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A Review of Feed Attractants as a Guide for Aquaculture Operations[1]

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This EDIS publication provides information to the aquaculture industry on available feed attractants and their effect on fish and crustacean production.

Introduction

The aquaculture and baitfish industry can use feed attractants to improve feed sustainability and feed intake for various fish and crustacean species. These attractants increase fish growth and survival rates necessary for successful aquaculture production. Thus, there is a need to review the types of attractants and their effectiveness in improving fish growth and survival. In this EDIS publication, we provide background information on how feed attractants work and a list of available feed attractants used by the industry.

The aquaculture industry aims to breed and harvest fish and crustaceans to produce food and other commercial products (NOAA 2024). Feed attractants are commonly used in aquaculture to enhance prescribed feed palatability and promote rapid feed intake (Polat and Beklevik 1999). Increased feed intake results in a faster growth rate and improved survival of the animals, thus increasing food and commercial production. Feed attractants also help wean post-larval and juvenile stages of fish from live feed to formulated, pellet-type diets to reduce feed costs (Kubitza et al. 1997).

Additionally, feed attractants improve the palatability of aquaculture feeds made of plant proteins, offering a sustainable substitute to resource-intensive fishmeal and fish oil products. Fishmeal and fish oil are common ingredients in aquaculture additives that increase feed palatability and provide high-quality sources of proteins and fatty acids reflected in a fish's normal diet (Schipp 2008; Zlaugotne et al. 2022). Despite their benefits, fishmeal and fish oil have dramatically increased in price within the last decade because of growing demand, and since they are derived from a limited supply of wild-caught fish, they can be seen as unsustainable sources of feed (Schipp 2008; NOAA n.d.). Plant proteins are an alternative to fishmeal and fish oil because of their affordability, availability, and high nutritional value (Ismail et al. 2020). Adding feed attractants to plant proteins will increase palatability by incorporating attractive chemical molecules into the plant feed, enhancing voluntary feed intake, weight gain, and nutrient absorption (Dias et al. 1997; Khajepour and Hosseini 2012; Zou et al. 2017). Feed attractants offer sustainable substitutions for traditional aquaculture feed, maximizing feed efficiency and minimizing waste.

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When applied to feed, feed attractants stimulate an organism's sensory systems, such as its visual, gustatory, and olfactory (i.e., sight, taste, and smell) systems (Kolkovski et al. 2000; Morais 2016). Once in the water, color and movement help the fish visually recognize the feed. The feed's chemical signals, when processed by the fish's central nervous system, elicit the fish's movement toward the source, its feeding, and its digestion (Kolkovski et al. 2000; Yacoob and Suresh 2003). Fish use their visual and olfactory systems to detect and identify feed at a distance, while their gustatory system determines whether the feed is nutritious (Morais 2016). These systems influence the abundance and speed of feed intake. The chemical signals of feed attractants target the fish's gustatory and olfactory systems. If a fish has a strong chemical attraction to the feed, there may be increased feeding and greater waste reduction, but the growth of the fish may not improve. However, the feeding stimulants, or the molecules within the attractant, can affect the amount of feed ingested and its effects on fish performance. Olfactory responses can enhance the investigation of feed items, but taste will ultimately determine the level of consumption (Morais 2016).

One of the main challenges when using feed attractants is that they can be species-specific (Morais 2016). Although one attractant may enhance the palatability of a feed for one species, another species may reject the feed despite the enhancement. Additionally, some attractants can lose their potency if continuously fed in diets for prolonged periods due to the animals' adaptability to the attractant (Zou et al. 2017). However, there is limited research on this topic, and a synthesis of the current knowledge is needed to aid fish culture operations.

What molecules attract aquatic organisms?

In aquaculture, fish and shellfish demonstrate a preference for feed attractants that include amino acids, nucleotides and nucleosides, quaternary ammonium bases, and organic acids (Morais 2016). Other feed attractants, such as sucrose, phospholipids, and biogenic amines, are occasionally used, but their effectiveness is either understudied or very species-specific.

Amino acids are highly efficient stimulants for freshwater and marine species (Kasumyan and Doving 2003). Free L-amino acids are the most common and abundant substances found in natural food organisms, and they enhance the feeding response in many fish species (Kubitza et al. 1997). Some examples of effective amino acids include alanine, glutamic acid, arginine, and glycine (Jannathulla et al. 2021). Although amino acids can be presented individually as the attractant, they also can be mixed with other amino acids or molecules. If done properly, a mixture can have the same level of palatability as a preferred food organism (Kasumyan and Doving 2003). Amino acids can be species-specific, but generally, most neutral amino acids, like those previously mentioned, are associated with an increased feeding response (Kubitza et al. 1997). For example, even though L-alanine may act as a deterrent to rainbow trout (*Oncorhynchus mykiss*), it can be used as an attractive stimulant for sea bream (*Pagrus major*) and tilapia (*Oreochromis niloticus*) (Kasumyan and Doving 2003). Thus, specific types and combinations of amino acids warrant testing for specific fish species to optimize uptake.

Another class of attractants includes nucleotides and nucleosides, compounds that are powerful gustatory stimulants (Morais 2016). Kubitza et al. (1997) demonstrated their effectiveness by finding that nucleotides were the most successful feed attractant of largemouth bass (*Micropterus salmoides*) compared to amino acids and betaine. Furthermore, a review by Hossain et al. (2020) posited that the properties of nucleotides and nucleosides promoted rapid intake, resulting in increased feed efficiency and growth. Reportedly, the nucleotide inosine monophosphate (IMP) has the best results as a feed attractant for carnivorous fishes. However, other compounds, including inosine, adenosine diphosphate (ADP), adenosine monophosphate (AMP), guanine monophosphate (GMP), and uridine monophosphate (UMP), have been used as well (Li and Gatlin 2006). Nucleotides and nucleosides can also synergistically interact with amino acids to create an effective attractant (Yacoob and Suresh 2003). If these compounds are used as a feed attractant, additional effects include nutritional benefits like enhanced immunity, disease resistance, and improved health performance (Hossain et al. 2020).

Quaternary ammonium bases, specifically betaine, are another commonly used feed attractant. Betaine is found in high quantities within marine invertebrates and microorganisms, and it is known to stimulate taste receptors, making feed more attractive to fish (Morais 2016; Polat and Beklevik 1999). Betaine is recorded to improve growth performance, health status, survival rate, feed digestibility, and immunity of marine and freshwater species (Ismail et al. 2020). In addition to being a potent stimulant, betaine aids in osmoregulation, acts as a methyl donor, and plays a role in lipid metabolism (Ismail et al. 2020). When mixed with amino acids, betaine also enhances the animal's

response to the amino acid molecule, thus increasing feed intake (Morais 2016).

Organic acids are used less frequently than the previous three attractant types; however, their use is increasing within aquaculture. Shrimp farmers have begun using organic acids to fight disease instead of excessively using antibiotics. As a result, many scientists are finding potential in organic acids as feed attractants (Romano et al. 2015). Organic acids and their salts positively affect various fish species and shrimp. When given to Beluga (*Huso huso*), Khajepour and Hosseini (2012) found that citric acid increased weight gain, specific growth rate (i.e., the percentage increase in fish weight per day), and nutrient digestibility. Similar results were found for marine shrimp (*Litopenaeus vammamei*), as organic acid salts like sodium butyrate and sodium propionate increased diet attractiveness, feed intake, and energy digestibility (da Silva et al. 2013). Although the concentration level of organic acids may influence their effectiveness as feed attractants, the optimal concentrations have been found to be about 0.5%–2% of organic acid salts for marine shrimp and about 0.5%–3% of citric acid for fish (da Silva et al. 2013; Romano et al. 2015).

Other molecules, such as sugar, phospholipids, and biogenic amines, have been suggested as feed attractants. Since there is a low dietary and energy metabolism requirement for carbohydrates in fish, fish species are indifferent to sucrose (Morais 2016). Some fish larvae species, such as ayu (*Plecoglossus altivelis)* and red sea bream (*Pagrus major*), require phospholipid molecules for growth and survival, so these molecules are often used as dietary supplements and not as feed attractants (Tocher et al. 2008). Phospholipids also support enhanced feeding activity and ingestion rate for larval and early juvenile fish, yet there is limited research determining if supplemental phospholipids are essential for adult fish (Tocher et al. 2008).

Another potential attractant is biogenic amines formed during the fermentation and decomposition of proteins. Biogenic amines have the potential to trigger feeding responses from crustaceans, but their effects vary based on the quantity of the supplement (Jannathulla et al. 2021). According to Jasour et al. (2018), although fishmeal with higher amounts of biogenic amines had better protein quality, the rainbow trout (*Oncorhynchus mykiss*) fed fishmeal with lower amounts of biogenic amines had better growth performance.

Available Feed Attractants for Aquaculture Industry

There are many different types of feed attractants available for aquaculture. The previously mentioned molecular attractants can be purchased independently and found naturally in animal products (Table 1).

Some feed attractants can be made from marine by-products due to their balanced amino acid profile and supply of free amino acids (Estruch et al. 2018). Through enzymatic hydrolysis, the by-products can be converted into protein hydrolysates that provide nutritional value to aquafeed (Khosravi et al. 2015). Since protein hydrolysates are low-molecular-weight compounds that have peptides with short chain lengths and a well-balanced amino acid profile, they can increase feed palatability and growth performance for fish and crustaceans (Khosravi et al. 2015). For example, tuna hydrolysate has the potential to stimulate innate immunity in fish and be a high-value feed additive for fish and shrimp (Khosravi et al. 2015). Also, krill hydrolysate provides higher weight gain and earlier weaning for several fish species (Kolkovski et al. 2000).

Additionally, chicken hydrolysates are being investigated for their uses as feed attractants. Recycling poultry by-products from slaughterhouses as attractants addresses some environmental and economic concerns. Previous studies have shown that the by-products' peptide and nucleotide contents serve as an effective feeding effector on shrimp growth performance, and their hydrolysates and amino acids are highly digestible protein sources for some fish. According to a recent study by Limpisophon et al. (2023), chicken hydrolysates, similar to commercial tuna hydrolysate, contain essential amino acids that benefit hybrid catfish and Nile tilapia (*Oreochromis niloticus*) growth performance. This further demonstrates their potential as feed attractants (Limpisophon et al. 2023).

Alternately, oligochaete worms, such as tubifex worms and earthworms, contain feed attractants for several species of catfish that may not be attractive to other types of fish. When effective, tubifex worms increase growth and survival rates potentially due to their tryptophan, or amino acid, content (Rawat et al. 2019).

Two natural yeast products used in aquaculture feeds could also replace fishmeal as an attractant: yeast hydrolysate and brewer's yeast (*Saccharomyces cerevisiae*). Yeast is rich in small peptides, nucleotides, mannan oligosaccharides, amino acids, and nucleic acids, enabling it to promote the absorption of nutrients, improve growth performance,

enhance innate immunity, and relieve stress in many fish species as well as Pacific white shrimp (Jin et al. 2018; He et al. 2022). Yeast can also be combined with other marine products, like squid visceral powder, squid paste, and shrimp paste, to promote feed intake and growth performance (He et al. 2022).

Feed Attractants for the Wild Fishing Industry

Feed attractants were originally used to improve catch rates for wild fish in fisheries, specifically for long-line fishing. Common live bait types include squid, mackerel, and herring, but due to rising prices from increasing demand, alternative artificial baits were desired (Løkkeborg et al. 2014; Masilan et al. 2022). In the 1980s, artificial baits were not as successful as natural baits in long-line fishing since various factors, such as bait taste, odor, size, and texture, were not considered (Walsh et al. 2002; Løkkeborg et al. 2014). By incorporating feed attractants into artificial baits, the attractants provided compounds that stimulated the food-search behavior necessary for bait fishing (Løkkeborg et al. 2014). Since visibility is limited within deeper waters, artificial baits need a chemical stimulus with a wide dispersal range and long release rate to attract fish (Løkkeborg 1990; Løkkeborg et al. 2014). For this purpose, marine by-products and hydrolysates, like squid waste concentrate, are effective feed attractants since they contain slow-releasing amino acids (Masilan et al. 2022). Using such feed attractants with artificial bait is economically and environmentally beneficial, and similar attractant products are being used increasingly in the aquaculture industry as a substitute for fishmeal and fish oil-based feed. While further research is needed to learn more about feed attractants and their uses, current insights on the attractants will help the bait fish industry and the aquaculture industry incorporate sustainable solutions into their practices.

Feed Attractant Application

Table 1 summarizes the feed attractants used for various species, their effects on production, and examples of available products that can be used by the aquaculture and wild fishing industry.

Feed attractants can be commercially purchased as liquid or powder products. The liquid and powder attractants can be integrated into the original meal. First, grind all dry ingredients into a powder and pass it through a fine mesh. Next, add liquid attractant or water to the powder, thoroughly mix, process the mixture through a pellet machine for individual pellets, air dry the pellets, and store them at −20°C until use (Zou et al. 2017). Liquid feed attractants can also be applied separately by top-coating pellets with an air-pressure spray gun (Khosravi et al. 2015). Powder attractants can also be diluted or dissolved with water and coated on the pellets (Kubitza et al. 1997).

Conclusion

This EDIS publication identifies various compounds that can be used as feed attractants for crustacean and fish species. The aquaculture industry can use these compounds to increase food uptake, reduce waste, and improve the survival and growth of cultured aquatic animals. Feed attractants also reduce reliance on fishmeal and fish oil by incorporating more plant-based or animal-based by-products into fish diets. This has major implications for the sustainability of the aquaculture industry, highlighting an important benefit of using feed attractants.

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Table 1. Feed attractant application for various species, effects on production, and available products.

Feed attractant	Species	Effect	Example products	Use in aquaculture or wild fishing
Amino Acids	Various marine and freshwater fish and shellfish species E.g., European eel, Japanese eel, sea bass, red sea bream, Tamura, rainbow trout (Polat and Beklevik 1999)	A most abundant and highly efficient stimulant that enhances feed response and can be mixed with other attractants to increase effectiveness	Marine Hydrolysates: AA Baits and Feeds British Aqua Feeds JH Baits	Both
Nucleotides and Nucleosides	Various marine and freshwater fish and shellfish species E.g., largemouth bass, sea bream, red drum, grouper, rainbow trout (Hossain et al. 2020; Kubitza et al. 1997)	Promotes rapid feed intake and increases feed efficiency and growth	Brewer's Yeast: AA Baits and Feeds Alibaba British Aqua Feeds	Both
Quaternary ammonium bases	Various marine and freshwater fish and shellfish species E.g., red sea bream, dover sole, European eel, tilapia, juvenile grouper (Ismail et al. 2020)	Improves feed digestibility, growth performance, and health status Plays a role as a methyl donor and aids in osmoregulation and lipid metabolism	Betaine: AA Baits and Feeds Alibaba Biochem Betaine British Aqua Feeds EChemi JH Baits	Both
Organic Acids	Various marine and freshwater fish and shellfish species E.g., Beluga, sea bream, rainbow trout, yellowtail, marine shrimp (da Silva et al. 2013)	Increases weight gain, feed intake, and nutrient digestibility	Citric acid, butyric acid, etc. AA Baits and Feeds ChemicalBook	Aquaculture Further research required for wild fishing