12.2
Portugal	—	57.0
Norway	—	50.0
Oceania	0.7	22.5
Industrialized countries	25.4	28.3
Economies in transition	3.7	12.7

Source: From FAO, *State of World Fisheries and Aquaculture*, Vol. 95. Food and Agriculture Organization of the United Nations, Rome, Italy, 2002. Courtesy, *Infofish*, Kuala Lumpur, Malaysia. With permission.

packaged, processed, and ready-to-cook, such as salmon steaks or hoki loin fillets. The second group consists of *processed*, *chilled*, *ready-to-eat* seafood products, such as cold smoked salmon or hot smoked mussels. In both types, a need for convenience and easy handling has been focussed. These demands can lead to development of novel techniques to extend the shelf life and add convenience to seafood.[34] The emergence and growth of supermarkets also facilitate a greater penetration of value-added seafood products such as salmon in regions that are far from the sea.[23,33]

The major reasons for changing consumer trends have been identified. The shrinking family size and more women entering the work force have resulted in less leisure time and increased purchasing power, which have made a demand for processed, convenient, ready-to-eat, or ready-to-prepare products. The second important trend is the increase in awarness of the importance of eating healthy. Consumers are becoming health conscious and are aware of the protective role of diet in the control of problems such as obesity, cancer, diabetics, and coronary heart diseases. Food items that are low in calorie, fat, sugar, and sodium are now recognized as health protecting foods. Furthermore, modern consumers

TABLE 1.5
Classification of Some Seafood According to Their Flavor

Mild	Cod, crab, flounder, grouper, haddock, hake, halibut, lobster, monkfish, orange roughy, pollock, scallop, seer fish, sole, see bass, shrimp, snapper, squid, tilapia, tilefish, white pomfret, wolffish
Moderate	Black pomfret, butterfish, catfish, cray fish, lake perch, lobster, mahi-mahi, octopus, shark, sturgeon, orange roughy, shrimp, tilapia, tuna, whitefish, whiting
Strong	Blue fish, clams, Indian salmon, mackerel, marlin, mussel, oyster, salmon, sardine, swordfish

are also aware of health hazards associated with food, such as the presence of pathogenic microorganisms, parasites, viruses, and industrial pollutants. These trends exert a considerable influence on food product development and marketing. Consumers expect a positive assurance that the food product including seafood is safe, tasty, easy, and quick to prepare, light in calories, easy to digest, and nutritive. Modern trends in seafood technology are essentially aiming to address the changing consumer interests.[35]

Generally, consumers relate freshness of fishery products to the inherent quality of the freshly caught fish. They consider that, if the time lapse after harvest is short, the product retains its original characteristics. This may not always be correct, since eating quality is a subjective attribute. The flavor of cooked cod, for example, has the strongest intrinsic characteristics after 2 days storage in melting ice. Many fatty species such as salmon, ocean perch, and halibut, improve much in flavor, taste, and texture during the first 2 to 4 days in ice. This is mainly due to the redistribution of fat, and the development of flavor components such as amino acids, nucleotides, or sugars, produced by the autolytic processes occurring during rigor mortis.[36] Butterfish, cod, crab, flounder, haddock, hake, lake perch, mussel, oyster, pollock, scallop, sole, whitefish, and whiting have delicate texture. Bluefish, crayfish, lobster, mackerel, orange roughy, salmon, sardine, shrimp, and tilapia are species having moderate texture. Clams, catfish, grouper, halibut, mahi-mahi, marlin, monkfish, octopus, salmon, see bass, seer, shark, snapper, squid, swordfish, tilefish, tuna, and wolffish are characterized by hard texture. Table 1.5 present tentative classifications of some seafood according to their flavor. In affluent countries, a significant amount of fish is consumed outside the home in the form of ready-to-eat products. Vast majority of the population in these countries has the means to purchase adequate food. Retailing of fish in these countries is not merely a question of satisfying a hungry consumer at a competitive price. Marketing campaigns launched for some fish products tend to affirm that consumption of fish is an appropriate means of satisfying the consumer's need for variety as well as for nutritious, tasty, healthy, and fashionable foods.

Shrimp being the major traded seafood, a detailed survey on the quality attributes of the shellfish that influence consumers has been conducted.[37] Quality attributes that influence consumers in buying the product are freshness, color, size, texture, taste, and other aesthetic and eating characteristics. Live prawns are the most preferred items, followed by chilled or cooked samples. Headless peeled prawn with or without tail is a highly preferred product form, followed by headless breaded form. Value-added breaded shrimp products fetch premium price. Aquacultured black tiger shrimp is the most preferred species, followed by sea-caught banana prawn. Consumers in Europe, particularly France, for example, favor shrimp products that are preprocessed and ready for consumption such as peeled shrimp, marinated shell-on or shell-off shrimp, shrimp on skewer, etc. The perceived value of a product can increase due to attractive packaging in bright colors and large windows.[23] The consumer opinion could be a road map for processors to develop products that can command high marketability.[35] In marketing, one of the trends predicted for the new millennium is the elimination of the seafood source counter in the grocery store. Self-service counters can help offer more opportunity for branding, packaging, and consumer education.[38]

A number of recent surveys by professional bodies have indicated the trends in seafood consumption in the United States.[38–41] According to the U.S. National Oceanic and Atmospheric Administration, overall seafood consumption in 2002 was 7.1% of total food consumption, with an annual per head purchase of 5 kg fish, consisting mostly of fresh and frozen items. A survey by the National Fisheries Institute showed that elderly people preferred seafood to red meat, since these people were aware of the nutritive merits of seafood. People in the age group of 50–64 are 71% more likely to eat fish; while those above the age of 65 ate 41 times a year. It was observed that the per capita consumption of fish might reach about 27–31 kg in the next 15 years in the United States.[40] Consumers preferences for value-added seafood products were shown in another survey. Grilled seafoods were more popular, particularly, preseasoned, ready-to-grill items, while boil-in-bag products were preferred less. Fried products attracted poor support, while boneless fillets were highly popular. Traditional battered and breaded items, which once formed 70–80% of the products consumed, decreased to a consumption level of 50%. Minimally processed products like salmon portions made up the rest.[38] Consumers liked an increase in sturdiness of the seafood packages with inclusion of recipes on the label. Zip-lock and vacuum-sealed packaging as well as see-through packaging were preferred.

Convenience is the driving force behind daily food choices in the United States and Japan.[44,45] Majority of food shoppers (69%) preferred *heat-and-eat*, *packaged for on-the-go* eating, even if their prices were 2 to 3 times more than their unprocessed counterparts.[42] Some of the criteria in food selection included shelf stability, minimal packaging, not soiling the hands, single-serve, bite-size, resealable, portion control, portable but safe at room temperature, and requirement of no extra utensils among others. The top three seafood items presently consumed in United States are shrimp, tuna, and salmon, followed by lobster, pollock, catfish, crab, clams, and tilapia.[40] Buying salmon was mainly due to recognized health benefits associated with consumption of the fish; taste and flavor were secondary in this respect. Trout is another preferred species, fresh fish commanding increased

TABLE 1.6
Preference of Seafood Among Consumers in the United States

Species	Mean rating (Maximum rating 7)
Lobster	6.25
Shrimp	5.85
Crab	5.46
Clams	4.82
Swordfish	4.71
Salmon	4.32
Cod	4.30
Sole	4.25
Flounder	4.15
Trout	4.09
Tuna	4.02
Haddock	3.96
Oyster	3.95
Mussel	3.91
Catfish	3.50
Shark	3.39
Snapper	3.36
Herring	3.15
Eel	2.13
Anchovy	1.48

Source: Reprinted from Dholakia, N. and Jain, K., *Infofish Int.*, 2, 21, 1992. With permission from *Infofish*.

acceptance than frozen samples.[43] There was an overall downward trend in the U.S. per capita seafood consumption from the mid-1980s due to reasons such as insufficient supply, lack of convenient products, high prices, lack of perceived value, and lack of general promotion campaigns. However, it has been predicted that seafood consumption could equalize muscle food in the next 30 years.[44] Seafood will be eaten as mince, *surimi*, soup, flavoring, and specialty, red-meat poultry seafood. Recently ready-to-eat shrimp in six different flavors have appeared in market.[44] Table 1.6 indicates preference of seafood among consumers and Table 1.7 gives per capita fish consumption in terms of species in the United States.

During 1965 to 1998, demand for fish in Japan paralleled the increase in average income. While elderly people favored *sashimi* or *sushi* products, younger generation preferred cooked or grilled steaks and fillets of tuna. Quantities of fish consumed in restaurants as ready-to-eat products also increased substantially in

TABLE 1.7
Per Capita Fish Consumption in 2003 by Species in the United States

Species	Per capita consumption (pounds)
Shrimp	4.00
Tuna (canned)	3.40
Salmon	2.22
Pollock	1.70
Catfish	1.13
Cod	0.64
Tilapia	0.54
Clam	0.53
Scallop	0.34

Source: Adapted from National Fisheries Institute, Washington, D.C., USA.

the country.[45] Consumption of fish and seafood in Europe is predicted to increase in all major European markets. This is attributed to a number of factors including consumers' attitudes and lifestyles, recent scare over meat safety and increased "add-value" opportunities for fish and fish products. It was shown that the main species presently consumed in Europe are mussel and cod followed by tuna, herring, cephalopods, sardines, salmon, shrimp, and trout.[36] Recently, the European Union has backed a collaborative seafood project, entitled "SEAFOODplus" to investigate the benefits of seafood for the consumer as well as related issues in aquaculture, the environment, and the economy.[46] Total fish production and consumption profiles in the 13 new countries joining the European Union are also available.[22]

1.5 NECESSITY AND IMPORTANCE OF VALUE ADDITION OF FISHERY PRODUCTS

Value is among the most important modern marketing concepts. Value is most often seen as a combination of quality, service (convenience), and price, which is often called the customer value triad.[47] In the case of food, the most basic benefits of value addition include the functional and emotional benefits related to quality and nutrition, convenience in preparation, and sensory appeal at a reasonable cost. Value addition in seafood is regarded as any activity along the supply chain that increases the usability, culinary attributes, or economic viability of a fish or shellfish item. The primary activities in value addition of fishery products include procurement of the material, processing (primary and further processing), transportation, and marketing. The secondary activities include procurement of ingredients, technology development, human resource, and company management.[47]

The changing market demands are generally favoring attempts to add value to basic agricultural commodities. According to a press release by the World Trade Organization,[48] pattern in agricultural trade during 1985 to 2003 has shifted away from commodities to processed foods. The reasons are changes in consumer attitudes emphasizing convenience in the handling of food products. In view of these changing trends, there is a need for diversification of conventional seafood-processing techniques to prepare consumer friendly products from shellfish, cephalopods, and finfish. In addition, emphasis on good nutrition is another factor that can work in favor of fish. Possibilities of preparation of several such value-added consumable product from fish and shellfish have been recently pointed out.[27,49–51]

Market studies describing trends, methodology, and results of innovative work in the seafood industry, with particular emphasis on Western markets, have been compiled in a recent publication. The study, which examined philosophy, processes, and marketing strategies of three major areas of value addition, namely, fillets, *surimi* seafood, and aquacultured products, also included 20 worldwide case studies on popular products. It was concluded that the reasons that will drive the demand for seafood in the coming years will be closely related to trends in lifestyles coupled with demand for products having convenience in preparation, quality, and health benefits.[47] It was recently pointed out that if the fishery industry has to compete with other center-of-the-plate foods and gain the environmental benefits more creativity in the use of seafood would be needed.[50]

Several factors are critical in the development of new food products. These include involvement of the consumer early in the process, real-life study of consumer liking for the food product, multidisciplinary cross-functional teams, cost reduction, and support of the management. The best recipe for success has been designated as consistency in quality, reliability in supply, consumer understanding, and constant improvement and innovation in all aspects of the business.[47] According to a recent report, a grilled hake fillet, squid ring salad, or a lobster tail with rosemary sauce is not to be "consumed" but to be "enjoyed."[52] With respect to appearance, the flesh can be red like a tuna loin, orange like a slice of salmon, white as sole fillet, or almost transparent. Seafood, fresh or frozen, whole or filleted, crude or cooked has its own typical flavor, more or less marine, which changes with cooking. The sensory properties can be enriched or minimized according to individual taste with a series of condiments. Improvement of the sensuality of the product to suite the consumer's choice represents value addition, which in turn, helps per capita seafood consumption. Table 1.8 shows classification of new products according to their degree of value addition.

Novel methods of value addition can be a boost to the rising aquaculture industry. Shrimp from aquaculture can be a major raw material for the purpose, because of its regular availability in adequate quantity. Further, the shellfish

TABLE 1.8
Classification of New Products

- Classically innovative products. These involve high cost and risk to the company, but can be highly beneficial, if successful
- Product line extensions. These new products supplement the market through variations in package, recipes, etc.
- Improved and revised existing products. New products that provide improved performance and greater perceived value
- Repositioned products. These are existing products that are targeted for new markets or market segments
- Cost-reduced products. New products that provide similar performance at lower cost than the original product

Source: Adapted from Moller, A.B. Studies on Seafood Value Addition, Fishery Industry Division, FAO/GLOBEFISH, Special Market Study, Food and Agriculture Organization, Rome, Italy, 2003, p. 93. With permission.

exhibits significant amenability for value addition and packaging in retail pouches or window-packs.[49] The value-added fishery products may be lightly salted, smoked, acidified, irradiated, high-pressure treated or heated, which can be packaged in a modified atmosphere or "sous vide."[51,53,54] Developments in technology can be highly beneficial in these efforts. For example, the traditional canning process, which is dependent on expensive metallic cans and large storage space, can be adapted to retort pouch packaging of ready-to-eat items. There is also scope to make use of the experience of chefs in these ventures. A fusion of culinary/chef skills and technical/scientific skills has shown initial success in development of attractive products from West Coast albacore tuna.[55] The modern seafood processors are generally willing to changing market requirements. In recent years, the processors have committed themselves to HACCP-based production, planning, processing control, and packing and labeling requirements.[49] Some of the value-added products currently traded commercially are summarized in Table 1.9. The traded product forms from bivalves are also given in Table 1.10.

Value addition of fishery products can benefit particularly developing countries. Some of the products that are currently produced for trade in ASEAN countries are shown in Table 1.11. There are immense possibilities for these countries to tap a growing European market for value-added fish and seafood products, particularly in view of their low-cost manpower and availability of raw material.[22,25,56,57] Nevertheless, the industry, in developing countries needs to demonstrate their capability to deliver quality products continuously, on time and at stable prices. A Concept Paper, "Fish for All" prepared by the WFC presented an overview of the characteristics and trends of the global fishery industry over the next two decades with respect to liberalization of trade and globalization of markets.[11] The study cautioned growing wises and controversies

TABLE 1.9
Currently Available Value-Added Products from Major Seafood Groups

Crustacea	Mollusk	Finfish
Live	*Mussel*: live, fresh: half shell, shucked meat	Live
Fresh/frozen: (IQF/block frozen)	Frozen: whole, half shell, shucked meat, cooked/uncooked	Fresh: whole/dressed
Peeled tail-on shrimp	Value added: smoked, canned meat/soup, breaded fritters, entries	Frozen: Bulk/IQF
Peeled tail on stretched (Nobashi)	*Squid*: peeled, double skinned, frozen blocks or IQF, head-on in boil-in-bag, breaded, all vacuum skin tray-packed.	Fish fillets, vacuum packed, canned
Butterfly tail-on shrimp	*Cuttlefish*: fillets, frozen, boil-in-bag	Composite fillets from mince
Head-on, tail-on, shrimp	*Scallop*: live, fresh, IQF, block-frozen with or without roe, shucked meat in sauce, smoked, breaded, battered	Raw steaks
Accelerated freeze dried	*Clam*: live, IQF, with shell/half shell, steamed meat, chopped or minced, stuffed, breaded, fried, juice, chowders, cakes etc.	Cooked tuna light meat
Breaded butterfly shrimp	*Oyster*: live, fresh: shell on, half shell, shucked meat, cooked or uncooked, smoked, canned, soups, breaded, fritters	Fish burger
Breaded round shrimp		Seafood stew
Shrimp delights		Seafood salad
Cooked head-on shell-on shrimp		Grilled steaks
Cooked, peeled, deveined tail-on shrimp		Cooked light meat
Cooked peeled deveined tail-off		
Shrimp rings		
Shrimp-based meals		
Breaded baby clams		
Cooked lobster		

are plaguing the seafood industry with increase in global fish consumption. While the world's oceans are being overfished, fish farming is leading to pollution of waters. The WFC studies, however, highlighted a necessity of value addition because of increasing consumer demand and rising markets and for better food security and value of the catch. The other advantages are total utilization of the catch including by-catch and nonconventional species, diversification of traditional technologies, better marketability, and by-product recovery.[58–61] In conclusion, development of value-added fishery is an exciting and rewarding task for the seafood industry. Innovations in technologies and improvised policies in both developed and developing countries can help create a thriving and sustainable fish industry.

TABLE 1.10
Main Product Forms of Bivalves in International Trade

Mussel	
Live	Shell on
Fresh	Half shell, shucked meat
Frozen	Whole, half shell, shucked meat, cooked and uncooked meat
Value added	Smoked, canned, soup and stew, breaded, fritters, entrees
Oysters	
Live	Shell on
Fresh	Half shell, shucked meat
Frozen	Whole, half shell, shucked meat, cooked and uncooked
Value added	Smoked, canned meat, soups, stews, breaded, fritters, entrees
Scallop	
Live	Rinsed, shell on
Fresh	Meat
Frozen	IQF, block frozen without shells, with or without roe
Value added	Smoked meat, breaded and battered (frozen), shucked meat in sauce
Clams	
Live	Rinsed, shell on
Fresh	Meat, whole steamed
Frozen	IQF half shell, whole with shell meat, raw and steamed
Value added	Canned meat, chopped or minced, stuffed, breaded, fried, prefried strips, clam juice, chowders, biscuits, cakes

TABLE 1.11
Major Fish and Shellfish Product Forms Traded by ASEAN Countries

Canned products	Anchovy, baby clam, crab meat, fish (mackerel) in tomato sauce, milk fish in oil, milk fish in tomato sauce, sardine in tomato sauce, canned shrimp, squid, cuttlefish, octopus, canned tuna in oil
Comminuted products	Comminuted breaded fish finger, breaded squid ring, cuttlefish ball, comminuted cuttlefish sausage, comminuted fish noodle, fish ball, fish cake, minced fish, prawn burger
Dried products	Several fish and shellfish, dried under varied conditions
Fermented products	Fermented sauce, muscle, pickled prawn, fish paste, shrimp paste
Frozen products	Several products including IQF fish fillets, eel, shrimp, cuttlefish, squid ring

Source: Adapted from Chng, N.M., Hoon, C.G., and Kwang, L.H., *Southeast Asian Fish Products*, 3rd ed. Southeast Asian Fisheries Development Center, Singapore, 1996. With permission.

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2 Postharvest Quality Changes and Safety Hazards

2.1 Introduction

Freshness and *quality* are perceived differently by consumers, processors, regulatory officials, and scientists. This is particularly so with respect to seafood, the freshness and quality of which are subject to wide interpretations. Maintenance of the quality of both wild and aquacultured fish is more difficult than in the case of other muscle foods. Unlike all other major food supplies, the production of seafood cannot be directly controlled, enhanced, or accurately predicted. There is an unusual diversity in the seafood industry depending on the types of harvest, fishing techniques, types of products, production volumes, and location. In addition, the inherent nature of seafood makes them more susceptible to food-borne hazards.[1,2]

The quality of fishery products is influenced by both intrinsic and extrinsic factors. Species, size, sex, composition, spawning, the presence of parasites, toxins, contamination with pollutants, and cultivation conditions are the factors responsible for changes in intrinsic quality.[3,4] The biochemical characteristics of fish muscle such as low collagen, comparatively higher contents of unsaturated lipids as well as soluble nitrogen compounds influence autolysis, rapid microbial proliferation, and spoilage. Fatty fish such as sardines and herrings deteriorate more quickly than lean fish. Small fish that have been feeding heavily prior to being caught may undergo tissue softening and break easily after death due to autolysis.[4] Larger fish have higher marketability and value because of the higher yield of edible material and longer shelf life.

The extrinsic factors influencing the quality of harvested fish are: the location of catch, season, methods of catch (gill net, handline, longline, or trap, etc.), on-board handling, hygienic conditions on the fishing vessel, processing, and storage conditions[5] (see Chapter 3). Developing high quality seafood products begins with the consideration of the condition of the animal in water, the impact of environmental stresses, nutritional deficiencies, or seasonal changes on the intrinsic quality and the effect of the method of capture on the natural state.[6]

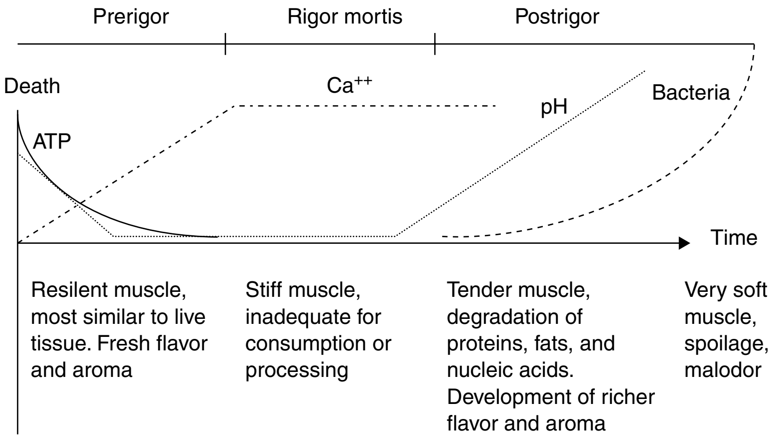

FIGURE 2.1 Schematic representation of the postmortem events occurring in fish muscle (Reprinted from Martinez et al., Outlook on Agriculture 26, 197, 1997, with permission)

2.2 SPOILAGE OF FRESH FISH

2.2.1 Postmortem Changes

Live fish muscle is relaxed and elastic. Immediately after death rigor mortis sets in, then the whole body becomes inflexible and rigid. The onset of rigor depends upon the temperature of the fish, particularly on the difference of temperatures between that of water and storage. The greater the difference, the shorter the time from death to rigor and vice versa. Aerobic respiration ceases and anaerobic oxidation of glycogen leads to accumulation of lactic acid, resulting in a drop in the muscle pH from about 6.8–6.5. Most teleost fish and crustaceans, however, have a lower carbohydrate content, whereas its content is higher in bivalve and molluskan shellfish. The final pH depends upon the species and composition of the animal. During rigor, the loss of adenosine triphosphate (ATP) due to autolytic degradation (about 1 μM/g tissue) results in a stiffening of the muscle as a result of the irreversible association of myosin and actin molecules. Slime is formed in certain cells of fish skin and the process becomes very active just after death. This is particularly so in most freshwater fish, which secrete slime to the extent of 2–3% of the fish mass that creates problems in processing. Slime contains large amounts of nitrogenous compounds and these provide good nourishment for microorganisms contaminating the fish from the environments. Resolution of the rigor is a slow process essentially due to the low pH-favored hydrolysis of actomyosin by acid proteases such as cathepsins that are present in the muscle.[4] Figure 2.1 depicts a schematic representation of the postmortem events that occurs in fish muscle.

Rigor mortis of fish has technological significance since the process influences the quality of fillets. Ideally, fish should be filleted postrigor. Fillets prepared in rigor will be stiff with poor yields. If the fillets are removed from the bone

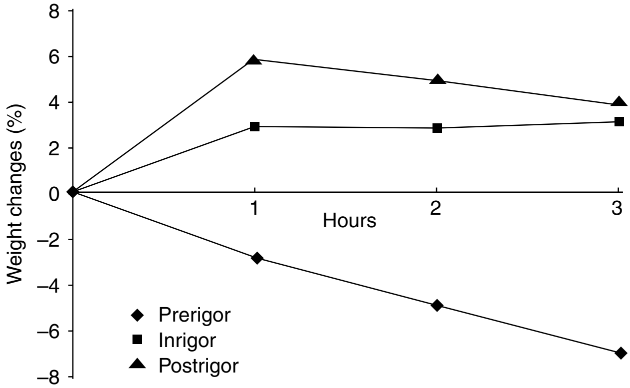

FIGURE 2.2 Average weight changes of pre-, in-, and postrigor cod fillets during brining for 1, 2, and 3 h (Reprinted from Elvevoll, E.O. et al., *Meat Sci.*, 43, S265, 1996. With permission from Elsevier)

prerigor, the muscle can contract freely and the fillets will shorten following the onset of rigor, and this phenomenon is called gaping. Further, the behavior of the fillets during processing also differs depending upon whether they are collected from prerigor or postrigor fish.[4,7] The influence of rigor on the salt absorption behavior of salmon and cod fillets have been reported. It has been shown that when the postrigor fish, was immersed in saturated brine, the fillets absorbed 3% salt showing a 6.5% increase in weight within a period of 1 h. On the other hand, the prerigor fillets lost 7% in weight in 3 h and absorbed the same amount of salt.[8] The texture may also become firm and dry if stressed fish is processed before rigor mortis.[4] Figure 2.2 depicts the influence of brining on pre-, in-, and postrigor conditions cod fillets. Fillets also undergo changes in length depending upon rigor state and storage temperature. Figure 2.3 shows reduction in the length of prerigor salmon fillets during storage at 0, 10, and 20°C. Maximum contraction of salmon fillets was attained after 12 h of storage at 20°C, while at 0 and 10°C a maximum contraction was attained after about 40 h of storage. The contracted fillets never regained its original length during different handling conditions. Furthermore, the shortened fillets were less shiny and hence had a poor appearance as compared with the postrigor filleted product.[8]

The biochemical changes during fish spoilage and the role of intrinsic and extrinsic factors on the phenomenon have been reviewed by several scientists.[4,9–16] Immediately after death, the initial biochemical quality of the muscle is prone to rapid changes due to cessation of respiration, breakdown of cellular ATP, autolytic action of proteolytic enzymes on the muscle, oxidation of lipids, and the metabolic activities of microorganisms. The ATP is sequentially degraded to adenosine diphosphate (ADP), adenosine monophosphate (AMP), inosine monophosphate (IMP), and inosine (HxR) by autolytic enzymes as shown below:

$$\text{ATP} \rightarrow \text{ADP} \rightarrow \text{AMP} \rightarrow \text{IMP} \rightarrow \text{HxR} \rightarrow \text{Hx} \rightarrow \text{X} \rightarrow \text{U}$$

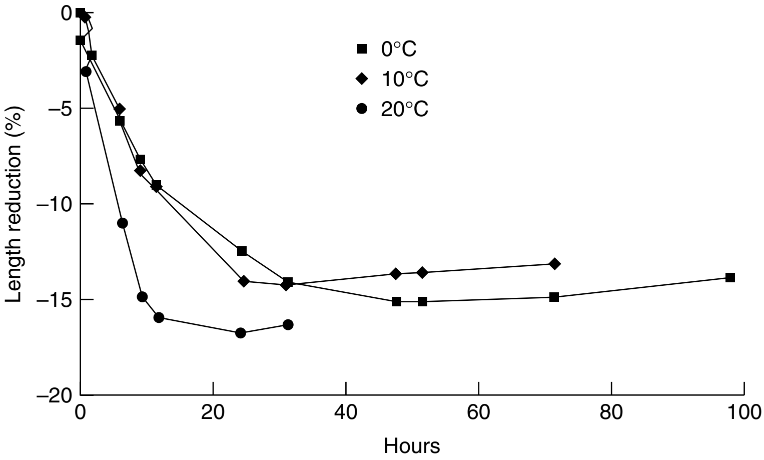

FIGURE 2.3 Reduction in the length of single fillets of Atlantic salmon stored at different temperatures as a function of time (Reprinted from Elvevoll, E.O. et al., *Meat Sci.*, 43, S265, 1996. With permission from Elsevier)

The first four steps of the reaction sequence proceed at a relatively faster rate in fish and shellfish. Oxidation of HxR to hypoxanthine (Hx) is much slower and is the result of microbial enzyme activity. A strong correlation has been observed between nucleotide catabolism and the loss of freshness of fish.[11,17] It was proposed that the freshness of fish could be determined in terms of "K-value," by estimating the contents of autolytic degradation products of ATP,[18] as given below:

$$K\text{-value} = \frac{[\text{HxR}] + [\text{Hx}]}{[\text{ATP}] + [\text{ADP}] + [\text{AMP}] + [\text{IMP}] + [\text{HxR}] + [\text{Hx}]}$$

where [ATP], [ADP], [AMP], [IMP], [HxR], and [Hx] represent the relative concentrations of ATP, ADP, AMP, IMP, HxR, and Hx, respectively, at any given time during the storage of the fish. As the K-value increases, the freshness of the fish decreases. The enzymatic reactions involved in the oxidation of HxR to Hx to xanthine (X) and finally to uric acid (U) are:

Inosine + Pi → Hypoxanthine + ribose − Pi (Enzyme:nucleotide phosphorylase)

Hypoxanthine + oxygen → Xanthine + hydrogen peroxide (Xanthine oxidase)

Xanthine + oxygen → uric acid + hydrogen peroxide (Xanthine oxidase)

Inosine monophosphate is known to contribute to fresh fish flavor, and its loss due to breakdown by bacterial nucleoside phosphorylase causes loss of flavor of fish flesh. Since the concentrations of ATP, ADP, and AMP significantly change within the first day of death, a simplified K_i-value has been employed, as:

$$K_i\text{-value} = \frac{[\text{HxR}] + [\text{Hx}]}{[\text{IMP}] + [\text{HxR}] + [\text{Hx}]}$$

The K_i-value has been found suitable for several fish species, although it has limitations for species such as cod.[7] Instead of K-value, a modified K_p-value, as a ratio of concentration of Hx to adenine has been found suitable for the evaluation of the freshness of certain shellfish. The K-value of threadfin bream stored in ice increased from 9 to 40% after storage for 12 days.[19]

2.2.2 Action of Muscle Proteases

Fish muscle contains several proteases including cathepsins, trypsin, chymotrypsin, and peptidases that also act on the muscle during postmortem storage.[7,19,20] The changes in the fish muscle as a result of these reactions may provide favorable conditions for bacterial proliferation. However, the reactions *per se* do not cause significant spoilage of the muscle.[21] The autolytic reactions nevertheless can support invasion of the muscle by organisms present in the intestines.[22] The contribution of autolysis and microbial reactions in change of nonprotein-nitrogen compounds of Antarctic krill stored at 3 and 20°C has been studied.[3] It was found that nonprotein-nitrogen formation as an indicator of autolytic reactions varied with respect to the harvesting season of the fish, suggesting the role of microorganisms in spoilage. Rough handling can damage cellular structures that result in the release of autolytic enzymes including proteases, that result in the enhancement of spoilage. One of the most adverse effects of autolytic proteolysis is the belly bursting of pelagic species such as herring and capelin.[11] The spoilage of cephalopods is dominated more by autolysis. Presence of a cathepsin D like proteinase of lysosomal origin can play a vital role in the degradation of squid mantle muscle. The result is an increase in the level of muscle-derived nitrogen, favoring proliferation of degenerative microflora and hence a shorter shelf life.[23]

2.2.3 Lipid Oxidation

Lipid oxidation is associated with early postmortem changes in the fish tissue. The process is initiated by removal of a proton from the central carbon of the unsaturated fatty acid, usually a pentadiene moiety of the fatty acid, and formation of a lipid radical. The latter reacts quickly with atmospheric oxygen making a peroxy-radical ($LOO^{\cdot}$). The chain reaction involving the peroxy-radical results in the formation of hydroperoxides that are readily broken down and catalyzed by heavy metal ions to secondary products. The reactions are favored by activation of haemoproteins and increase in free iron, while antioxidants negatively influence the oxidation.[24] Lipid oxidation is comparatively more during frozen storage than during chilling (0 to 2°C) storage, and can be both nonenzymatic as well as enzymatic. Enzymes such as lipoxygenase, peroxidase, and microsomal enzymes from animal tissues can also potentially initiate lipid peroxidation producing hydroperoxides. The breakdown of hydroperoxides into aldehydes, ketones, and alcohols causes development of off-flavors. Fish lipids, rich in n-3 polyunsaturated fatty acids, are very susceptible to oxidation, giving rise to n-3 aldehydes that cause distinctive oxidative off-flavors. These compounds include *cis*-4-heptenal, *trans*-2-heptenal, *trans*-2-*cis*-4-heptadienal, etc. and also 1,5-octadien-3-ol, 1-octen-3-ol, and hexanal.[24–27]

Lipoxygenases are concentrated in the skin tissue and remain active for upto 48 h of chilled storage. Lipoxygenase-dependent oxidative activity has been detected during chilled storage of fatty fish species such as sardine (*Sardina pilchardus*) and herring (*Clupea harengus*).[24,25,27] The pro-oxidative activity due to haem proteins continued longer than that due to lipoxygenase. The most abundant degradation products of the hydroperoxides formed from arachidonic and docosahexaenoic acids are 12- and 16-hydroxy acids.[24,25] The formation of fluorescent compounds resulting from the interaction between lipid oxidation products and biological amino constituents has been noticed during chilled storage.[27] The extent of lipid oxidation can be reduced by glutathione peroxidase, which reduces unstable lipid hydroperoxides to nonradical, stable products, which are inactive in the oxidative chain propagating mechanism. Other enzymes useful in this respect are superoxide dismutase and catalase, which remove superoxides from the peroxidation mechanism.[24] Fish lipids are also prone to hydrolysis by lipases with the formation of free fatty acids. Lipid hydrolysis is more in ungutted than in gutted fish, probably due to the involvement of lipases present in the digestive enzymes. Cellular phospholipases are known to hydrolyze the lipids, particularly, phospholipids that leads to increased oxidation of the hydrolyzed lipids.[7]

2.2.4 Microbial Spoilage

It has been estimated that about one-third of the world's food production is lost annually due to microbial spoilage.[28] Microbial activity is responsible for spoilage of most fresh and several lightly preserved seafood. Microorganisms associated with fishery products generally reflect the microbial population in their aquatic environment.[11,29,30] The fish muscle is sterile at the time of catch, but becomes quickly contaminated by surface as well as intestinal bacteria, and bacteria from water, equipment, and humans during handling and processing. Microorganisms are found on the outer surfaces (skin and gills) and in the intestines of live and newly caught fish. The microflora of fish from temperate waters is dominated by psychrotrophic, aerobic or facultative anaerobic Gram negative, rod-shaped bacteria and in particular *Psuedomonas*, *Moraxella*, *Acinetobacter*, *Shewanella*, *Flavobacterium*, *Vibrio*, *Photobacterium*, and *Aeromonas* spp. The Gram positive organisms that are isolated from fish include *Bacillus*, *Micrococcus*, *Clostridium*, *Lactobacillus*, *Coryneforms*, and *Brochothrix*.[7,30] In polluted waters, high numbers of Enterobacteriaceae may be found. During chilled storage, there is a shift in bacterial types, with psychotrophic *Pseudomonas* and *Shewanella* spp. dominating after 1 to 2 weeks of storage. At higher storage temperatures, for example, 20°C, the microflora, which will ultimately grow on the products, are mesophilic ones including *Bacillus* and *Micrococcus* spp.[30]

Although the level of bacterial contamination influences fish spoilage, all the contaminant organisms are not equally responsible in the spoilage process. Therefore, total viable count can be a poor indicator of both the quality and the remaining shelf life of chilled fish. Instead, a count of organisms producing hydrogen sulfide (H_2S) has been found to be a better indicator of fish quality.[31] Although most of the data on microbial spoilage that have been collected are on fish of marine origin, the spoilage pattern of both marine and freshwater fish species are comparable.[32] However, depending upon the nature of flora, variations in spoilage rates are possible. The spoilage potential of individual bacterial isolates from fish have been determined by assessing the extent of spoilage they cause during growth in sterile fish muscle.[7,33,34] These studies showed that bacterial spoilage of fish was essentially caused by organisms belonging to *Pseudomonas* and *Alteromonas* spp., *Aeromonas*, and *Proteus* spp. were found to cause proteolysis in shrimp.[35] The role of *Aeromonas hydrophila* in the spoilage of tropical fish has been recognized.[33,36] Some of the other major microbial spoilers include *Pseudomonas fluorescens*, *P. perolens*, and *Alteromonas putrefaciens*.[37]

Bacteria initially grow at the expense of soluble, low molecular weight compounds present in the fish muscle and slime that serve as nutrients. Organisms belonging to *Pseudomonas* spp. grow more rapidly in the protein-free fraction of fish press juice containing soluble components than in the protein fraction devoid of soluble compounds.[38] Initially bacterial growth is on the surface, and when slime builds up, conditions become more favorable for the growth of anaerobes. With the exhaustion of nutrients, protein catabolism becomes essential for the survival of microflora. Therefore, at terminal spoilage, only those organisms that secrete proteases can survive in the fish muscle, which leads to a predominance of proteolytic bacteria in spoiling protein foods including fish.[39] The role of extracellular bacterial proteases in fish spoilage is well understood.[40]

The bacterial spoilage reactions in chilled fish have been elucidated.[29] The contaminant organisms initially utilize lactic acid and nonprotein-nitrogen compounds, particularly trimethylamine-oxide (TMAO) with the liberation of trimethylamine (TMA), dimethylamine (DMA), ammonia, and other volatile compounds. During 4 to 7 days of storage of fish in ice, a sharp reduction in the content of free amino acids can be noticed without any significant extent of proteolysis. Thereafter, the bacterial counts increase to above 10^8 colony forming units (cfu) per cm^2 skin surface or per g tissue, causing breakdown of proteins accompanied by increase in amino acids and volatile sulfur compounds, such as mercaptans and H_2S. This stage is also marked by adverse changes in the organoleptic quality of the fish. The number of H_2S producing bacteria could, thus, be taken as a general index of the extent of proteolysis and hence, spoilage.

Trimethylamine-oxide is a natural nontoxic compound, generally associated with the osmoregulatory function of marine fish. After the death of the fish some of the bacterial species such as *Alteromonas*, *Proteus*, *Photobacterium*, *Vibrio*, and *S. putrefaciens*, and also intestinal bacteria of the Enterobacteriaceae present are able to carry out anaerobic respiration by using TMAO as an electron acceptor. The bacterial enzyme TMAO-reductase reduces TMAO to TMA. Formation of TMA depends primarily on the content of TMAO in the fish. Most marine animals contain TMAO in appreciable quantities, with elasmobranchs and deep-sea fish species containing higher levels. Many freshwater fish do not contain TMAO but some species like the Nile perch and tilapia contain TMAO. Therefore, apprehensions have been raised on the use of TMAO as a reliable indicator for marine origin.[41] Bacterial reduction of TMAO results in accumulation of about 10 to 25 mg TMA per 100 g muscle of spoiling fish, contributing to the characteristic spoiled fish odor. TMA, in addition to ammonia and other volatile amines, is a major component of the total volatile basic nitrogen (TVBN) compounds in the spoiled fish. TMA production in many fish species is also paralleled by bacterial production of Hx. Many spoilage-causing bacteria such as *Shewanella putrefaciens* and *Vibrio* spp. also produce off-smelling volatile sulfur compounds such as H_2S methyl mercaptan, and dimethylsulfide, from sulfur containing amino acids.

Shewanella putrefaciens and *Psuedomonas* spp. have been recognized as the *specific spoilage organisms* (SSOs) in iced fresh fish such as cod.[30,38] During the storage of seafood at particular conditions of temperature, atmospheres, salt, a_w, preservatives, etc. these SSOs grow faster than the remaining microflora, and eventually produce the metabolites responsible for off-flavors and sensory product rejection. Modified atmosphere-stored marine fish from temperate waters are spoiled by the CO_2-resistant *Photobacterium phosphoreum*. The bacterium has also been identified as the main spoiler in vacuum-packed cod and ice stored squid.[42,43] Fish products with high salt contents may spoil due to the growth of halophilic bacteria, anaerobic bacteria, and yeast, whereas in lightly salted fish, spoilage could be due to lactic acid bacteria and certain Enterobacteriacea.[7,30] Consequently, the numbers of SSOs and the concentration of their metabolites can be used as objective quality indices for shelf life determination in seafood. With SSOs responsible for spoilage, a close relationship between log-numbers of SSOs and the remaining shelf life has been suggested.[7,38,42] This also helps to predict shelf life of seafood based on knowledge about initial numbers and growth of SSOs. The number of four different SSOs, that is, *S. putrefaciens*, *P. phosphoreum*, *Brochothrix thermosphacta* and lactic acid bacteria have been shown to correlate significantly with the remaining shelf life of the product.[7,30] Table 2.2 shows examples of SSOs responsible for the spoilage of some seafood.

2.2.5 Flavor Changes

The flavor of fish significantly influences its consumer acceptability. Fresh marine fish are nearly odorless, because they contain only a small quantity of volatiles. Immediately after harvest the product is considered to retain its original characteristics. However, the lower quantity of volatiles need not be related with freshness of fish as perceived by the consumer, since eating quality is a subjective experience. In fact, most fish gourmets prefer "matured" postrigor fish. The ripening period, like the onset, intensity, and duration of rigor mortis, differs from species to species. The flavor of cooked cod, for example, has the strongest intrinsic characteristics after 2 days in melting ice. Many fatty species such as salmon, ocean perch or halibut, improve much in flavor, taste, and texture during the first 2 to 4 days in ice. This is mainly due to the redistribution of fat and the development of flavor components, such as amino acids, IMP, and sugars, produced by the autolytic processes occurring in the postrigor muscle.[44] During storage, the action of endogenous enzymes in the postmortem tissue contributes to flavor changes. Rapid oxidation of large amounts of unsaturated lipids in fish is a major reason for changes in smell, taste, color, texture, and nutritional value. Enzymatic as well as nonenzymatic oxidation of polyunsaturated fatty acids of fish muscle produce a variety of carbonyls, alcohols, etc. that are responsible for flavor changes in fish. Associated with the lipid oxidation compounds, formation of several volatile compounds due to microbial action results in significant loss of fresh fish flavor.[45] In the case of elasmobranchs like sharks and rays, ammonia generated by the action of endogenous enzyme urease on urea influences the flavor. Similarly, rapid formation of ammonia in shrimp is correlated with adenosine deaminase activities on nucleotides, arginase-catalyzed formation of urea and its conversion to ammonia.[7] The factors influencing the flavor of farm-raised fish have been discussed in detail.[46]

2.2.6 Changes in Texture

Texture is an important quality parameter of muscle foods including fish. Fish is generally softer than red meat because of its low content of connective tissue and lower degree of cross-linking. Fish can be grouped into three types according to their texture (Chapter 1). The textural deterioration of fish takes place essentially due to degradation of the connective tissue by endogenous proteases.[20] Tenderization or softening of the flesh is associated with the disappearance of Z-disks in the muscle cell with the release of α-actinin, dissociation of the actomyosin complex, destruction and general denaturation of the connective tissue.[47] Proteolytic digestion of sarcolema that links the major structural units together is a major reason for tenderization.[48] Muscle proteases including cathepsin D and cathepsin L, calcium-activated proteases (calpains), trypsin, chymotrypsin, alkaline proteases, and collagenases are all involved in the softening of fish tissue during storage.[2,20] Softening of tissues of cephalopods during cold storage is a major problem. The involvement of proteolytic enzymes has been implicated in the phenomenon.[23] The major source of hydrolytic activity in Bombay duck, a marine fish, is concentrated essentially in the drip, while in the freshwater fish, tilapia, it is in the skin. Removal of cathepsin-D by removing drip or skinning tilapia suppressed enzyme-mediated softening.[49] Collagenases have been found to be involved in the development of mushiness in prawns stored in ice.[50]

As a result of proteolysis during storage, the gel strength (compressive force) of red hake (*Urophycis chuss*) was reduced to 46% after being stored in ice for 3 days, and to 63% when stored in chilled seawater.[51] During ice storage of threadfin bream up to 6 days, significant reduction in breaking force of washed mince has been reported.[19] These changes can influence the *surimi* quality made from fish. Similarly, a decrease in the breaking force and deformation of *surimi* has been observed in the big eye snapper stored in ice.[52] Changes were observed in the octopus arm muscle during the early stage of chilled storage as a result of the autolysis of myosin heavy chain and also paramyosin. Therefore, care should be taken to control the loss of the quality of octopus during processing to ensure the functionality of myosin.[23] Proteolysis can also adversely affect water holding capacity (WHC) of fish muscle during storage. Fresh muscle is able to retain water, a functionality, which is of importance both to the industry and consumers.[53,54] Decreased WHC of muscle has often been described as the result of structural alterations in the muscle postmortem such as detachment of sarcolemma, gaps in the extracellular matrix, increased myofibrillar space and transverse shrinkage.

2.2.7 Discoloration

Another quality problem facing the seafood industry is the discoloration of products. The pink/red color of the skin of most fish fade during iced/chilled storage due to oxidation of the carotenoid pigments. The extent of the loss of color depends upon the fish, availability of oxygen, and the storage temperature.[55] Color is a very important quality parameter for salmonid fish. Wild salmon and trout flesh are naturally reddish due to the presence of carotenoid pigments. Generally astaxanthin and other carotenoid pigments are added to the diets of aquacultured salmon to improve appearance of the fish fillets. Fading of carotenoid color may take place due to (i) autooxidation of the conjugated double bonds, (ii) free radicals released during lipid oxidation that combine with carotenoids to form lipid hydroperoxides, and (iii) enzyme activity.[56] The activities of the enzymes involved in the oxidation of carotenoids are influenced by hydrogen peroxide and halides, particularly bromides and iodides. Bleaching of β-carotene could be due to one of the above three mechanisms.[57] Oxidation of myoglobins in the muscle is another reason for color change in fish. Oxidation of bright red myoglobin to brown metmyoglobin can occur through both nonenzymatic and enzymatic routes. An enzyme, metmyoglobin reductase, has been isolated from the skeletal muscle of dolphins and bluefin tuna.[25]

2.2.8 Melanosis

Development of black spots or melanosis is a problem found in most commercial shrimp, lobster, and other crustacea, that can cause a negative impact on the commercial value and consumer acceptance of the product.[58] Melanosis is triggered by a biochemical mechanism by which phenols are oxidized to quinones by the enzyme polyphenol oxidase (PPO). The quinones are highly reactive and undergo nonenzymatic oxidation and polymerization giving rise to dark pigments having high molecular weight. PPO is found in the zymogen form on the exoskeleton, chiefly on the shell of the cephalothorax of the crustaceans. The zymogen is converted to active enzyme by the action of a serine protease that exhibits trypsin-like activity. The zymogen can also be activated by nonphysiological agents such as detergents, organic solvents, gamma radiation, and heat or by immune response to microbial invasion.[58] The enzyme remains active during ice storage and