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Review

Seafood spoilage microbiota and associated volatile organic compounds at different storage temperatures and packaging conditions

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ABSTRACT

Seafood comprising of both vertebrate and invertebrate aquatic organisms are nutritious, rich in omega-3 fatty acids, essential vitamins, proteins, minerals and form part of healthy diet. However, despite the health and nutritional benefits, seafood is highly perishable. Spoilage of seafood could be as a result of microbial activity, autolysis or chemical oxidation. Microbial activity constitutes more spoilage than others. Spoilage bacteria are commonly Gram negative and produce off odours and flavours in seafood as a result of their metabolic activities. Storage temperature, handling and packaging conditions affect microbial growth and thus the shelf-life of seafood. Due to the complexity of the microbial communities in seafood, culture dependent methods of detection may not be useful, hence the need for culture independent methods are necessary to understand the diversity of microbiota and spoilage process. Similarly, the volatile organic compounds released by spoilage bacteria are not fully understood in some seafood. This review therefore highlights current knowledge and understanding of seafood spoilage microbiota, volatile organic compounds, effects of storage temperature and packaging conditions on quality of seafood.

1. Introduction

Seafood such as bivalve molluscs, finfish and crustaceans have been described as one of the fastest growing sources of food in the world and serve as major source of income to many developing and developed countries (Sudha et al., 2012). Bivalve molluscs such as mussel, oyster, clams and scallop are marine organisms characterized by sedentary nature, filter feeding, contact with sediment, low metabolism, high tolerance to chemical exposure and wide distribution in marine environment (Illanchezian et al., 2010; Wery et al., 2003; Yazdani et al., 2006) and feed on phytoplankton (Castilho et al., 2009). They filter 4–20 l of sea water per hour (Aberoum and Jooyandeh, 2010; Krzyminska et al., 2012) thereby concentrating bacteria such as marine bacteria such as *Shewanella* species, *Aeromonas* species, and *Vibrio* species (Hassan et al., 2011). Harvested mussels need to be properly processed to reduce microbial load of indigenous bacteria. The initial microbial load of indigenous bacteria that are present in mussels and other fresh cultured shellfish are usually found at low levels (Feldhusen, 2000). However, improper pre and post-harvest handling conditions can enhance exacerbation of indigenous bacteria that could cause spoilage (Huss et al., 2000). In addition, water activity, packaging method and storage temperature could increase rate of spoilage (Marıa Elisa Cayre et al., 2003).

Over the years, few seafood research scientists have attempted to review seafood spoilage (Gram, 1992; Gram and Huss, 1996). However, due to advancement in seafood microbiology with the advent of molecular methods such as next generation sequencing and increase in spoilage microbiota, there is need to review recent development in seafood spoilage research with a view to identify knowledge gaps and recommendation of future research areas.

2. Description of dominant seafood spoilage bacteria

Seafood spoilage microbiota have been studied in different seafood as summarized in Table 1. These studies involved shrimps (Broekaert et al., 2013b), peeled brown shrimps (Calliauw et al., 2016), cooked whole tropical shrimp (Macé et al., 2014), cooked and peeled tropical shrimps (Jaffrès et al., 2011), peeled and unpeeled brown shrimp (Broekaert et al., 2013a); fish (Mikš-Krajnik et al., 2016), raw salmon (*Salmo salar*) (Mace et al., 2012), raw salmon fillets (Mace et al., 2013); vacuum-packed (VP) cold-smoked salmon (Olofsson et al., 2007); modified-atmosphere-packed (MAP) cold-smoked salmon (Paludan-Muller et al., 1998); cold-smoked salmon (Leroi et al., 1998), cold-smoked salmon (Joffraud et al., 2001), vacuum-packed cold-smoked

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Table 1
Techniques in monitoring spoilage microbiota in seafood.

Technique	Seafood	Bacteria	References
Culture dependent			
PCA, MA, IA, MRS STAA, VRBGA, TSA, LH	Peeled cooked brown shrimp, oysters, fish, Peeled cooked tropical shrimps, cold smoked salmon, fish fillet, raw salmon, catfish, sea bass, sea bream	*Arthrobacter bergerei*, *Shewanella putrefaciens*, *Brochothrix thermosphacta*, *Vagococcus salmoninarum*, *Shewanella*, *Pseudomonas*, *Psychrobacter*, *Carnobacterium*, *Serratia liquefaciens*, *Buttiauxella noackia*, *Escherichia coli*, *Enterococcus* spp., *S. phymutica*, *Enterobacter agglomeran*, *Hafnia alvei*, *Flavobacterium damsel*, *Acinetobacter baumanii*, *Aeromonas salmonicida*	Calliauw et al. (2016) Cruz-Romero et al. (2008); García et al. (2015); Jaffres et al. (2009); Jørgensen et al. (2000); Koutsoumanis and Nychas (1999), Leroi et al. (2015); Leroi et al. (1998); Madigan et al. (2014); Miks-Krajnik et al. (2016); Milne and Powell (2014); Noseda et al. (2012b); Olofsson et al. (2007); Parlapani et al. (2015a); Parlapani et al., 2014); (Parlapani et al., 2013b)
Culture independent			
PCR-DGGE	Raw lobster tails, whole lobster,	*Psychrobacter* spp., *Pseudoalteromonas* spp., *Pseudomonas* spp., *Luteimonas* spp., *Aliivibrio* spp., *Psychrobacter*, *Planocuccus*, *Exiguobacterium*, *Carnobacterium*, *Pseudomonas*, *Chryseobacterium*,	Bekaert et al. (2015)
	Fresh shrimp	*Staphylococcus*, *Carnobacterium*, *Shewanella* *Psychrobacter*, *Carnobacterium* spp., *Psychrobacter*, *Brochothrix*, *Shewanella*.	(Broekaert et al., 2013a; Broekaert et al., 2013b) Calliauw et al. (2016)
	Peeled cooked brown shrimp	*Pseudomonas* spp., *Photobacterium* spp., *S. putrefaciens and Pseudomonas* spp.,	Hovda et al. (2007b);
	Farmed Atlantic cod	*P. phosphoreum*, *Pseudomonas* spp., *S. baltica*, *S. putrefaciens*	Hovda et al. (2007a)
Next-generation sequencing (NGS), Pyrosequencing	Peeled cooked brown shrimp half shell Pacific oysters	*Carnobacterium*, *Psychrobacter*, *Shewanella*, *Aeromonas*, *Chryseobacterium*, *Flavobacterium*, *Prosthecomicrobium*, *Arcobacter*, *Pseudoalteromona Mycoplasma*, *Vibrio*, *Helicobacter*, *Terasakiella*	Calliauw et al. (2016) Madigan et al. (2014); Olofsson et al. (2007) Milne and Powell (2014)
ssPCR	Refrigerated seafood products, shrimps, cold smoked salmon raw salmon, sea beam	*Streptococcus parauberis*, *Vagococcus penaei*, *S. proteamaculans*, *P. phosphoreum*, *B. thermosphacta*, *Yersinia intermedia*, *H. alvei*, *C. maltaromaticum*, *C. divergens*, *Lactococcus piscium*, *S. quinivorans*, *Acinetobacter baumanii*, *A. salmonicida*	Fernández-No et al. (2012); Jaffrès et al. (2010); Leroi et al. (2015); Parlapani et al. (2013b)
MALDI-TOF MS	Seafood products, Tropical cooked and peeled shrimps, raw salmon	*S. parauberis* *S. liquefaciens*, *B. thermosphacta*, *Enterococcus faecalis*, *C. divergens*, *C. maltaromaticum*, *L. piscium*, *P. phosphoreum*	Fernández-No et al. (2012) Jaffres et al. (2009); Mace et al. (2012)
SDS–PAGE	Vacuum-packed salmon	*C. piscicola*	Paludan-Muller et al. (1998)
AFLP	Salmon products	*P. phosphoreum*	Jérôme et al. (2016)

PCA = Plate Count Agar; MA = Marine Agar; IA = Iron Agar; LH = Long and Hammer Agar; MRS = de Mann, Rogosa, Sharpe agar; STAA = Streptomycin Thallium Acetate Agar; VRBGA = Violet Red Bile Glucose agar, TSA = Tryptone Soy Agar; PCR-TTGE = Polymerase Chain Reaction - Temporal Temperature Gel Electrophoresis; ssPCR = Species Specific Polymerase Chain Reaction, MALDI-TOF MS = Matrix-Assisted Laser Desorption/Ionization Time-of-Flight Mass Spectrometry; AFLP = Amplified fragment length polymorphism.

salmon(Jørgensen et al., 2001), MAP salmon (Milne and Powell, 2014; Powell and Tamplin, 2012); North-Atlantic cod (Hovda et al., 2007a; Hovda et al., 2007b; Reynisson et al., 2009); Mediterranean Boque (Fall et al., 2010; Koutsoumanis and Nychas, 1999), Mediterranean gilt-head sea bream (Koutsoumanis et al., 1999); sea bream fillets (Parlapani et al., 2014), European seabass(Leduc et al., 2012), sea bream (Zaragozá et al., 2013); fresh hake (García et al., 2015); crab (Chen et al., 2016), Chinese mitten crab (*Eriocheir sinensis*) (Wu et al., 2014b); haddock fillets (Olafsdottir et al., 2006); shelf-fish such as shucked blue mussels (Aru et al., 2016a, 2016b), green mussels (*Perna canaliculus*) (Tuckey et al., 2013), oysters, coockles (Fratini et al., 2012), Pacific oysters (*Crassostrea gigas*) and Sydney rock oysters (Madigan et al., 2014). Spoilage bacteria in lobster (Bekaert et al., 2015), refrigerated seafood products (Fernández-No et al., 2012), VP and MAP fillets (Noseda et al., 2012b) and other fish samples (Xujian et al., 2014), turbot (*Psetta maxima*) (Xu, Liu, et al., 2014; Xu et al., 2016) have been studied. Dominant spoilage bacteria are briefly described below.

2.1. Shewanella

The genus *Shewanella* comprises of Gram negative, motile, rod shape, glucose non-fermenters, oxidase positive, catalase positive bacteria and member of the family *Shewanellaceae* mostly found in aquatic environment (Satomi et al., 2007; Wright et al., 2016). Member of the genus such as *S. putrefaciens*, *S. baltica*, *S. proteamaculans*, also known as *S. liquefaciens*-like are psychrotolerant, capable of producing H_2S as seafood spoilage markers in low storage temperature (Zhu et al., 2015). Members of this genus have been isolated from cold smoked salmon (Joffraud et al., 2006), shrimps (Jaffrès et al., 2009), cooked shrimps (Mace et al., 2014), oysters (Richards et al., 2008) and raw ice stored fish (Vogel et al., 2005). In a recent study, both *S. baltica* and *S. putrefaciens* were predominant spoilage species at end of shelf-life of refrigerated yellow croaker (Zhu et al., 2016). They can also cause spoilage of seafood stored under vacuum packaging (VP) or modified atmosphere packaging (MAP) conditions (Gram and Melchiorsen, 1996).

Characteristically, seafood spoilage members of the genus *Shewanella* produce trimethylamine and off flavour dimethylamine compounds (Satomi et al., 2007). They are capable of utilizing lactate as carbon source during growth in seafood samples (Koutsoumanis and Nychas, 1999). The ability of this genus to grow in laboratory agar such as Iron agar with characteristic black colouration makes it easy to isolate and identify. Among the species of this genus, *S. putrefaciens* is most studied due to its presence in other food like meat and chicken (Vogel et al., 2005). Diversity of *Shewanella* in seafood has been studied using molecular methods like SDS-PAGE (Tryfinopoulou et al., 2007).

2.2. Pseudomonas

Members of the genus *Pseudomonas* are psychrotrophic, aerobic,