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Review Article

Review on Spoilage and Quality Indices of Prawns

J. Ginson[1]*, K. R. Remya Kumari[2] and J. Bindu[3]
[1] *School of Industrial Fisheries, Cochin University of Science and Technology, Fine Arts Avenue, Cochin, Kerala, India*
[2] *National Institute of Fisheries Post Harvest Technology and Training, Foreshore Road, Cochin, Kerala, India*
[3] *Central Institute of Fisheries Technology, P. O. Matsyapuri, Cochin - 682 029, India*

Abstract

Prawns are a highly nutritious and most traded seafood commodity that contains a commendable quantity of easily digestible protein, minerals, vitamins and low saturated fats, especially omega-3 fatty acids. Nevertheless, high water content, pH, natural autolytic enzymes, free amino acids and microbes in prawns make it vulnerable to rapid spoilage, consequently affect the shelf-life. Know-how regarding the spoilage patterns of prawns would aid to adopt suitable processing technology to overcome this menace. The freshness or spoilage pattern of the prawns could be scientifically demonstrated by assessing the physicochemical and microbiological quality indices. The main intention behind this article was to demonstrate a comprehend review for the post mortem changes of prawn and associated physicochemical quality indices ie., pH, trimethylamine (TMA), total volatile base nitrogen (TVB-N), K-value, indole, thiobarbituric acid (TBA), free fatty acids (FFA), black spot formation, hardness, colour, organoleptic properties and bacterial flora during storage.

Keywords: Prawn, trimethylamine, total volatile base nitrogen, K-value, indole

Introduction

Palatability and nutritional significance of prawns are the main reason for the popularity and demand in seafood trade. However, prawns are easily vulnerable to spoilage due to the accumulation of spoilage microflora through filter-feeding and the presence of significant quantities of amino acids, pH, and autolytic enzymes (Dalgaard, 2000). According to Simidu (1962), free amino acids available in prawns also make it more susceptible to bacterial spoilage. Microorganism's especially Gram-negative bacteria play a vital role in the spoilage of seafood (Cann, 1977). During spoilage, autolytic enzymes cause changes in endogenous biochemical compounds in prawn meat which facilitates bacterial action (Ababouch et al., 1996). The invaded bacteria decompose the muscle into various low molecular weight constituents which produce off-odour and off-flavor compounds such as hydrogen sulfide (H_2S), ammonia (NH_3) and volatile metabolites (Gennari et. al., 1999) and thus alter the appearance, flavor and odor of the prawn. These compounds are quantifiable and are widely used as quality indices. Commonly adopted quality indices for the estimation of spoilage level in prawns are pH (Gentles & Braggs, 1993), TMA, TVB-N (Montgomery et al., 1970), TBA (Goulas & Kontominas, 2007), K-value (Ehira, 1976) and mesophilic aerobic count (ICMSF, 1986). Accumulation of TMA content in prawns could be the action of enzymes and bacteria on the TMAO compound. Similarly, decomposition of various nitrogenous compounds produces TVB-N, hydrolysis of lipid releases FFA, which contribute significantly towards textural changes (Sikorski & Kolakowska, 1994) and lipid oxidation of seafood (Sequeira-Munoz et al., 2006). According to Harada (1991), texture and hue of fish and fishery products are the prime factors which directly influence the consumer acceptability. Several novel processing techniques have been emerging for the preservation of seafood without compromising on its natural attributes. Hence, this comprehen sure review would be useful while optimizing the process

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*E-mail: ginsonjoseph@cusat.ac.in

parameters of innovative processing methods for the preservation of seafood especially prawns. Keeping this fact in mind, this article reviews the spoilage pattern and the formation of physicochemical and microbiological quality indices in seafood with special reference to prawns.

Post mortem changes in prawn

Prawns contain high-quality protein, very low fat, vitamin A and D and several dietary minerals such as calcium (Ca), iron (Fe), etc. which are beneficial to the consumers. Iodine content in prawns is good for the proper functioning of the thyroid gland. However, prawns are highly perishable in nature. Enzymes and microflora available in prawn accelerates the spoilage mechanisms after rigor mortis. Immediately after the death of prawn, cessation of circulation of haemocyanin will take place which causes depletion of oxygen supply to the tissues and thus lead biochemical changes (Eskin et al., 1971). Degree of exhaustion prior to death and the available reserve glycogen in the muscle are the two major driven forces behind the biochemical changes of seafood during the post-mortem period (Eskin et al., 1971). The adenosine triphospahte (ATP) level in the muscle gets depleted due to the continuous action of autolytic enzymes. During spoilage, synthesis of ATP from the aerobic breakdown of glycogen through electron transport chain and oxidative phosphorylation ceases and the available ATP degrades into adenosine diphosphate (ADP). Glycogen content in the seafood undergoes anaerobic breakdown and produces lactic acid (glycogenolysis) thus leads to the reduction of pH of the muscle from 7-7.3 to about 6.2-6.3. Ratio of changing the pH depends on the initial level of glycogen content in the seafood. The low pH condition leads to rupture of the lysosomes and release of all the enzymes capable of degrading muscle constituents to low molecular weight compounds. Degradation of proteins and peptides by the action of proteolytic enzymes and bacteria leads to softening of the flesh which again raises the pH level in the muscle to 7.5-8.0. This is a favorable condition for the proliferation of microorganisms (Sareevoravitkul, 1995). Bacterial metabolism of low molecular weight constituents produces off-odour and off-flavor compounds like H_2S (hydrogen sulfide), NH_3 (ammonia) and volatile metabolites which further lead to increase in the level of pH in seafood (Gennari et al., 1999).

Physicochemical spoilage of prawn

Prawns are highly perishable than other commercial crustaceans such as lobsters and crabs. Usually, storage temperature and time would be the important factors for maintaining the quality of prawn immediately after harvesting (Reilly et al., 1987). Icing or chilling is the widely adopted and cheap preservation technique for seafood. However, physicochemical and microbiological degradation of prawn would have taken place during the storage period. Quality changes of cultured prawn in ice storage were reported by Jayaweera & Subasinghe (1988), Peranginangin et al. (1992). Storage characteristics of wild prawn have been discussed by several authors (Cobb & Vanderzant, 1971; Flick & Lovell, 1972; Cobb et al., 1973; Flores & Crawford, 1973; Shamshad et al., 1990; Yamagata & Low, 1995). Joseph et al. (1988) investigated the quality deterioration of cultured Indian white prawn during chilled storage. According to Flick & Lovell (1972), combined action of tissue enzymes and microbes accelerates quality deterioration in chill-stored prawns which generates several biochemical compounds including protein and non-protein nitrogen, trimethylamine, total volatile base nitrogen, indole, nucleotide degradation, lipid oxidation products.

Changes in pH

Changes in the pH of seafood are mainly due to the activity of bacteria and enzymes which affect the concentration of free hydrogen and hydroxyl ions by shifting the oxidation reduction balance of the food (Varlik et al., 2000). pH has a close relationship with organoleptic properties of seafood and could be accepted as an index of quality (Flores & Crawford, 1973). During post mortem changes of prawn, the pH gets reduced which leads to denaturation of muscle, this reduces water holding capacity and enhances drip loss, and in extreme cases flesh becomes translucent with a soft flabby texture (Tomlinson et al., 1965). Love (1975) revealed that the unacceptable toughness of seafood occurs at lower pH levels. Shellfish pH in a range of 7 to 8 is suitable for consumption (Ludorff & Meyer, 1973). Shamshad et al. (1990) made an attempt to evaluate the variations of pH in untreated fresh prawns stored at a temperature between 0 to 35°C and they observed an increase of pH from 7 to 8.25 on the 16^{th} day of storage. An increase of pH from 6.73 to 7.81 was also noticed in fresh, unprocessed prawns after four days of storage at 4°C (Varlik et al., 2000).

Changes of protein and non-protein nitrogen

During spoilage, proteins undergo several biochemical changes. Post mortem tenderization is one of the most unfavorable quality deterioration in seafood. Devadasan & Nair (1970) reported the changes in the major extractable protein nitrogen fractions of prawns during ice storage. The authors found that myofibrillar proteins undergo rapid changes than sarcoplasmic proteins during ice storage. The relationship between collagen content and texture has been discussed by Hatae et al. (1986). Reduction of collagen content leads to softening of the muscle. Changes in the microstructure of *Macrobrachium rosenbergii* during chilled storage have been reported by Nip & Moy (1988). Rowland et al. (1982) suggested that morphological changes in tail of *M. rosenbergii* were due to proteolytic activity. Following biochemical compounds generated during the degradation of proteins and which could be used as quality indices of prawns.

Trimethylamine (TMA)

Trimethylamine oxide (TMAO) is a non-protein nitrogenous compound that exists in fish and shellfishes. The highest level of TMAO was found in elasmobranches and lowest in freshwater fishes (Harada, 1975). Yamada (1967) studied and reported TMAO content in prawns, especially under the genus *Penaeus*. Finne (1992) recorded that TMAO content is around 5% of the total non-protein nitrogen in crustaceans. Yamagata & Low (1995) found 18-84 mg 100 g^{-1} of TMAO content in *P. indicus*. TMAO content in seafood gets converted into dimethylamine (DMA), formaldehyde (FA), and TMA by the action of bacteria or endogenous enzymes (Regenstein et al., 1982). An increase of TMA-N level in seafood is a prime characteristic of spoilage; hence, it has been using as an objective index of quality (Chang et al., 1976). Harada (1975) studied the enzymatic formation of DMA and formaldehyde out of TMAO in seafood. According to Hebard et al. (1982), endogenous and exogenous enzyme-producing bacteria are responsible for the production of TMA from TMAO. Laycock & Regier (1971) reported a linear relationship between the number of *Pseudomonas putrefaciens* and TMA production. However, Hebard et al. (1982) suggested that *Enterobacteriace* have the capability of reducing TMAO to TMA. Fatima et al. (1988) found a perfect correlation on the pattern of changes of TMA and bacterial load in *P. merguiensis* stored in ice. The authors also reported that the initial level of TMA, 0.01 mg 100 g^{-1} increased to 3.75 mg 100 g^{-1} on the 20th day of storage. Basavakumar et al. (1998) also observed an increasing trend of TMA-N content in tiger prawn (*P. monodon*) during chilled storage. The occurrence and significance of TMAO and its derivatives in fish and shellfish were reviewed by Hebard et al. (1982).

Total volatile base nitrogen (TVB-N)

Trimethylamine and non-protein nitrogen in prawns degraded into TVB-N both microbiologically and enzymatically during chilled storage. Cobb & Vanderzant (1971) suggested that the level production of TVB-N is dependent on the type and load of bacteria in the seafood. Basavakumar et al. (1998) reported an increase in the level of TVB-N of tiger prawn during ice storage. For prawn, it has been found that the ratio of TVB-N to free amino acid nitrogen correlates better with sensory quality than TVB-N alone (Cobb et al., 1973). The authors also reported a higher correlation between the total volatile nitrogen/amino nitrogen ratio (TVB-N/AAN) and the quality of the prawn. Montgomery et al. (1970) reported that TVB-N is a useful indicator for acceptability studies of prawns. Smaldone et al. (2011) discussed the effectiveness of TVB-N for the measurement of the freshness of chilled-stored prawns. Authors also suggested the limit of acceptability of TVB-N content in prawns were 30 mg 100 g^{-1}. However, TVB-N along with TMA has been used to assess the spoilage of prawns. Siddiqui et al. (2011) suggested that both TVB-N and TMA contents might be used as an indicator for spoilage of brackish water tiger prawn kept at ambient temperature. Contrary to the above statement, Iyengar et al. (1960) asserted that TVB-N and TMA content of prawn were not good indicators for assessing the quality because it leaches out with the effect of melted ice. Karthikeyan et al. (1999) reported a reduction of TVB-N content in prawns during ice storage and had attributed it to the leaching action of the ice melt water; hence, TVB-N was not recommended as a spoilage index for prawn. However, this leaching could be prevented by proper packaging of the sample during the chilled storage.

Nucleotide degradation

After the death of prawn, ATP in the muscle undergoes breakdown to adenosine diphosphate (ADP) by the action of sarcoplasmic ATPase which

is further degraded by deaminase action, this would lead to the accumulation of inosine monophosphate (IMP) (Saito & Arai, 1958). Nakamura et al. (1985) reported the degradation of ATP and its related compounds in *P. japonicus* during chilled storage. An increase of hypoxanthine (1.68 to 3.67 mg g^{-1}) in black tiger prawn stored at 22°C was observed by Lou (1998). Mendes et al. (2001) found that adenosine monophosphate (AMP) was the predominant nucleotide (9.3-11.8 m mol g^{-1}) in Norway lobster and red prawn immediately after catching. This accumulation of AMP was due to the action of AMP deaminase (Yokoyama et al., 1992). Breakdown products of nucleotide have been used to determine the level of spoilage in crustaceans (Mendes et al., 2002).

Nucleotides in seafood are the derivatives of purine in the catabolism of adenosine triphosphate (ATP). The highest purine content has been reported in prawns than other seafood (Lou et al., 1996). Cheuk et al. (1979) reported the potential use of adenosine deaminase and AMP deaminase as quality indices for fresh prawns stored in ice. Hashimoto (1965) reported the significance of IMP for the flavor of good quality fish. IMP is further dephosphorylated by phosphatase to inosine. Inosine is a tasteless compound which further degrades into ribose and hypoxanthine by the action of nucleoside hydrolase enzyme. A similar pathway of nucleotide degradation in *P. aztecus* and *P. monodon* has been reported by Flick & Lovell (1972). Adenosine deamination pathway led to the accumulation of inosine in some prawns during chilled storage (Cheuk et al., 1979).

The degradation pattern of ATP in marine molluscs and crustaceans differs from that of fish. Sakaguchi et al. (1989) reported the major pathways of nucleotide degradation of marine molluscs and crustaceans. Arai (1966) investigated the nucleotide degradation pathway and catalyzing enzymes in prawns and the author proposed two major pathways for nucleotide degradation. However, different pathways of nucleotide degradation in molluscs and crustaceans will not affect the measurement of K-value (Lakshmanan & Gopakumar, 1999). K-value, indicating the ratio between the sum of inosine and hypoxanthine to the sum of all other ATP breakdown products. According to Ehira (1976) the rejection level of K-value in seafood is 60% (Ehira, 1976). The rate of nucleotide degradation differs from species, mode of harvesting, handling, storage conditions, etc (Obatake et al., 1988).

Indole

Indole is a metabolite released from the degradation of amino acid tryptophan by the action of bacterial enzyme tryptophanase. Bacteria responsible for the production of indole from prawns are *Proteus morganii* and *Escherichia coli* (Chambers & Staruszkiewich, 1981). According to Matches (1982), *P. morganii* is a rapid indole producing organism in prawn stored a temperature range of 11.1°C to 22.2°C. Indole is used as a freshness indicator for raw prawn, especially very small prawns that are difficult for organoleptic assessment (Ponder, 1978). It is also used as a better-quality indicator than the sensory assessment of processed prawns (Chambers & Staruszkiewich, 1981). Salwin (1964) has demonstrated a good correlation between indole and sensory evaluation of fresh prawns. The level of indole indicates the rate of decomposition of prawn; whereas, decomposed prawn might not be contain indole. The presence of indole in prawn reveals the poor sensory quality and its amount is an index of the extent of putrefaction. The amount of indole produced in prawns was proportional to the extent of decomposition (Ponder, 1978), bacterial flora, temperature, handling, and storage (Chambers & Staruszkiewicz, 1981). Indole content in fresh prawn would be 1 μg 100 g^{-1} or less (Chambers & Staruszkiewicz, 1981). As per USFDA (United States Food and Drug Administration), fresh prawns should contain an indole level less than 25 μg 100 g^{-1} (Finne, 1992).

Fonseka & Ranjini (1994) reported a sharp increase of indole in tiger prawns stored at ambient temperature. According to Botta (1995) the formation of indole was mainly due to the effect of storage temperature than time. The maximum allowable indole content in canned and pre- cooked frozen shrimps is 25 mg 100 g^{-1} (Skura, 1986). Chang et al. (1983) found that an indole level more than 25 μg 100 g^{-1} in highly decomposed prawns at 12°C than at 22°C storage. These findings clearly indicated that temperature has a great role to accelerate the production of indole in prawns during storage. Shamshad et al. (1990) observed that the level of indole increased in *P. merguensis* with respect to storage temperature and time. Thomas et al. (1995) reported an indole level of 25 μg 100 g^{-1} in prawns kept at ambient temperature for more than 12 h. The authors also pointed out that even at low level of indole in prawns could not be considered as a good quality.

Oxidation of lipid

Oxidation starts in fish and shellfish immediately after capture (Harris & Tall, 1989). Changes in marine lipid is mainly due to the action of lipolysis (hydrolysis of lipids) and oxidation. Pro-oxidants, substrates such as amino acids, heme compounds, organic acids and pigments could accelerate the oxidation process. Copper (Cu^{2+}) is one of the most important metal ions involved in lipid oxidation (Khayat & Schwall, 1983). Lipids are hydrolyzed by lipases, phospholipases and free fatty acid catalyze, etc. Oxidation of lipid affects the quality of seafood. Fatty fishes contains a high level of unsaturated fatty acids which undergo oxidative rancidity and produce peroxides and hydroperoxides which cause changes in flavor, colour and texture of seafood (Hultin et al., 1982). Several factors such as degree of unsaturation, temperature, light, water activity, and pH cause lipid oxidation in seafood. Non-enzymatic reaction between auto-oxidative lipids, proteins and sugars (Maillard reaction) cause discolouration in fish muscle (El-Zeany et al., 1975). Products from auto-oxidative lipid reaction with protein are due to ionic condensation of primary amino groups of protein with conjugated unsaturated aldehydes of similarly active lipid oxidation products resulting from cleavage of unsaturated hydroperoxides (Ashie et al., 1996). Auto-oxidation of major fatty acids follows the order C18:0<C18:1<C18:2<C18:3 (Shahidi, 1994). The formation of fatty peroxides and hydroperoxides during the oxidation of fat could be determined by an iodimetric method which is the most widely accepted chemical test for rancidity. An increase of PUFAs in phospholipid and no change of PUFAs in total lipid had been reported in ice stored freshwater prawn by Chanmugam et al. (1983). Bottino et al. (1979) reported that there was no change in fatty acids in brown prawns after 18 days of ice storage. Significant changes of fatty acid in rose-shrimp croquettes during the production process have been reported by Cankirilig & Berik (2017). It is believed that lipid oxidation did not occur if bacterial spoilage has not been initiated. The products of phospholipid hydrolysis and a number of non-protein nitrogen compounds retarded autoxidation (Sikorski, 1990). The thiobarbituric acid content is used to measure the oxidation of marine lipids. The acceptable limit of TBA values is 1-2 mg malonaldehyde kg^{-1} (Goulas & Kontominas, 2007). Usually, free fatty acids content in marine lipids leads to hydrolytic rancidity. Hence, the amount of free fatty acids available in marine oils determines their quality. Fuller et al. (2020) suggested the acceptable limit of free fatty acids in commercially available krill oils is up to 2 wt%. Increasing of thiobarbituric acid and free fatty acid in spanish mackerel (*Scomberomorus commersoni*) and white cheek shark (*Carcharhinus dussumieri*) during frozen storage has been reported by Nazemroaya et al. (2009).

Melanosis

Black spot formation is a common phenomenon in prawns and other crustaceans; it is mainly due to the action of polyphenoloxidase enzyme which converts amino acid tyrosine to melanin; hence, it is also known as melanosis. The other nomenclatures of the enzyme responsible for melanosis are phenoloxidase, phenolase, monophenol, diphenol oxidase and tyrosinase. Black spot formation in prawns has been first reported by Fieger et al. (1950). Black spots cannot be considered as spoilage, but it affects the appearance of crustaceans ultimately its market value. After a few hours of the harvest of crustaceans, the black spot occurs chiefly under the carapace of the cephalothorax due to the interaction with atmospheric oxygen and the lack of a proper cold chain system (Gokoglu & Yerlikaya, 2008). Polyphenol oxidase catalyzes two basic reactions using the substrates phenols and O_2 which is hydroxylation at the ortho-position adjacent to an existing hydroxyl group of the phenyl substrate (monophenol oxidase activity) and oxidation of the diphenol to o-benzoquinones (diphenol oxidase activity) which further reacts non-enzymatically in the presence of O_2 to form melanin.

In Indian white prawns, phenoloxidase is chiefly distributed in cephalothorax, shell and tail (Antony & Nair, 1969; Savagaon & Sreenivasan, 1978). Antony & Nair (1969) studied the distribution of phenolase in certain species of *Penaeid* prawns and they found that among the species *M. affinis, M. monoceros* and *F. indicus* showed comparatively higher phenoloxidase activity than *Parapenaeopsis stylifera* and *M. dobsoni.* Bailey et al. (1960) observed that the vital enzyme responsible for melanosis is released from the blood leucocytes. The authors also reported that phenoloxidase activity in prawns (*P. setiferus, P. aztecus*) increases at 40°C to 60°C and on exposure to air temperature. Copper and other metallic ions accelerate the PPO activity (Fieger et

al., 1961). Martinez-Alvarez et al. (2008) studied the diphenoloxidase activity in the presence of haemocyanin in deepwater pink prawns (*Parapenaeus longirostris*) and observed that haemocyanin acquired the ability to oxidize diphenols. Zamorano et al. (2009) reported the characterization and distribution of PPO in *P. longirostris* (deep water pink prawn). Polyphenol oxidase isoenzymes have been first isolated from mushrooms. Simpson et al. (1987) purified phenoloxidase from the heads of *P. setiferous* by affinity chromatography and found that the enzyme was stimulated by copper and was stable at pH 8 and 50°C, but unstable at acidic pH. Opoku et al. (1992) extracted PPO from lobster (*Homarus americanus*). Sodium bisulfite was first introduced in the 1950s for inhibiting the formation of black spots (Fieger & Novak, 1961). Usage of sulfite was approved by USFDA in 1956 (Otwell & Marshall, 1986). The residual phenoloxidase activity in sulphite treated frozen *M. monoceros* during storage was evaluated by Chakrabarti (1998). This bisulfite could be removed from prawn by rinsing with hypochlorite (Weigartner, 1975).

Changes in hardness

The texture is defined as the sensory and functional manifestation of the structural and mechanical properties of foods detected through the senses of vision, hearing, touch and kinaesthetic (Szczesniak, 2002). Texture properties of raw fish and prawns are mainly contributed by connective tissue and muscle fibers (Dunajski, 1980). A positive correlation between muscle fiber density and texture characteristics such as chewiness and firmness had been observed in seafood (Johnston et al., 2000). The texture of prawns differs due to species, biological condition, mode of catch and culinary treatments, etc. Texture profile in seafood had been reviewed by Szczesniak (2002). According to Szczesniak (1963), instrumental texture analysis was divided into three classes like fundamental, empirical and imitative tests in which texture profile analysis falls in the imitative test. Many instrumental methods have been developed for measuring the textural properties of fish and fishery products (Hyldig & Nielsen, 2001). The invention of the general food texture meter aids the food industry in texture profile analysis of various products (Szczesniaket al., 1963). The most common types of instrumental texture analysis are based on rheological principle, shear strength, puncture and compression.

Changes in colour

The colour of the crustaceans plays a significant role in determining their commercial value. Astaxanthin, a protein-pigment complex gives red-orange colour in crustaceans (Armenta-Lopez et al., 2002). According to Katayama et al. (1972) and Okada et al. (1994), astaxanthin is a predominant carotenoid pigment in Penaeids. Three forms of astaxanthin reported in black tiger prawn were free astaxanthin, astaxanthin monoester, and astaxanthin diester (Okada et al., 1994). Among these, free astaxanthin is the predominant colour pigment and the other two have no significant difference (Okada et al., 1995). According to Britton (1996), this complex was green, purple, or blue in colour in living crustaceans which turns to red colour during thermal processing. Red colouration in cooked prawns had been observed by Okada et al. (1994) and the authors also suggested that the intensity of colour formation is dependent on the level of carotenoid pigment present in the prawn. Enzymatic and non-enzymatic oxidation of carotenoid pigment present in skin, shell or exoskeleton of fish and shellfishes leads to surface discolouration. Formation of melanin provides black discolourationin seafood mainly in shell fishes. Sikorski (1990) suggested that dark brown to black discolouration in seafood was mainly due to the breakdown of melanin pigment. Colour degradation occurs due to chemical reaction than by enzymatic browning due to Maillard reaction and auto-oxidative lipid reactions. In Maillard reaction, browning is caused by the reaction between sugars and amino acids; while, oxidative lipids react with proteins.

Changes in sensory characteristics

Organoleptic assessment is the universally accepted methodology to determine the quality of raw and processed food products. Sensory assessment is sensitive and reliable which should be conducted in standardized conditions with trained personnel (Sims et al., 1992). Sensory evaluation is one of the oldest and most widespread means of evaluating acceptability and edibility which can be defined as the scientific discipline used to evoke, measure, analyze and interpret the characteristics of food as perceived by the senses of sight, smell, taste, and touch. Fish and shellfish show characteristic changes of sensory parameters like appearance, odour, taste and texture during spoilage (Shewan et al., 1953). As per USFDA (2005), good quality prawn has a

translucent appearance, fresh odour, firm texture, and sweet taste. Overall appearance was found to be good in prawn stored at chilled condition even after two days; however, slight blackening occured in gill area. Huidobro et al. (2002) studied the effect of onboard chilling with liquid ice and traditional chilling with flake ice on the quality of deepwater pink prawn (*P. longirostris*) and they found that prawn stored in flake ice got higher colour score; whereas, better firmness was reported in liquid ice stored prawn.

Changes of bacterial flora of prawn

Quality deterioration of seafood is mainly due to bacterial spoilage (Liston, 1980) and very less role is attributed to autolytic changes (Liston, 1980). Microorganisms, mainly Gram-negative bacteria play important role in the spoilage of seafood (Cann, 1977; Gram & Huss, 2000). Bacteria generate unpleasant off-odour and flavor compounds during spoilage (Liston, 1980). Shellfish are more susceptible to bacterial spoilage than fish because of their high content of NPN-compounds. Newly caught healthy fish are considered to be sterile (Shewan, 1961). After death, autolytic enzymes cause changes in endogenous biochemical compounds in the meat which conditions the substrate for bacterial action (Ababouch et al., 1996). Bacteria from different parts of the body pave the way to prawn muscle which causes the decomposition of various low molecular weight constituents and produces off-odour and off-flavor compounds like H_2S, NH_3 and volatile metabolites (Gennari et al., 1999). Enzymes produced by bacteria breakdown are nitrogenous compounds, nucleotides and alter marine lipids to produce compounds having rancid flavors in fish (Liston, 1965). Chai et al. (1968) and Herbert et al. (1975) investigated the substrates utilized by different bacterial species during spoilage, the rate of degradation among different spoilage groups, and the type of end products responsible for putrid and offensive odour. Population and type of bacteria in shellfish could be due to the contamination during catching, handling, and processing. Cann (1971) and Newell (1973) reported that mesophilic bacteria are more in tropical crustaceans than in cold water.

Total plate count (TPC) is considered as an index for the shelf life of the products (Bonnell, 1994). So, it determines the level of deterioration of fish and shellfishes (Tanikawa et al., 1955) and it is also used to assess the level of sanitation practices in the processing plant. Storage temperature plays a great role in the changes of microflora in prawns. An increasing trend of TPC in shrimp (*Penaeus semisulcatus*) and White Shrimp (*Litopenaeus vannamei*) during chilled storage has been reported by Prabhu et al. (2016) and Jeyakumari et al. (2019). Lakshmanan et al. (2002) found that the total mesophilic count of *P. semisulcatus* was 10^5 $CFUg^{-1}$.

Spoilage of chill-stored prawn or fish meat was mainly due to the action of psychrotrophic bacteria (Van-Spreekens & Toepoel, 1981). Generation period of *Pseudomonas* spp. at 0 to 5 °C was very less and it has the capability to utilize various NPN components of muscle fluid. *Pseudomonas* spp. easily dominates over other mesophilic bacteria and causes spoilage of seafood. Significant reduction of bacterial load in prawns treated with potassium sorbate and sodium metabisulphite during chilled storage has been reported by Jeyakumari et al. (2019). Reduction of bacterial flora in Indian white prawns after the treatment of high pressure processing has been reported by (Ginson et al. 2016).

Reports are available on the survival and growth of pathogenic bacteria in low-temperature storage (Hall & Slade, 1980). Thampuran & Iyer (1990) reported that the count of H_2S producing bacteria of the prawn was in the range of 1.41×10^3 CFU g^{-1} to 8.4×10^5 CFU g^{-1} and it comprises 0.4 to 10.3% of the total count. Out of the H_2S producer bacteria, the count of *S. putrefaciens* ranged from 1.1×10^2 CFU g^{-1} to 8.9×10^2 CFU g^{-1} which comprise 0.5-3.28% of the total flora and 31.6 to 42% of the total H_2S producer bacteria. Thampuran & Iyer (1990) reported that *Pseudomonas* species is an active spoiler and found only in a few numbers in shellfish. The authors also reported that *Aeromonas* were the major spoiler followed by *Vibrio, Alteromonas* and *Pseudomonas*; however, it differs in the tropical fish on the basis of volatile sulfide production.

Conclusion

This comprehensive review asserts the role of quality indices such as pH, trimethylamine, total volatile base nitrogen, K-value, indole, thiobarbituric acid, free fatty acids, hardness, colour, organoleptic properties and bacterial flora for the determination of the level of spoilage in seafood, especially in prawns. Spoilage pattern including postmortem quality deterioration and its associated products of prawns are also discussed. Physicochemical and

microbiological quality attributes of prawn varies with respect to species, habitat, mode of harvesting, handling and storage conditions. The combined action of enzymes and microbes are responsible for quality deterioration in prawns. Novel preservation techniques that are capable of inactivate these parameters and extend the shelf life of prawn without compromising of its natural attributes has been greater significance.

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