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Water Stability of Shrimp Pellet: A Review

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Abstract

The quality of shrimp diets is determined not only by their nutritional make-up but also by their physical properties, especially water stability. Shrimp pellets should be physically stable to minimize disintegration and loss of water-soluble nutrients upon exposure to water, and during the ingestion process. Water stability can be improved through the use of binders. A wide variety of natural, modified or synthetic products have been tested as binders with varying degrees of success. The water stability of pellets can also be greatly improved by proper selection of feed ingredients, processing techniques and the use of proper processing equipment. However, the degree and duration of water stability required can be lower if diets possess suitable texture, size or shape and contain chemotactically-attractive substances (attractants) which enhance feed consumption. Proper feed distribution and daily feeding schedule, and more frequent feeding decrease the time in which feeds must remain in the water, and thereby reduce the duration of pellet water stability required.

Introduction

Formulated feed mixtures for aquatic animals are often compressed by steam pelleting or extrusion method into particles that allow maximum utilization of the feed in the water. The particles should be of high durability to withstand handling and transportation and of good water stability to minimize disintegration and loss of nutrients upon exposure to water. The duration of pellet water stability required is dependent on the time required by the fish or shrimp to consume its ration. Many finfishes such as trout, salmon, channel catfish and tilapia are fast feeders and will swallow any suitable size pellet once they have learned to feed on the prepared diets. For these fish, the pellets need to be stable in the water for only a few minutes. Shrimp, on the other hand, require a much higher degree of water stability because shrimp are selective and slow eaters. They take the feed with their chelate pereiopods and masticate it outside the buccal cavity prior to ingestion. The compounded diet for shrimp, therefore, should be well bound to withstand feeding manipulation, minimize feed waste and maintain good water quality.

It is generally known that the physical quality of a pellet, especially its water stability, is affected by the physical properties and composition of the feed mixture and the processing method employed. A number of binding agents may be added to the formulae to reduce the amount of residual fine particles and improve the water stability of the pellets. Many of these products have been found to impart good water stability and may contribute to the nutritional value of the diet. Some, however, have been shown to adversely affect feed consumption and growth performance of shrimp.

This paper reviews information on various factors which affect the water stability of pellets for shrimp. These include composition of the diet, method of manufacturing, and binders. Problems associated with the methods used for evaluation of water stability, and factors affecting the length of water stability required are also discussed.

Factors Affecting Water Stability of Pellets

Composition of Diets

Feeds are normally formulated to contain desired levels of nutrients to meet the nutritional requirements of shrimp at the least possible cost. Allowances are usually made to compensate for loss of nutrients during processing, and for nutrients for which no requirement data are available. Restrictions are also imposed on the level and quality of some ingredients since the composition of the formulae affects not only the nutritional value of the diet but also its physical properties, especially water stability. Some feedstuffs, because of their physical and chemical properties or so-called functional properties, do not possess desirable pelleting quality and can be used only in limited quantity in the formulae. For example, ingredients that are hard to grind or have little or no binding properties, such as rice and oat hulls, may weaken the pellets. Hygroscopic ingredients such as salt, sugar and molasses absorb water, thereby increasing the moisture content of the stored pellets to a level that may often soften them, even before their use in water (Hastings 1970). It has been reported that high levels of soybean meal in the diet (42% or higher) significantly decreased the water stability of pellets (Lim and Dominy 1990), whereas a high level of high gluten wheat flour improved the water stability of pellets (Hepher 1969; Balazs et al. 1973). The protein in peanut meal and wheat gluten is more easily expandable than protein in blood meal or meat by-products (Kazemzadeh 1992).

High fat ingredients and high levels of added fat reduce expendability of extruded feeds and binding properties of pelleted feeds by lubricating the ingredients and reducing compression in the die. Pellets formed with little compression (due to the overlubricating effect) break easily during handling and wetting by water. Fat also covers the surface of carbohydrate particles preventing proper starch gelatinization during steam conditioning and the pelleting process (Hastings 1970). Commercial shrimp pellets usually contain no more than 8% total lipid. However, if a high percentage of fat is desired in the finished feed, liquid fat or oil can be applied by spraying directly on the surface of the pellets after they exit the die or are discharged from the dryer-cooler. The addition of fat to the surface of pellets may also improve palatability of the diet and water stability, and reduce the leaching rate of water-soluble nutrients.

Feed Manufacturing Processes

Due to their benthic feeding habits, shrimp require pellets that sink in the water. Two manufacturing processes, cooked extrusion and steam pelleting, are commonly used to produce shrimp feeds. Extrusion processing is widely used to manufacture floating or expanded pellets for finfishes. Sinking feeds can also be produced using a cooker extruder by reducing the expansion rate and pressure of the extrudate in the barrel. The resulting pellets usually have good water stability due to the high level of starch gelatinization. However, most shrimp feeds currently available in the market are processed using a pellet mill equipped with steam injected and steam jacketed conditioners. Thus, discussions in this section will be limited to processing parameters associated with steam pelleting.

GRINDING

Grinding of feed ingredients is a major task in feed manufacturing. Generally, the finer the grind, the harder and more durable the pellet. Hastings (1980) obtained almost a three-fold increase in water stability in a standard catfish feed by grinding the feed mixture through a 2-mm screen prior to pelleting. The smaller particles tend to fill a larger percentage of void spaces allowing closer surface-to-surface contact between particles. This results in a more compact and durable pellet, and reduces the rate of pellet fracture which normally occurs between large pieces of feed ingredients (Stivers 1970). Grinding also increases the surface area of the particles, thus allowing more space for steam condensation during the conditioning process. This results in higher feed temperature and more water absorption which together, within the time available, increase starch gelatinization (Hastings 1980). Fine grinding also enhances proper and homogeneous mixing, uniform pellet texture, and improves acceptability (Stivers 1970) and digestibility of feed (Robinette 1977). Tan (1991) indicated that 95% of the ingredients for shrimp feed should be ground to a particle size of 0.25 mm or smaller, and the remainder not larger than 0.4 mm. This recommendation is a compromise between the cost of grinding and water stability.

CONDITIONING

Conditioning of the ground feed mixture (mash) is the most critical stage in the manufacture of shrimp feeds. Most pellet mills are equipped with one to three direct or indirect steam conditioner barrels where steam can be injected directly into the mash or into the conditioner jackets to partially gelatinize starch and/or activate binders which aid in binding the ingredients. The jackets maintain higher temperatures within the conditioning barrel. Steam is normally added to the feed mixture to increase moisture content to 16-18% and temperature to 80-90°C before entering the pellet die. Under the conventional conditioning and pelleting process, 30-35% of starch is gelatinized (Chin 1989). Depending on the amount of starch in the formulae and type of ingredients used, this level of starch gelatinization may not be sufficient to produce a good water stable pellet. Tan (1991) recommended that a pelleted shrimp feed should achieve 50% starch gelatinization.

Starch gelatinization can be raised by increasing retention time of the mash in the conditioners or by use of multiple conditioners and controlling the quality of steam. A conditioning time of more than 90 seconds is recommended to permit heat and moisture to penetrate into the feed mixture (Tan 1991). Tan indicated that this can be achieved by a 3-stage conditioner where the mash should be heated to a temperature of more than 50°C in the first conditioner and 80°C in the second conditioner. Under these conditions, the feed mixture in the third conditioner should reach a temperature of more than 90°C before entering the pellet die.

A sufficient quantity of good quality steam is essential for good pellet quality and efficient pelleting operation. The steam systems should be equipped with water separators, steam traps and pressure controls to ensure an adequate supply of good quality steam. The steam must be as dry as possible and delivered to the conditioners at a constant pressure to ensure proper control of temperature and moisture. At the conditioner, a low steam pressure (1.5-2 bars) is used to deliver the required moist steam. Wet steam with condensate will cause mash clumping which will choke the die and roller assembly and/or produce uneven colored pellets (Tan 1991). Addition of steam to the mash prior to pelleting considerably increased water stability of channel catfish feed (Hastings 1980).

PELLETING

The pre-conditioned mash that discharges into a rotating die ring is compressed by rollers through die holes into pellets which emerge from the outer edge of the die and are cut into desired length by adjustable knives. The uniformity and speed at which the mash is introduced into the die and the rotational speed of the die and rollers are essential for proper compaction, good binding and high production rate. Selection of proper die thickness, and hole diameter and type are also crucial in the pelleting operation. A thicker die and smaller hole diameter increases compaction and friction which results in improved pellet quality (Hastings 1980). The optimum ratio of die thickness to hole diameter (compaction ratio) for shrimp feed is approximately 18:1 (Tan 1991). For example, for a die hole diameter of 2.2-2.5 mm, the die thickness should be 40-45 mm.

DRYING AND COOLING

Immediately after pelleting, the pellets need to be dried to a moisture content of about 10% and cooled to 5°C above ambient temperature in a dryer-cooler. This process increases pellet hardness and water stability. However, if the pellets are dried too quickly, cracks will occur as moisture in the center and near the surface migrate outward at different rates. Feeds that are not sufficiently dried and cooled will become soft during storage and handling and hasten mold growth.

In the pelleting process in which final pellet temperature does not reach the required gelatinization temperature of raw starch, heated air may be used in the drying-cooling process. This method is generally uneconomical but results in better water-stable pellets (Hastings 1980). However, hot air drying can cause cracks in the pellets due to quick evaporation of moisture, and can also produce an over-toasted appearance (Khim 1989).

MILL OPERATOR

Another factor which has a significant effect on pellet quality is the mill operator whose experience and skill are reflected in the quality of the products. The pelleting process is not simply the mechanical operation of equipment. It is more of an art rather than a science. There are many factors unique to producing good quality shrimp pellet. Moreover, feed formulae are subjected to change as price and availability of ingredients change. Thus, the mill operator must be able to adjust processing conditions according to the ingredients' characteristics and behavior. Unfortunately, a complete listing of ideal mill operating conditions, such as proper product conditioning, die selection, die and roller settings to obtain a vast number of pellet sizes with desirable texture and water stability required by shrimp, does not exist in any known milling operation manual.

Binders

As previously discussed, diet composition and processing conditions are important factors which affect quality of pellets. However, controlling these parameters alone is sometimes not sufficient to produce satisfactory pellet water-stability, and some binding materials need to be added to give the pellets greater stability. Stivers (1970) indicated that there are at least three actions by which binders increase the hardness and durability of pellets. Binders act as a filler to reduce the percentage of void spaces in the mix, thus providing a more compact and durable pellet, exclusive of any other chemical or adhesive action. Some binders possess an adhesive action, actually gluing the various particles together to provide a more durable pellet. Some binders, after undergoing heat, moisture and pressure treatments during the pelleting process, are thought to exert a chemical action which changes the nature of the feed mixture, thus increasing pellet durability.

There have been several studies and reports on the evaluation of different types of natural, modified or synthetic substances as binding agents for shrimp diets (Forster 1972; Meyers and Zein-Eldin 1972; Balazs et al. 1973; New 1976; Lim and Destajo 1979; Castille and Lawrence 1988; Huang 1989; Dominy and Lim 1991; Meyers 1991). Some binding agents used in the preparation of dry pellets for shrimp are presented in Table 1.

Table 1. Binders used in dry pelleted feed for shrimp.

Binder	Type of binder	Amount used (%)	Comment
Natural substances			
Casein	Protein	4	Fair, expensive
Wheat gluten	Protein	3 - 5	Good, moderate cost
Sago palm starch (5%) + wheat flour (15%)	Starch Starch + protein	20	Good, moderate cost
High gluten wheat flour	Starch + protein	20	Good, moderate cost
Other starchy products (rice, sorghum, corn, cassava, etc.)	Mostly starch	>20	Fair to good, inexpensive
Modified substances			
CMC	Carboxymethyl cellulose	2 - 6	Fair, expensive
Alginate (1-3%) + Na hexametaphosphate (1%)	Polysaccharide Sequestrant	2 - 4	Good, expensive
Manucol	Propylene glycol alginate	2	Good, expensive
XB-23	Anionic heteropolysaccharide	2	Good, expensive
Lignin sulfonate	Polysaccharide	2 - 4	Poor, inexpensive
Synthetic substances			
Na or Ca bentonite	Mineral	2 - 3	Poor, inexpensive
PVA	Polyvinyl alcohol	2	Good, expensive
BASFIN	Urea formaldehyde	0.5 - 1	Very good, inexpensive but may be toxic
Aquabind	Ethylene/vinyl acetate copolymer	2 - 4	Good, expensive

The binding potential of the different binders reported here is based on results of water stability tests using different formulations and prepared under various laboratory conditions. Feed processing conditions employed may not be optimum to activate some binders. Thus, it is likely that some of the binders which performed poorly or were not selected could give better results if different formulations and processing conditions were employed. Meyers and Zein-Eldin (1972) reported that for feed with little or no shrimp meal, a level of 0.75% alginate was sufficient to insure pellet stability for 24-48 hours. However, when shrimp meal was incorporated at more than 15%, an alginate level of 1.25-1.5% was necessary to give comparable pellet stability.

Dominy and Lim (1991) evaluated the effect of 17 binders on the water stability of a standard shrimp diet containing 32.5% soybean meal and 17.3% wheat flour, and on the growth performance of *Penaeus vannamei*. The amount of binder added and the processing conditions used were in accordance with the binder manufacturer's recommendations. The pellets were processed with a laboratory model California Pellet Mill equipped with a 3-stage conditioner and dried in a forced-air Dispatch oven at ambient temperature for 8 minutes. All test binders imparted better pellet stability than the no-binder control processed under similar conditions. The effectiveness of different binders, expressed as percentage of dry matter retained after 8 hours immersion in seawater is given in Table 2.

Table 2. Effect of different binders on water stability of shrimp pellet after 8 hours in seawater. (Source: Dominy and Lim 1991. Source and addresses of binder manufacturers are given in Appendix Table 1)*

Binder	Type of binder	DM retained (%)	Amount used (%)	Binder cost (US$/T feed)
Natural substances				
Gampro	Wheat gluten	86.0^{cd}	4.0	60.0
AP-520	Plasma protein	83.3^{fg}	4.0	108.0
Nutraflex 40 Mega	Collagen protein	85.0^{de}	0.25	4.7
EX-5819	Xanthan and locust bean gum	88.0^{a}	1.0	156.9
EX-5820	Xanthan and locust bean gum	87.5^{ab}	0.43	61.4
RE-9556	Carrageenan mix	85.0^{de}	0.50	37.4
RE-9556/9557	Carrageenan mix	86.6^{bc}	0.50	37.4
Modified substances				
Gampro-Plus	Modified wheat gluten	85.5^{d}	4.0	72.0
Ameri-Bond 2000R	Lignin sulfonate	85.3^{d}	2.0	3.7
Ameri-Bond D-357	Modified lignin sulfonate	83.9^{ef}	2.0	*
Nutri-Binder	Modified sorghum	83.0^{fg}	5.0	12.3
Synthetic substances				
Aqua-Firm 1A	Urea formaldehyde	82.5^{g}	1.0	17.0
Aqua-Firm 2A	Urea formaldehyde	84.1^{ef}	1.0	17.0
Aquabind	Ethylene/vinyl acetate copolymer	85.7^{cd}	4.0	116.0
BASFIN	Urea formaldehyde	85.2^{d}	1.0	13.2
Pel-Plus 100	Mineral	85.5^{d}	3.0	23.0
Pel-Plus 200A	Mineral	85.3^{d}	4.0	13.7

*Cost not available.

Among the various materials evaluated, high gluten wheat flour, wheat gluten, tuber or cereal starches and/or their combination are the most commonly used natural binders in shrimp pellets especially in Asian countries (Meyers 1991). These products require proper control of heat, moisture and time for full activation. Commercial binding agents, such as lignin sulfonate and bentonite, commonly used for fish feeds, have been found to be less effective for shrimp feeds that require much longer water stability than fish feeds. However, they do increase pellet durability and pelleting capacities. Organic hydrocolloids, such as carboxymethyl cellulose, alginate and gums have been used successfully in laboratory-prepared diets but their use in commercial production may be limited by high cost and limited adaptability to large-scale production. Synthetic binders, especially BASFIN (a formaldehyde-based product) have been used successfully in shrimp diets. At a level of 0.5-1%, with proper steam conditioning, it produced pellets that remained intact in water for several hours. However, at this level of inclusion, the growth rate of shrimp decreased due either to reduced palatability or toxicity (Castille and Lawrence 1988; Huang 1989; Lovell 1989; Dominy and Lim 1991). Currently, this product has been removed from the market and is no longer being manufactured. Products similar or identical to BASFIN (Aquafirm 1A and Aquafirm 2A) produced by AGresearch, Inc. (Appendix Table 1), are appearing in the market as aquatic feed binders. Another synthetic binder, Aquabind (ethylene/vinyl acetate copolymer) of Du Pond de Nemours (Appendix Table 1), has recently been introduced and is being marketed to shrimp feed manufacturers.

Methods for Determination of Water Quality

Although the water stability of aquatic diets is a major concern among aquatic animal nutritionists, farmers and feed manufacturers, there is still no standard method to determine water stability. However, a laboratory test for measuring water stability of channel catfish feed was proposed by Hastings (1964). According to this method, 10 g of pellets of known moisture content are distributed uniformly on 115.5 cm^2 (7.6 x 15.2 cm) of no. 10 Tyler mesh aluminum screen, framed with 1.9-cm wood. Replicate samples are lowered into quiet freshwater of an aquarium or tank and the pellets are completely immersed in the water. After 10 minutes, the trays are gently removed from the water, tipped slightly to let excess water drip off, dried in an oven at 130°C for 2 hours, and cooled in a dessicator. The pellet residue on the screen is scraped into a tared dish and the dry weight of the sample recorded. The time for disintegration of the pellet and/or the percentage of solid residue remaining after 10 minutes in water are used as comparative measures of pellet stability. This method was modified by Hepher (1969) to determine the water stability of carp pellets by use of a larger mesh screen (No. 8), longer time period (45 minutes) and creating repeated water movement to simulate pond conditions and to avoid clogging the screens. The screens are hung with string and connected to an eccentric point of a rotating wheel, which moves the screens up and down at a speed of one dip per 4 seconds at a depth of 10 cm. The screens (of known dry weight) with pellets, are dried at 110°C for 3 hours, cooled in a dessicator, then weighed directly instead of scraping the dry pellet into a tared dish.

Forster (1972) devised a method to estimate the water stability of shrimp pellets by further modifying the methods described by Hastings (1964) and Hepher (1969). Approximately 1 g of pellet of known moisture content is placed in a bowl-shaped sieve (0.5-mm mesh) and held near the bottom of a 1-l glass beaker. The beaker is filled with seawater to a level just below the rim of the sieve, and placed in a water bath at 28°C. The pellets are gently but continuously agitated by a constant air flow bubbled through a 3-mm bore glass tube that opens at the bottom of the beaker directly under the sieve. After 16 hours, the remaining feed is removed, dried, cooled in a dessicator and weighed. The proportion of feed loss is then calculated.

Currently, laboratory tests for water stability of pellets for penaeid shrimp are done mostly in seawater using a flow-through system provided with continuous aeration. The time period ranges from 1 to 24 hours.

In addition to the above described methods, the visual water stability and pellet hardness tests are also frequently used. In the visual test, pellets are placed in a glass beaker filled with water. After a predetermined time, the submerged pellets are rated for physical appearance and integrity. This method is often used by farmers. The pellet hardness test which is commonly used by feed manufacturers measures the pressure or force required to breakdown the pellets. However, the dry pellet hardness does not necessarily correlate with the pellet water stability (Hastings 1980).

The water stability tests, either based on actual weight loss or visual observation or both, are subjective evaluations and do not by themselves determine the nutritional value of the diets. Goldblatt et al. (1979) found no correlation between the ration dry weight retention in water and nutrient retention. They suggested that pellet stability is of marginal utility in evaluating the ability of rations to retain nutrients. This is in agreement with Lim (1993) who reported that the percentage of dry matter loss of an amino acid supplemented diet and shrimp meal control diet were 20 and 8%, but the amounts of methionine loss were 53 and 7%, respectively. Thus to better assess the nutritional value of the rations, the nature of nutrient loss and the rate at which such losses occur should also be evaluated.

Factors Affecting the Length of Water Stability Required

No information is available on the optimum value of pellet water stability for various species of shrimp. Observations made by Cuzon, at AQUACOP, Tahiti, indicated that, for *P. vannamei* or *P. stylirostris* grown in a semi-intensive pond system, the pellets should remain intact in the water for at least 1 hour. In a super-intensive system or if frequent feeding is practiced, a shorter duration of water stability is required. However, it is generally perceived that the more stable the pellet, the better its nutritional value for shrimp. Feed that disintegrates quickly in the water represents not only an economic loss but also reduces water quality. Several factors to be described below, when properly controlled, can significantly reduce the length of water stability required and cost of producing very water-stable pellet.

Pellet Texture, Size and Shape

Relatively little is known about the effect of pellet texture, size and shape on feed acceptance and consumption by shrimp. However, it has been reported that texture, size and shape of pellets often directly affect acceptance or rejection of an otherwise nutritionally suitable diet (Meyers and Zein-Eldin 1972). Small and irregular size pellets have more surface area per unit weight than larger and regular size pellets, and thus there is an increased rate of nutrient dissolution. The optimum size of pellets varies depending on the size of shrimp.

Crumbles of 0.6-2 mm are used for postlarvae, and pellets of 2-3-mm diameter are fed from juveniles to marketable size.

Attractiveness of Pellet

Shrimp find their food by chemosensory mechanisms rather than vision (Lim and Persyn 1989). Thus, the pellets must emit some chemotactically-favorable substances (attractants) to minimize food searching and enhance feed consumption. This would decrease the time in which feeds must remain in the water, thereby reducing the loss of water soluble nutrients and improving feed efficiency.

Feeding Methods

Shrimp, like other animals, are creatures of habit. Feeding them at the same time, in the same manner and in the same area each day is important. However, unlike fish, shrimp are territorial and do not swim a great distance to get feed. Thus, feeds must be distributed over a wide area around the pond. This can be accomplished by use of a feed blower or hand-broadcast feeding. Pellets must not be thrown in areas where there is aquatic vegetation or deep mud. Low levels of dissolved oxygen in the water probably depresses feeding activity of shrimp. Thus, because of low dissolved oxygen in the pond water in early morning, feeding of shrimp at that time should be avoided. It is also necessary to ensure that at each feeding, all shrimp should have access to at least one pellet.

Because shrimp are slow eaters and feed more or less continuously, multiple daily feeding is desirable. Frequency of feeding varies inversely with the size of shrimp. Traditionally, postlarvae are fed six or more times each day, two to four times for juveniles, and once to twice for large shrimp. Increasing daily feeding frequency would reduce the exposure time of feed in the water, thus reducing the leaching rate of water-soluble nutrients. More frequent feeding also increases feed consumption. Our observations indicate that shrimp prefer fresh feed over feed which has been exposed to the water for sometime. However, information on the optimum feeding frequency for various stages of shrimp cultured under different production systems is not available.

Conclusions

Due to their feeding habits, shrimp require sinking pellets that remain stable in the water for several hours. Good water stable pellets may be achieved by proper feed formulation and careful selection of ingredients with desirable functional properties. The durability of pellets can be improved by the use of good feed manufacturing processes. Fine grinding, proper steam conditioning, good pelleting techniques, proper die selection and sufficient drying and cooling are essential in obtaining satisfactory water stability. However, sometimes binders are needed to further improve pellet quality. Natural products such as wheat gluten, high gluten wheat flour and other starch-rich ingredients are the most commonly used binders in shrimp feed. Some synthetic binders have also been used successfully but some are too costly and others adversely affect growth of shrimp.

It is generally recognized that the water stability of pellets is a major concern in shrimp nutrition, but current methods to evaluate pellet stability in water are subjective and arbitrary in assessing the nutritional value of diets. The nature and rate of nutrient losses may be different even for pellets of similar water stability. However, the duration of water stability required can be significantly reduced if the pellets have proper texture, size and shape. The pellets should also emit some chemotactically-attractive substance to minimize food searching and enhance feed consumption. Proper feed distribution and timing of feeding, and increased feeding frequency reduce the exposure time of pellets in the water, thus decreasing the adverse effects of leaching of water-soluble nutrients.

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