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Viewpoint

A paradigm shift in safe seafood production: From contaminant detection to fish monitoring – Application of biological warning systems to aquaculture

Harkaitz Eguiraun[a,*], Urtzi Izagirre[a] and Iciar Martinez[a,b,c]

[a]Research Center for Experimental Marine Biology and Biotechnology, University of the Basque Country (UPV/EHU), Areatza s/n, E-48620 Plentzia, Spain (Tel.: +34 94 601 8448; e-mail: Harkaitz.eguiraun@ehu.es)

[b]IKERBASQUE, Basque Foundation for Science, Maria Diaz de Haro 3, 6th Floor, E-48013 Bilbao, Spain

[c]Norwegian College of Fishery Science, Faculty of Biosciences, Fisheries and Economics, University of Tromsø, N-9019 Tromsø, Norway

The annual global increase in the production, particularly from aquaculture, and consumption of seafood is expected to continue in the future. One of the main worldwide concerns from the point of view of seafood safety is the increasing number of novel and unexpected chemical substances that contaminate the aquatic environment. Currently, there is a lack of cost effective, user-friendly methods to detect many of these contaminants and there is no method to detect unknown contaminants. A paradigm shift is necessary in the seafood production industry from contaminant detection only, to monitoring the effects of the contaminants as well. This can be achieved by introducing a systems approach and using a biological warning system (BWS) specifically adapted to fish farming. In this manner, it would be possible to develop affordable, on-line identification of production units displaying atypical responses or behaviour – and therefore potentially contaminated – regardless of whether the contaminant is an identified or an unknown substance. Once developed, the BWS should be implemented within the HACCP plans and the results accompany the traceability documentation of the products.

Chemical contaminants in seafood production

According to FAO (2014) global fish production has grown steadily during the last 50 years, with seafood supply increasing at an average annual rate of 3.2%. Most of the growth in later years has been due to the dramatic increase in aquaculture production in China. The top in aquaculture production took place in 2012, with 90.4 million tonnes of aquatic seafood (66.6 million tonnes of fish and 23.8 of aquatic alga) for an estimated total value of US$144.4 billion. The estimates for 2013 are 70.5 and 26.1 million tonnes of fish and aquatic alga respectively. World food fish aquaculture production has increased at an average annual rate of 6.2% from 2000 to 2012, mostly in Africa, Latin America, the Caribbean and Asia, while in Europe and in the USA it is decreasing (FAO, 2014).

On the 28th of January 2002 the European Parliament and the Council adopted Regulation (EC)178/2002 laying down the General Principles and requirements of Food Law. The Regulation establishes the basic principle that the primary responsibility for ensuring compliance with food law, and in particular the safety of the food, rests with the food business. The same principle applies to feed production. The food business operators must

* Corresponding author.

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therefore take all the necessary measures to ensure that the food they produce is fit for human consumption. The safety of the produced seafood remains therefore a highly relevant central issue, particularly in view of the increase in global trade, the different demands and expectations in different world regions and the number and variety of unexpected contaminants that have been recently discovered. Thus, to ensure the safe production of seafood, the implementation of the Hazard Analysis and Critical Control Point (HACCP) system and Risk Analysis concepts have become obligatory. FAO has published some very useful technical reports on the subject (Huss, 1994; Huss, Ababouch, & Gram, 2004). Seafood can become contaminated at any step during its production and processing from the egg to the table (Huss *et al*., 2004). The main routes by which contaminants are introduced during fish production are the feed, the water and the veterinary treatments (Dahle *et al*., 2010). The type of contaminants one would expect to find vary according to factors such as whether the fish is farmed or wild, placed high or low in the trophic chain, its feed or prey, age and geographical origin, water temperature, proximity to populated areas, terrestrial farms or industrial activities. Additionally, some contaminants, like methyl-mercury, until recently considered to be of concern only in large, long-lived marine organisms placed high in the trophic chain (such as whales, swordfish and tunafish), have been found to be ubiquitous in the aquatic environment (Chen *et al*., 2012) and present in detectable amounts in a large variety of species and seafood products of wild and farmed fish species from different geographic origins including the Atlantic (Vieira, Morais, Ramos, Delerue-Matos, & Oliveira, 2011), the Arctic, the Antarctic, Asia and the UK (Knowles, Farrington, & Kestin, 2003), South China, Spain, USA and Australia (Qiu, Lin, Liu, & Zeng, 2011).

Challenges in classical safety monitoring

Monitoring and detection of chemical contaminants in the seafood chain remain some of the most challenging activities for the following reasons: i) the price of their analyses is high and only highly specialized laboratories perform them; ii) many of them consist not of one, but of "families" of compounds (i.e., a compound and their metabolites or congeners) with different degrees of toxicity; iii) the nature of chemical contaminants is very diverse: they may be organic or inorganic, natural or synthetic, the result of industrial activities (cosmetic and oil industries, mining activities), agricultural activities (pesticides, fertilizers), the aquaculture industry itself (veterinary treatments, rests of non eaten food pellets in decomposition, faeces) and of the habits of the human populations close to the production or harvesting area (use of medicines, hormones, recreational drugs); iv) only expected contaminants are tested (maliciously introduced, unexpected, novel and emergent contaminants commonly remain undetected until the wildlife, the farmed species or the consumers are severely affected) and v) novel contaminants are being detected in environmental, sewage and drinking waters at an increasing rate (Dahle *et al*., 2010; Roose *et al*., 2011). Examples of malicious and of emergent contaminants are given below.

Malicious contaminants

Perhaps the most famous case of an unexpected maliciously introduced chemical contaminant was the use of melamine in feeds and foods (Sharma & Paradakar, 2010). The products had been manufactured in China, killed thousands of pets and the case was best documented in the USA (Dobson *et al*., 2008). It caused the deaths of at least six babies and the illness of about 300,000 who consumed adulterated infant formula milk in China. The reason why melamine was added to foods and feeds was to increase the profit by falsifying the protein content of products. The amount of protein in foods and feeds is indirectly estimated by multiplying by a factor of 6.25 (for meat and feeds) the total nitrogen of the sample estimated by the Kjeldahl method (Tacon, 1987). When a large amount of the nitrogen in the sample originates from nitrogen-rich contaminants such as urea, melamine and their derivatives, the protein amount is wrongly overestimated. Fraudulent actors can then sell their products with much lower protein content and increase their profits. It seems that after the addition of urea was made illegal the addition of melamine became more popular. It was a practice that had apparently been taking place for years, but it was not suspected until deaths started to take place. The main reason for the deaths was that coingestion of melamine and its derivatives cyanuric acid and melamine cyanurate form insoluble crystals that precipitate in kidney tubules physically blocking them and inducing renal failure and death (Brown *et al*., 2007).

The scandal had global proportions: it originated in China but the deaths of pets were first detected in the USA and then contaminated products were found all over the world (including Australia, Canada, India, Hong Kong, Malaysia, New Zealand, Japan, Switzerland, Taiwan, The Netherlands and USA) and in products from multinational reputed brands such as Cadbury, Heinz, Nestlé, Lipton and Tesco. Food products such as chocolate, cookies, coffee, eggs, pork, marketed fish fillet, chicken and pet food, swine, poultry and fish feeds were contaminated, suggesting that adulteration of feeds had been a common practice for some years prior to its detection (Brown *et al*., 2007, Dobson *et al*., 2008, Sharma & Paradakar, 2010). As a consequence of this scandal, several analytical methods have been developed and become obligatory to ensure that foods and feeds are free of this contaminant (Liu, Todd, Zhang, Shi, & Liu, 2012).

In cases such as this, where the contaminant is unexpected, introduced purposely and fraudulently and completely unrelated to any of the materials expected to come in contact with the product, its identification is extremely unlikely: in one of the earliest studies trying to

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