Biosecure Shrimp Feeds and Feeding Practices: Guidelines for Future Development

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Abstract
For the purposes of this paper, biosecure shrimp feeds and on-farm feeding strategies refer to the “feed, whether live, fresh, or formulated, and the management of the feed on the farm, should not be an entry point of potential pathogens to the shrimp and/or to the culture system.” The paper reviews the different feeds commonly used for the production of farmed shrimp and discusses their potential risks from a disease perspective, including the use of live hatchery and nursery feeds, the use of live and/or fresh food organisms for the production of broodstock, and the use of dry formulated shrimp feeds for shrimp growout operations. In addition, the paper discusses the critical role played by feed-processing techniques for the pasteurization and destruction of pathogens within shrimp feeds and the need for nutritionists to formulate feeds for optimal nutrition and health, and not just for optimal growth. The importance of the development and implementation of good on-farm feed management practices by farmers is discussed, including the prohibition of the top-dressing of pelleted feeds on farm by farmers with unapproved feed additives such as antibiotics. Finally, the paper discusses the responsibilities of farmers, feed manufacturers, and traders regarding the development and use of recommended biosecure shrimp feeds and feeding practices.

KEYWORDS
biosecure feeds, feeds, shrimp, shrimp feeding

Economic Importance of Shrimp Farming and Impact of Shrimp Diseases

Shrimp farming represents one of the most profitable segments of the aquaculture sector, with shrimp production being the second-most valuable crop after carp production at US$23.58 billion in 2014 (FAO 2016a) and the white-leg shrimp, Litopenaeus vannamei, being the world’s top cultivated aquatic species by value in 2014 at US$18.46 billion (Table 1).

Notwithstanding the above, the shrimp farming sector has been beset by numerous major disease outbreaks and consequent losses in shrimp production (Chanratchakool and Phillips 2002; Flegel et al. 2008; Smith and Hauton 2009; Lightner 2011; FAO 2013, 2016b, 2016c, 2016d; NACA 2014, 2015; Merican 2016; Shinn 2016; Thitamadee et al. 2016). While the emergence of new diseases is no different to that experienced by any other new and rapidly growing animal production sector, it is important that shrimp farmers learn from the experiences gained from other food-production sectors and, in particular, from the agricultural livestock-production sector, in particular with respect to biosecurity (FAO/OIE/World Bank 2008; FAO 2010a; FAO 2010b; AFIA 2015).

According to the FAO, “Biosecurity is defined as the implementation of measures that reduce the risk of disease agents being introduced and spread. It requires that people adopt a set of attitudes and behaviors to reduce risk in all activities involving domestic, captive/exotic, and wild animals and their products” (FAO/OIE/World Bank 2008).

Biosecurity Risks from the Use of Contaminated Shrimp Feeds

While biosecurity concerns and risks associated with the importation, transport, and
handling of shrimp broodstock and larvae are well understood (Lotz 1997; FAO 2003; Lightner 2005; Subasinghe and Bondad-Reantaso 2006; Hine et al. 2012), biosecurity concerns relating to feeds and food safety, including on-farm feed management practices, are generally less well understood and appreciated (Tacon and Metian 2008; Chimsung 2014). For the purposes of this paper, biosecure shrimp feeds and feeding practices refer to that “feed, whether live, fresh, or formulated, and the management of the feed on the farm, should not be an entry point of potential pathogens to the shrimp and/or culture system.”

In marked contrast to salmon farming, in which animals are raised under similar intensive land-based and cage-based culture systems (irrespective of country) and exclusively fed on dry biosecure extruded pelleted feeds formulated to a relatively fixed (and well-known) dietary nutrient profile from first feeding to harvest, shrimp farming is characterized by the use of a wide range of different production systems and feeds, the latter ranging across the use of (1) wild-caught live and/or processed natural feed items, including marine polychaetes, squid mantle, Artemia biomass, mussels, oysters, polychaete worms, crabs, and pelagic shrimp; (2) cultured live and/or processed natural food organisms (including micro-algae, rotifers, Artemia nauplii and biomass, marine polychaetes, in situ-produced microbial biomass (also known as biofloc); (3) supplementary farm-made feeds (including fermented feedstuffs, farm-made feed mashes, and pelleted feeds; and (4) commercial manufactured formulated semi-moist and/or dry-steam-pelleted or extruded shrimp feeds (Tacon et al. 2013).

In particular, the current production of shrimp broodstock and shrimp larvae is characterized by the universal use (with a few variations over the past 30 yr) of a combination of different live and/or processed natural feed items, including marine polychaetes, squid mantle, Artemia biomass, mussels, oysters, shrimp, krill, crabs, and formulated dry or semi-moist pelleted feeds (in the case of shrimp broodstock and shrimp maturation operations), and micro-algae, nematodes, Artemia nauplii, in combination with a cocktail of different formulated flake, micro-particulate, and/or dry/liquid microencapsulated larval feeds. Moreover, since the origin of the industry in the mid-1980s to the present day, it is still generally believed that the use of live and/or processed natural feed items is essential for the successful maturation of shrimp broodstock and the production of strong and healthy shrimp larvae (Tacon 1993; Browdy 1998; Sorgeloos et al. 1998; Wouters et al. 2001; Panakorn 2015).

### Reported Disease Risks from the Use of Live, Fresh, and/or Unprocessed Natural Feed Items

Despite the widespread use of live and/or fresh unprocessed shrimp feed items, there is growing concern and evidence that many of these feed items may also pose a biosecurity risk through the introduction of potential viable pathogens to the cultured shrimp, including (but not limited to):

- White spot syndrome virus (WSSV): polychaete Dendronereis spp. (Nereididae; Desrina 2016); polychaete Pereneis nuntia (Laoaroon et al. 2005), polychaete worms

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**Table 1. Global aquaculture production by major fish and crustacean species group classification and species in 2014.**

<table>
<thead>
<tr>
<th>Major species group</th>
<th>Metric tons (million)</th>
<th>Value (US$ billion)</th>
<th>Major species</th>
<th>Metric tons (million)</th>
<th>Value (US$ billion)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carps, barbels, cyprinids</td>
<td>28.23 (1)</td>
<td>40.84 (1)</td>
<td>Whiteleg shrimp</td>
<td>3.67 (4)</td>
<td>18.46 (1)</td>
</tr>
<tr>
<td>Miscellaneous freshwater fish</td>
<td>9.08 (2)</td>
<td>17.92 (4)</td>
<td>Atlantic salmon</td>
<td>2.33 (5)</td>
<td>14.67 (2)</td>
</tr>
<tr>
<td>Tilapia and other cichlids</td>
<td>5.31 (3)</td>
<td>8.82 (6)</td>
<td>Grass carp</td>
<td>5.54 (1)</td>
<td>7.09 (3)</td>
</tr>
<tr>
<td>Shrimp</td>
<td>4.58 (4)</td>
<td>23.58 (2)</td>
<td>Silver carp</td>
<td>4.97 (2)</td>
<td>6.60 (4)</td>
</tr>
<tr>
<td>Salmon, trout, smelt</td>
<td>3.42 (5)</td>
<td>20.14 (3)</td>
<td>Nile tilapia</td>
<td>3.67 (4)</td>
<td>5.96 (5)</td>
</tr>
<tr>
<td>Freshwater crustaceans</td>
<td>2.02 (6)</td>
<td>11.55 (5)</td>
<td>Common carp</td>
<td>4.16 (3)</td>
<td>5.90 (6)</td>
</tr>
</tbody>
</table>

*FAO FishStat database (FAO 2016a)."
BIOSECURE SHRIMP FEEDS AND FEEDING

(Vijayan et al. 2005); Artemia biomass (Chang et al. 2002; Sahul Hameed et al. 2002; Li et al. 2003; Parenrengi 2004; Alday-Sanz 2016); phytoplankton, rotifer, Artemia, shrimp (Jiang 2012); copepods, amphipods, nonpenaeid shrimp, crabs (Song et al. 2001); shrimp – cannibalism (Satoh 2012); hermit crabs (Chang et al. 2012); live molluscs (Tendencia et al. 2011)

- Hypodermal hematopoietic necrosis baculovirus: shrimp, phytoplankton, small crustaceans, fish (Huang et al. 1995)
- Infectious hypodermal and hematopoietic necrosis virus: wild shrimp and crabs (Lavilla-Pitogo et al. 2009), Artemia biomass (polymerase chain reaction [PCR] positive; Alday-Sanz 2016)
- Bacteria – general: Artemia (Igarashi et al. 1989; Hoj et al. 2009); luminous bacteria: Artemia (Abraham and Palaniappan 2004); Enterococcus spp.: Artemia (Babu et al. 2014); Vibrio parahaemolyticus: broodstock, fresh feed (Yingkajorn et al. 2014), pond zooplankton (Karunasagar 2016); Vibrio: Artemia (Vaseeharan and Ramasamy 2003; Lavilla-Pitogo 2016); Vibriosis contamination: mantis shrimp Squilla spp. (Lee and Najiah 2009), live feeds including polychaetes and bivalves for broodstock maturation (Songsangjinda et al. 2016)

Acute hepatopancreatic necrosis disease (AHPND): live polychaetes and bivalves (NAAC 2014, 2015); filter feeders and zooplankton (Brock 2016); polychaetes, squid, Artemia, clams (positive for AHPND AP2 detection; Flegel 2016a); Artemia contamination during the nursery phase (Chanratchakool 2016); polychaetes (PCR positive; Desrina 2016)

- Microsporidean parasites: sergestid shrimp Acetes spp. (Turnbull et al. 1994); polychaetes, mussels, and other filter feeders; crustaceans (Alday-Sanz 2016)

Enterocytozoon hepatopenaei: live polychaetes (NAAC 2014, 2015); live diseased shrimp, frozen Artemia biomass (Han et al. 2016); polychaetes, clams, snails (PCR positive; Flegel 2016b); polychaetes (PCR positive: Desrina 2016); live feeds, including bloodworms, bivalves, and gastropods (Tran 2016)

In addition to the above disease biosecurity concerns regarding the use of specific hatchery and broodstock feeds, there is also a risk of possible disease transmission through the use of raw and/or inadequately processed contaminated shrimp products within growout feeds (including shrimp meal or shrimp head meals produced from wild-caught or farmed shrimp; Chou et al. 1998; Pongmaneerat et al. 2001; Corsin et al. 2005; Flegel 2009) and/or through the top-dressing of commercial pelleted shrimp feeds by the farmer prior to feeding, with contaminated shrimp or fishery products (including shrimp pastes, shrimp fishery products, shrimp hydrolysates, and/or shrimp silage) so as to stimulate shrimp fermentation products, shrimp hydrolysates, and/or shrimp silage) so as to stimulate shrimp appetite and feed consumption (Tacon 1993).

Although it is reported that viable pathogens such as WSSV that may be present within potentially contaminated feed ingredients, such as shrimp head meal, are readily destroyed during the conventional steam pelleting process (Pongmaneerat et al. 2001), there is real risk that more heat-resistant bacterial pathogens and parasites may survive the conventional pelleting process (as compared with extrusion processing in which higher cooking temperatures are involved and the feed is usually completely pasteurized; Muñoz 2011).

Need for a New Generation of Biosecure Shrimp Feeds

In view of the above reported disease risks from the current use of live, fresh, and/or unprocessed natural feed items, it is clear that the commercial shrimp feed manufacturing industry must step up to the plate and start producing a new generation of standalone biosecure nutritionally complete formulated feeds for the entire shrimp production cycle, from first feeding larvae to maturing broodstock.

There is no nutrient or naturally occurring substance (including enzymes, hormones, pigments, polysaccharides, organic acids, or beneficial
microflora) present with live foods and/or fresh natural feed items such as marine polychaetes, _Artemia_, or squid that cannot be put into a fully biosecure commercially formulated dry, semi-moist, or liquid shrimp feed. For a review of recent studies concerning the replacement of live and/or fresh natural food items see:


Although there is no larval or broodstock shrimp feed currently available in the market-place with a proven record of totally replacing live hatchery feeds or maturation feeds with equivalent success in terms of larval production and survival, numerous commercial feed companies are actively pursuing this goal (Dhert 2014; Dominy 2014; Lorenzen 2014; Naessens et al. 2014; Ortiz 2016). In view of the potential disease risks from the use of pathogen-contaminated, live and fresh natural feed items, it would be prudent for the shrimp industry to sacrifice lower hatchery performance and contamination of their valuable specific pathogen-free broodstock by moving over completely to the use of commercially manufactured biosecure larval and maturation feeds.

**Roles and Responsibilities**

Shrimp feed companies, traders, farmers, and governments all have an important role to play in ensuring the adoption and use of biosecure shrimp feeds and on-farm feed management practices, including the following:

Shrimp feed manufacturing companies:

- Formulate nutritionally complete feeds on a digestible nutrient basis for optimal shrimp health and well-being
- Ensure full ingredient and nutrient disclosure, including prohibiting the use of shrimp and locally sourced crustacean meals as feed ingredients within feeds for biosecurity concerns
- Ensure feeds manufactured and sold as being fully biosecure and pathogen free
- Discourage farmers from top-dressing their feeds on farm with unregulated feed additives
- Provide training assistance to farmers and, in particular, to small-scale farmers, concerning good feed management practices, including the disposal of dead shrimp and molts
- Beware of using adulterated ingredients

It is important to mention here the existing internationally accepted aquaculture feed regulations regarding the prohibition of intraspecies recycling (the feeding of the same or closely related species back to the same cultured species) for biosecurity concerns, including the following:

- The FAO Good Aquaculture Feed Manufacturing Practice (FAO 2001): ‘The re-feeding of feed ingredients derived from non-processed and/or processed aquaculture products (including farmed fish and shellfish processing wastes, fish meal, shrimp meal, dead animals etc.) should be avoided at all costs so as to prevent the possibility for the spread of disease through feed.’
• The Global Aquaculture Alliance (GAA) Best Aquaculture Practices, Standards, and Guidelines for Finfish, Crustacean, and Mollusk Hatcheries and Nurseries (GAA 2014a): “7.6: No feeds that contain material derived from the flesh or carcasses of the same species that is reared in the facility shall be used, even if such materials have supposedly been disinfected by cooking or other treatment.”

• GAA Best Aquaculture Practices, Standards, and Guidelines for Feed Mill (GAA 2014b): “6.14: The applicant shall respect prohibitions of the refeeding of ingredients from like aquaculture organisms to prevent transmission of disease.”

Shrimp feed traders:

• Provide local government authorities and shrimp farmer associations with a register of the feed additives sold to individual farmers within their sales area or district on a regular weekly or monthly basis
• Prohibit the sale of illegal feed additives, including antibiotics, direct to shrimp farmers
• Prohibit the sale of adulterated feed ingredients and expired feeds to shrimp farmers

Shrimp farmers:

• Know the importance of recordkeeping for monitoring feed intake and calculating feed efficiency on a tank, pond, and farm basis
• Top-dress feeds immediately prior to feeding using only legally approved feed additives of known composition
• Prohibit the use of antibiotics on the farm (unless under veterinary control) and the feeding of fresh feed items
• Ensure the speedy disposal of dead shrimp and exoskeleton molts using biosecure sterilization methods such as ensiling or incineration so as to prevent disease transmission
• Adhere to the implementation of good on-farm feed management practices
• Maintain shrimp at optimal dissolved oxygen levels (>4 mg/L) and water temperatures (28-30°C) and feed on a continuous little and often basis over a 24-h working day, and by doing so preventing overfeeding and consequent feed decomposition and sludge accumulation

Responsible government authorities:

• Legislate for feed companies to formulate shrimp feeds for optimal health and well-being, with full ingredient use and nutrient level disclosure
• Prohibit intraspecies recycling and the feeding of crustacean meals for biosecurity concerns
• Legislate for feeds to be certified and sold as being fully biosecure and pathogen free
• Prohibit the importation of live feeds, fresh food organisms (including Artemia cysts), dried crustacean meals, and/or finished feeds unless they can be shown to be certified as being disease free (Massaut and Camposano 2016)
• Prohibit farmers from top-dressing their feeds with unregulated feed additives including antibiotics (unless under strict veterinary control)
• Provide training assistance to farmers and, in particular, to small-scale farmers, concerning good on-farm feed management practices, including biosecure methods for the proper disposal of dead shrimp and shrimp molts
• Clamp down and prosecution of unlicensed traders and sale of nonregistered or illegal feed additives, including banned antibiotics

Conclusion

As with modern intensive livestock production systems in which animals are usually reared under strict indoor environmentally controlled “biosecure” production systems (Waage and Mumford 2008), it is believed that the shrimp industry will soon follow suit as a means of excluding pathogens from their current outdoor pond production systems (Browdy et al. 2016). Moreover, by controlling the environmental rearing conditions for the shrimp, water-quality fluctuations can be kept to a minimum and therefore
optimized (i.e., including water temperature, dissolved oxygen levels, etc), and shrimp stress and consequent disease susceptibility and risk can be kept to a minimum.

Last, but not least, it is also important to mention here that shrimp have a dietary requirement for around 40 essential nutrients for optimal growth, but also have an additional requirement for optimal health and well-being, and as such it is important that feed companies formulate their feeds bearing this in mind. In this respect, apart from the use of higher dietary nutrient levels (for specific essential amino acids, fatty acids, sterols, minerals, and vitamins), the feed compounder has many other feed additives to assist with optimizing shrimp health and possible disease resistance, including the use of specific microbial and marine polysaccharides, nucleotides, organic acids, essential oils, prebiotics, and many beneficial probiotics (Bachere 2000; Wang and Qian 2006; Fu et al. 2009; Van Hai and Fotedar 2010; Luna-Gonzalez et al. 2000; Wang and Qian 2006; Fu et al. 2009; Van Hai and Fotedar 2010; Luna-Gonzalez et al. 2012; Zhao et al. 2012; Zokaeifar et al. 2012; Nimrat et al. 2013).

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