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Review

Synthetic Chemical Application in Aquaculture Production

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Abstract

The expansion of commercial aquaculture in meeting the demand placed upon its products by the increasing world population has necessitated the intensification in its production activities. Predominantly, the use of synthetic chemicals (compounds) in the prevention and treatment of disease outbreaks owing to pathogens, and in other operations to boost production. This in no doubt has compromised the quality of aquaculture products and the stability of the environment; generating various public health concerns as well as significant economic losses. Consequently, the aquaculture industry is finding it more challenging to guarantee its sustainable development. This study becomes necessary as there are efforts towards developing and integrating an operational strategy with more adaptable production approaches which addresses the various health and product quality issues, and environmental impacts caused by aquaculture operations. This study reviews the primary environmental and human health issues associated with the use of synthetic chemicals in aquaculture to provide hands-on information on synthetic chemical application in aquaculture production and create relevant awareness on the need for better alternatives.

Key words: Antibiotics; Aquaculture; Bio-compounds; Fish; Public health; Synthetic chemical

Introduction

It has been estimated that fisheries and aquaculture supplied the world with about 110 million metric tons of food fish per year [1], 47% of which is contributed by aquaculture production. However, with the current increasing intensification of production, commercial aquaculture is still unable to meet the increasing global demand for its products. Yet, production continues to witness various constraints including problem of better culturable species (seed) and health related issues. This, which in a bid to address, has caused fish farmers to frequently resolve to the use of synthetic chemicals in various stages of aquaculture production with the aim of alleviating constraints and boost production [2, 3]. Various synthetic chemicals **(Table 1)** including hormones, antibiotics, vitamins and several other chemicals have been used in aquaculture practices for various purposes (remedies) including disinfectants (e.g., hydrogen peroxide and malachite green), antimicrobials (e.g., sulfonamides and tetracyclines), anthelmintic agents (e.g., pyrethroid insecticides and avermectins), immunostimulant (e.g., b-1,3-glucans and peptidoglycans), sex steroids (e.g., 17 α-Methytestoterone), herbicides (e.g., 2,4-dichlorophenoxyacetic acid) and fertilizer (e,g., ammonium phosphate and urea), Anaesthetics (e.g., tricainemethanesulphonate and quinaldine) [4, 5, 6, 7, 8].

The use of synthetic chemicals in aquaculture has well-known positive effects (as par their specific purposes). However, their recommendation for use in commercial aquaculture production is being faced with restrictions due to their public health hazards. Several side effects that affect both the cultured animal and the environment – which include the development and spread of antimicrobial-resistant pathogenic agents and resistance genes, and the presence of chemical residues in aquaculture products and the environment [9,10]. Though, there are only a few studies that analyze the side effects of synthetic chemicals use on cultured organisms themselves; there is evidence that some can induce various defects including nephrotoxicity as well as inhibiting larval growth and defense mechanisms [10,11]. Also, the indiscriminate use of antibiotics in prophylactic treatment has led to the development of the resistant strains and the need to switch over to other antibiotics [12,13]. Many of the synthetic chemicals also generate sensitization reaction and other undesirable side effects [14,15].

The use of synthetic compounds in aquaculture has been proven for their efficacies. Nonetheless, they pose a great deal of public health issues which mostly arise from their indiscriminate uses [15]. Though the use of synthetic compounds in aquaculture depends on the local regulations, which vary widely from country to country [16]. However, a large proportion of global aquaculture production takes place in places (countries) with permissive regulations [10] -the rural areas, where little or no attention is placed on the regulated use of these chemicals [16].

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Table 1. Some synthetic chemicals used in aquaculture

Chemical	Use	Dosage	Comments	Application
Acriflavin	Against bacteria, fungi, protozoa	5mg/l for 5 days	Damages plants	Water
Antibiotics	Against bacteria	Varies according to drug	Resistance is common to certain antibiotics	Water, feed, injection
Benzalkonium chloride	Against bacteria	2mg/l (active ingredient) for 60minutes for 3 days	More toxic at high temperatures and soft water. Removes body mucus	Water
Copper sulphate	To control algae, protozoa, flukes, fungi	Harden water to above 170mg/l then add 0.1 copper sulphate / l for 10 – 20 minutes	Effective dosage close to lethal dose, not recommended. More toxic in soft water	Water
Formalin	Against protozoa, flukes	0.125 – 0.250 mg/l for 60 minutes. 0.015 – 0.025 mg/l for several days	Cancer forming, highly irritating, toxic, not recommended. Do not use if fish have open wound. Do not use with potassium permaganate	Water
Hydrogen peroxide (H_2O_2)	Against protozoa, Fungi on eggs	0.10ml of 3% H_2O_2 /l for 10 – 15 minutes (every other day)	May not be tolerated by all species	Water
Malachite green	Against fungus, protozoa, bacteria, trichodina	0.10mg/l for 12 days, repeat with have dosage each on days 3, 6 and 9	Cancer forming. Highly toxic to certain species. Only use zinc-free form. Aerate during treatment.	Water
MS-222 (tricaine)	Anaesthetic	10mg/l during transport		Water
Potassium permanganate ($KMnO_4$)	To control bacteria, protozoa, trichodina, flukes, lice, fungi,	2mg/l on day 1, 1mg/l each on day 2, 3, 4, and 5 OR 5mg/l as a single treatment	$KMnO_4$ should not be used in sea water	Water
Praziquante	Against Flukes	2mg/l for several days		water

Source: Aquaculture Innovations (2010)

Synthetic Chemicals in Aquaculture and Public Health

The primary environmental and human health issues associated with synthetic chemical use in aquaculture include:

Persistence in Aquatic Environments

Some aquaculture chemicals degrade rapidly in aquatic systems (e.g., formalin) while some others persist for longer periods, retaining their biocidal properties (especially the metal-based compounds such as the organotin molluscicides and copper-based algaecides) [7]. In general, residues in water are less likely to be of long-term concern because of photo-degradation and dilution to below biologically significant concentrations. Residues incorporated into sediments tend to persist for longer periods, particularly if the sediments are anaerobic as may be expected under fish cages [12]. Very little is known about the environmental fate of many aquaculture drugs with available data being derived largely from temperate latitudes [17]. Persistence in tropical environments is poorly studied and may be different due to soil characteristics or temperature-dependent microbial activity. However, it is clear that the persistence of chemical residues is highly dependent on the matrix and ambient environmental conditions [17]. Thus, proper selection of farm sites can substantially reduce the environmental impacts of aquaculture chemicals [7]. However, about 70-80% of antibiotics given to fish are excreted into water and spread rapidly through water systems [4].

Residues in Non-Cultured Organisms

Use of synthetic chemicals including pesticides, antibacterial and other therapeutants in aquaculture has the potential to result in chemical residues appearing in wild fauna of the local environment. For example, uningested medicated feeds or faeces containing drug residues provide routes by which local fauna may ingest and incorporate mendicants [18]. Such inadvertent chemical exposures and subsequent human consumption of aquatic products can present hazards to human health. Sport and commercial fishermen, including fish farmers, may also take advantage of the enhanced density of fish and shellfish in the vicinity of aquaculture facilities and this may result in increased human exposures to residues [10]. A number of authors have reported synthetic chemical residues in a range of wild fish and shellfish around pond site [11, 18].

Toxicity to other Species

Toxicological effects on non-target species may be associated with the use of chemical bath treatments, pesticides, disinfectants, or leaching of toxicants from antifouling chemicals employed in aquaculture. Among the pesticides that may have toxicological effects on the surrounding fauna are the organophosphate ectoparasiticides, such as those employed in fish culture in many parts of the world [9,17]. Chemical bath treatments result in the release into the surrounding waters of significant quantities of toxic material liable to affect invertebrates particularly larval stages [12]. Other compounds such as Sodium met bisulfate usually used as a postharvest treatment of shrimp can cause localized fish kills in natural waters [8].

Stimulation of Resistance among Environmental Micro biota

The use of antimicrobial drugs for treatment of infectious diseases in intensive aquaculture has however being impractically avoidable [10]. The most common routes of antimicrobials application include oral (especially through feed) and immersion. In both procedures, significant quantities of antimicrobials may reach the environment and lead to the stimulation of resistance among the environmental microbiota. The use of antimicrobial in fish farming has been reported to result in increased frequency of resistant microorganisms – both obligate and opportunistic pathogens [13,19,20,21]. Microorganisms (bacteria) can take advantage of their mobile genetic elements, such as plasmids and transposable elements to access a large pool of itinerant genes that move from one bacterial cell to another and can spread through bacterial populations [10]. Thus, the transference of resistance to human pathogens and even to pathogens of other organisms is therefore of public health concern. In a microbiological study of market products, Duran and Marshall (2005) examined several brands of ready-to-eat shrimp that were obtained from grocery stores. A total of 1,564 isolates corresponding to 162 bacterial species were recovered while screening for resistance to the following 10 antibiotics: ampicillin, ceftriaxone, chloramphenicol, clindamycin, erythromycin, nalidixic acid, streptomycin, tetracycline, trimethoprim, and vancomycin. These authors reported that 42% of the isolates and 81% of the species showed resistance to antibiotics. Several human pathogens were observed among the resistant isolates, including Escherichia coli, Salmonella, Shigella and Vibrio parahaemolyticus, V. vulnificus, V. cholera, motile Aeromonas spp, and Edwardsiella trade.

Antimicrobial-resistant bacteria in aquaculture present a risk to public health. The appearance of acquired resistance in fish pathogens and other aquatic bacteria indicates that such resistant bacteria can act as a reservoir of resistance genes from which genes can be further disseminated and may ultimately end up in human pathogens [10]. This can be viewed as an indirect spread of resistance from aquatic environments to humans caused by horizontal gene transfer. The consequences of antimicrobial resistance in bacteria causing human infections could include increased severity of infection and increased frequency of treatment failures [23]. However, there are dearth of recorded cases of human infections caused by antibiotic-resistant bacteria from aquaculture products [24].

Nonetheless, the aquatic environment receives effluents from various sectors that use antimicrobial and other synthetic chemicals, e.g. industry, human medicine (hospital effluents), and agriculture (crop cultivation and animal husbandry); and natural water (which aquaculture source water from most times) may be contaminated with antimicrobial residues (or antibiotic-resistant pathogens) and that of other synthetic chemicals derived from these different sectors (Figure 1). Thus, the issue of antimicrobial resistance and synthetic compound residues cannot be addressed for one sector (e.g. aquaculture) alone, but requires a comprehensive approach involving all sectors of antimicrobial and other chemicals usage [24].

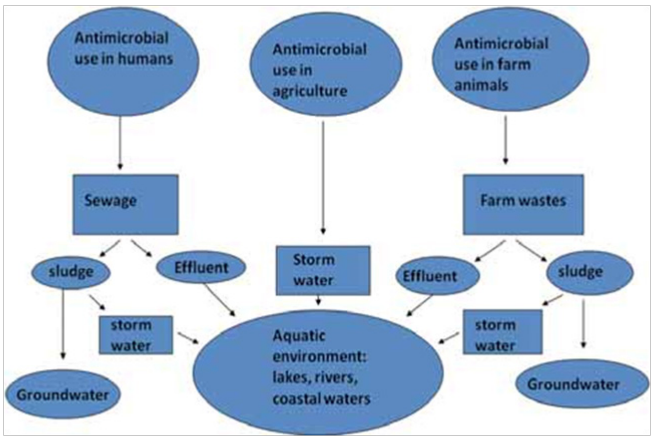

Figure 1. Pathways for spread of antimicrobial residues and resistant bacteria in the aquatic environment (Karunasagar, 2012).

Effects on Aquatic Sediment

The microbial communities of aquatic sediments degrade organic matter and recycle associated nutrients. Composition of substances such as oxygen, ammonium and sulphide in aquatic sediments is highly dependent upon microbial activity. Accumulation of antimicrobial residues in sediments exerts a selective pressure on the microbial activity and reduce the rate of organic matter degradation. As this happens, there could be adverse consequences to farm production. Anaerobic degradation yields more toxic products such as sulphides and ammonia. If the presence of antibacterial residues reduced the extent of aerobic degradation of organic matter, more organic carbon would be incorporated into the anaerobic portion of the sediment column. Subsequent anaerobic degradation could result in an increased production of toxic end-products [17].

Pollution and Nutrient Enrichment

Fertilizers are often used in aquaculture operations to increase primary productivity. In most cases, the nutrient input associated with the use of fertilizers is additional to the contributions of feed. However, whether these nutrient inputs are of significant ecological consequence depends on local conditions [17]. Fertilizer nutrients dissolve in water and oftentimes are discharged from ponds in effluents. These waters on getting to receiving waters effect similar results which most times result to water pollution and eutrophication [8].

Health of Farm Workers

Synthetic compounds used in aquaculture pose health risks to farm workers. Farm workers exposure to pesticide can occur via various exposure pathways such as ingestion of soil, inhalation of air and soil dust, dermal contact of soil and water, and ingestion of pesticide contaminated agricultural and aquaculture foods [25]. However, with proper handling and proper use of safety equipment the risks are brought to considerable level. Chemicals such as liming materials (slaked lime and hydrated limestone) are caustic in nature and can burn the skin of workers and cause serious and permanent damage to the eyes. Other compounds, such as the organophosphates (dichlorvos and trichlorfon), hydrogen peroxide and malachite green are toxic by inhalation and may cause respiratory problems. Even compounds like hydrogen peroxide present major problems in handling and transport because of their explosive nature. While compounds like antimicrobial agents pose serious human health risk associated with hypersensitivity reactions [4].

Residues in Aquaculture Products

Synthetic chemicals use in aquaculture production, or by-products from the applied substances, that have bioaccumulation potential, are regularly found as residues in aquaculture products [7]. And perceptions regarding the hazards of these chemical residues in aquaculture products are an increasing source of public health concern and anxiety among consumers [8]. To this effect, countries are imposing restrictions on compounds used by their own fish farmers and introducing residue monitoring programmes for imports. Concept of the Maximum Residue Levels (MRLs) has been set by many governments through their food safety experts **(Table 2)**. Nonetheless, the rural farmers are the most involving in aquaculture production and most are with little or no knowledge of these regulations. Besides, they lack adequate opportunities to improved aquaculture practices and cannot most times understand the application instructions (dosages) that come with these chemicals (drugs), to talk of proper application [10, 26].

The public health risk associated with drug (chemical) residues depends on the quantity of the drug encountered or consumed, i.e. the exposure [10]. However, the concern for the presence of residues in aquaculture products is associated with possible effects on consumer health, either in the form of immediate hypersensitivity reactions, such as may occur in people sensitized to antibiotics, or from potential toxicological effects [14, 17]. Although these risks may be difficult to quantify, it is essential that aquaculture products conform to standards no less protective than those already in place for many other areas of animal production [4].

Table 2. Maximum Residue Levels (MRLs) in flesh and skin of fish allowed for different markets

Antimicrobial Agent	United States	European Union	Japan	Chile
Oxytetracycline	2 000 µg/kg	100 µg/kg	200 µg/kg	100 µg/kg
Oxolinic acid	Absence	100 µg/kg	Absence	100 µg/kg
Flumequine	Absence	600 µg/kg	Absence	600 µg/kg
Sulfadiazine	Absence	100 µg/kg	Absence	Absence
Trimetropim	Absence	50 µg/kg	Absence	Absence
Florfenicol	Absence	1000 µg/kg	Absence	1000 µg/kg
Erythromycin	Absence	200 µg/kg	Absence	200 µg/kg
Enrofloxacin	Absence	100 µg/kg	Absence	Absence
Amoxycillin	Absence	50 µg/kg	Absence	Absence
Spiramycin	Absence	Absence	200 µg/kg	Absence
Ivermectin	Absence	Absence	Absence	Absence
Emamectin benzoate	Absence	100 µg/kg	Absence	100 µg/kg
Diflubenzuron	Absence	100 µg/kg	100 µg/kg	–
Deltamethrin	Absence	10 µg/kg	30 µg/kg	–

Source: FAO (2012).

Need for Alternatives

It generally understood that one of the current fundamental initiatives in the strategic agenda of stakeholders in commercial aquaculture is ensuring safer processes and products. The increasing concern and anxiety about public health hazards pose by synthetic compounds use in aquaculture have not stopped intensifying as the consumers are becoming more interested in wholesome, safe, and healthy products and the world focusing on environmental sustainability. Considering this and the resultant growing regulations (barring) being placed upon synthetic chemicals use in aquaculture by different countries as well as their limited availability (for the approved ones); and high cost; sustainable aquaculture development involving the use of synthetic compounds has been generally considered unsuccessful [27, 28]. Hence, It is therefore of critical importance to discourage the reliance upon the use of synthetic compounds in aquaculture practices and focus efforts on exploring cheaper, safer and eco-friendly alternatives for the development and expansion of the industry towards its production and products trade sustainability. Bio-compounds – substances that are derived from natural sources – have been identified to hold the potential of "shifting the demand curve" for synthetic chemicals application in aquaculture [7,10, 13, 29, 30]. They (Plant extracts and animal originated products) are considered dependable as they can be easily obtained, are not expensive, fit into a broad spectrum of applications, and also of environmental value as they are biodegradable.

Another very significant role to protect public and environmental health is to regulate and manage synthetic chemicals. However, worldwide regulatory jurisdictions are lack of hazardous chemical regulations [25]. Also, many pesticide standard values currently promulgated cannot even protect public health, which have been evaluated by using health risk models [31]. Thus, sustainable aquaculture development also needs worldwide regulatory agencies get involved in providing reasonable chemical standard values.

Conclusion

Developing and implementing measures towards minimizing the use of synthetic chemicals in aquaculture is a critical step in putting aquaculture on a sustainable footing. Bio-compounds application has been identified as a promising operational approach. However, further studies for more innovative discoveries on their application in aquaculture practices are needed.

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