STORAGE AND HANDLING
OF
FEEDS FOR FISH AND SHRIMP

1. INTRODUCTION

Prepared feeds for fish and shrimp are perishable products. They are also more or less fragile, depending on the type of feed. Feed processors attempt to formulate and manufacture aquaculture feeds to extend their shelf life and improve durability. However, the degree to which aquaculturists can reduce wasted feed and realize its full purchase value is ultimately dependent on how well the basic principles of feed storage and handling are understood and applied.

Feed most often represents the greatest percentage of the total cost of raising fish and shrimp, and substantial amounts can potentially be wasted through spoilage and breakage. Even so, practical information about proper storage and handling of the most common types of feed is difficult to find, and usually only addressed in the literature in a general sense. Specific storage conditions and handling procedures are usually left to assumption.

This article is intended to provide some detailed discussion, and information references where possible, on the most common causes of degradation and waste of aquaculture feed on the farm. It is impractical to address every conceivable storage and handling situation that may occur with each type of feed. However, guidelines presented here, along with some practical recommendations, should help in those instances where judgements or compromises are required.

STORAGE

For reasons of cost and convenience, dry diets are presently the most widely used feeds in aquaculture. These include extruded feeds, hard pellets, crumbles, and flakes. The general rule for preservation of these feeds is to store them in a dry, well-ventilated area that affords some protection from rapid changes in temperature. Cooler temperatures are best, although actual ambient temperature is less important than minimizing extreme changes. A good storage facility should also provide adequate containment for control of pests.

No matter what type of feed is used, there is little or nothing that can be done to enhance its potential storage stability once it has been delivered to the farm. Much of what is subsequently done during storage, however, can substantially affect whether or not a feed can remain acceptable over the intended shelf life. A practical knowledge of the most important factors that contribute to feed degradation and a little attention to maintaining proper storage conditions can significantly minimize loss of vitamin potency, mold growth, fat rancidity and infestation by insects and rodents.

Vitamin Potency

The potency of most vitamins contained in formulated feeds declines during storage. This is because many of these organic compounds are highly reactive and unstable. Under certain conditions they can be easily denatured by heat, oxygen, moisture and even ultraviolet light (2). The rate of vitamin activity loss in a given feed formulation is dependent on the particular vitamin, its source and the conditions under which feed is stored. The average storage stability values of different vitamins and vitamin sources in dry feeds are summarized in Table 1. These data can be used to estimate normal vitamin activity losses under proper storage conditions (3,4).

Most manufacturers of aquaculture feeds recognize these potential losses. They attempt to fortify their diets with sufficient overages of each vitamin to provide the intended levels of activity within the declared product shelf life.

Typical changes in vitamin activity levels that occur in fish feeds have been studied during prolonged storage (5). Results showed that after 3 months, if stored under proper conditions, vitamin levels in well formulated diets could meet or exceed the National Research Council (NRC) recommendations for Pacific salmon. Further monitoring of vitamin activity losses in these feeds revealed that, after doubling the recommended storage time, only vitamin C activity declined below minimum acceptable levels.

It is important to recognize that even significant losses of vitamin activity during storage need not render feed unusable. Vitamin requirements are actually a function of feed consumption and desired biological response of the fish, rather than a specific concentration in the feed (6). As long as storage deterioration of feed is restricted to vitamin loss, meaning that there are no other quality problems such as molding or fat rancidity, feed stored over a long period of time can still be put to beneficial use. Some appropriate applications of feed with low vitamin activity levels would be: short term feeding of harvest size fish, or prolonged feeding of fish or shrimp raised under extensive culture conditions. Conversely, these feeds should not be used where increased vitamin activity is required to promote an adaptive response such as disease resistance, or achieve maximum tissue storage as required in broodstock feed.

Table 1. Average Vitamin Stability in Stored Feeds

Vitamin	Ingredient Source	% Vitamin Retention At Month:		
		1	3	6
A	Beadlet	83	69	43
D_3	Beadlet	88	78	55
E	Acetate	96	92	88
	Alcohol	59	20	0
K	MSBC [1]	75	52	32
	MPB [2]	76	54	37
Thiamin	Hydrochloride	86	65	47
	Mononitrate	97	83	65
Riboflavin	Riboflavin	93	88	82
Pyridoxine	Hydrochloride	91	84	76
B_{12}	Cyanocobalamin	97	95	92
Pantothenic Acid	Calcium d-Pantothenate	94	90	86
Folic Acid	Folic Acid	97	83	65
Biotin	Biotin	90	82	74
Niacin	Nicotinic Acid	88	80	72
Vitamin C	Ascorbic Acid	64	31	7
	Fat Coated Ascorbic	95	82	50
	Ascorbyl Phosphate	98	90	80
Choline	Chloride	99	98	97

[1] MSBC = Menadione Sodium Bisulfite Complex

[2] MPB = Menadione Dimethyl Pyrimidinol Bisulfate

Mold Growth

All too often, feed stored in fish hatcheries and farms is destroyed by common molds. The potential for this to occur is always present because of the fact that mold producing fungi and other microorganisms exist naturally throughout the environment. They are present in grains after harvest and in animal carcasses prior to rendering. Food processing operations involved in stabilizing these feedstuffs and in manufacturing feeds typically use heat and dehydration steps that are sufficiently destructive to eliminate the original contaminating microflora. However, some fungal spores can survive harsh processing conditions. Other airborne spores may also recontaminate feed during handling and storage. All of these spores then remain dormant in and on the feed until conditions exist that are favorable for growth.

Contaminating fungi grow best when the moisture content of the feed is 14.5 to 20% and in equilibrium with a relative humidity of 70 to 90% (7). Extruded and pelleted feeds are manufactured at considerably lower moisture levels, allowing a safety margin for variability among individual feed particles. The maximum recommended moisture content for extruded pet feeds is 12% (8). Most aquaculture feed manufacturers take this a step further, keeping moisture levels at or below 10%. This is generally done because of the superior handling characteristics of low moisture pellets in bulk bins, and the tendency for fish feeds to be stored over prolonged periods.

Special additives, which reduce water activity and inhibit germination of fungal spores within the feed, can be used to further diminish the possibility of mold growth. However, many of these additives are relatively expensive. Cost-effective application is mostly in specialty diets such as semi-moist feeds that have moisture levels of 14 to 20%, but do not require storage conditions different from dry feed.

On a large production scale there is no economical way of eliminating fungi spores in feed. The most effective mold prevention strategy, therefore, is to maintain moisture levels in stored feed below requirements for fungal growth. To do this it is obviously necessary to provide a dry area where feed can be protected from rain. Less obvious is the need to control moisture migration within the feed. Sufficient temperature differentials, even in feed with only 10%

average moisture, can cause that moisture to concentrate at much higher levels in the cooler areas of a sack or bulk bin.

It is usually not practical to provide climate-controlled storage for large quantities of feed. However, every effort should be made to avoid conditions that allow extreme temperature changes to occur over a short period of time. In situations where bagged feed is stored outdoors under tarpaulins or bulk feed is held in dark colored and poorly ventilated bins, moisture in the feed can volatilize during the heat of the day and condense near the top and surrounding container surfaces when the temperature rapidly decreases at nightfall. Similar moisture migration can even occur when bags of feed at ambient temperature are stacked on or against cool concrete floors and walls. Once feed has been subjected to these kinds of storage conditions, it is only a matter of time before mold growth begins in localized areas of high moisture.

The first species of fungi to develop in feed is usually *Aspergillus glaucus*, which has a minimum environmental moisture requirement of only 14.5% (7). If identified at an early stage, feed containing trace amounts of pellets with this type of mold can usually be fed to fish with little risk of adverse consequence. With more time, however, the number of mold colonies multiplies quickly, creating higher temperature and moisture conditions. As the environmental conditions within the feed undergo a succession of changes caused by the growth of these spoilage microorganisms, other species quickly emerge and proliferate.

At moisture levels near 18%, there is a possibility that molding feed will become infested with *A. flavus* (7). This is an especially dangerous species of mold, because it is capable of producing aflatoxins. Rainbow trout are particularly sensitive to these carcinogenic metabolites (9,10). Consumption of only 0.5mg of aflatoxin B_1 per kg of body weight causes mortality within 3 to10 days. Feeding aflatoxin-contaminated feeds with as little as 0.1 to 0.5 ppb aflatoxin B_1

results in hepatomas after 4 to 6 months. Other aquatic species such as coho salmon (9), catfish (11) and shrimp (12,13,14) are believed to be more tolerant, though similarly affected.

The probability of aflatoxin production in complete feed is actually quite low. It is much more likely to occur in high moisture crops like peanuts, cottonseed and corn. Studies have shown that the presence of other microorganisms in a complex substrate like fish feed tends to interfere with aflatoxin production (7). However, among these interfering microorganisms, there are also species of *Fusarium* and *Penicillium* fungi that can produce their own mycotoxins. For this reason, the practice of using feed that is obviously molded should be avoided.

Lipid Rancidity

Lipids used in aquaculture feeds are usually the type that contains significant levels of unsaturated fatty acids, which are required for good health and growth of most species of fish and shrimp. The high degree of unsaturation of these fatty acids causes them to be particularly prone to oxidative rancidity. Feed manufacturers attempt to prevent oxidation in lipid sources such as fish oil by stabilizing them with antioxidants. However, the commonly used antioxidants such as ethoxyquin, butylated hydroxy anasole and butylated hydroxy toluene are sacrificial in the way that they protect the oil. Once they are used up, free radicals that are already present in the oil begin to react with unsaturated fatty acid components and the process of oxidation begins.

It is often thought that freezing is the best method of long term preservation. However, cold temperature in the range achievable with most freezers is not effective in reducing the rate of free radical formation or the resulting lipid oxidation. In actuality, the experience with low moisture feeds has been that freezing accelerates lipid oxidation (15). It is believed that the reason for this is that only free water is frozen at ordinary freezer temperatures. This results in the concentration of metal salts and other pro-oxidants in an unfrozen phase, making interaction with lipids more probable. It is also thought that the further reduction of water activity caused by freezing dry feed allows oxygen to penetrate the pellets more freely.

What all of this means is that there is very little that can be done on the farm to improve lipid stability in stored feed. Rotating the feed inventory as quickly as possible is the only effective strategy to avoid having feed go rancid before it is used. This can be accomplished easily with feeds that are fed in high volume. However, inventories of starter feeds, crumbles and broodstock pellets are usually more difficult to manage. Animals that eat these feeds are also most likely to be at a point in their life stage where they are extremely vulnerable to the negative effects caused by consuming rancid lipids.

Pest Infestation

The presence of insects and rodents in feed storage areas can often be an overlooked but serious problem in aquaculture. These pests not only consume feed but also cause additional and sometimes greater feed losses through packaging damage and the creation of environmental storage conditions that promote mold growth. They also have the potential to serve as vectors for transmission of disease to humans.

<u>Insects</u>

Insect infestation can be a very serious problem in feeds stored over a prolonged period of time. Jokes about how insects “just add a little protein to the feed” tend to divert attention from the magnitude of feed loss that they can cause. An actively reproducing population of insects can quickly consume significant amounts of food and deteriorate the physical quality of remaining feed (16). Internal infesting species such as grain weevils and warehouse beetles can bore through feed sacks, providing a port of entry for other insects. If present in sufficient numbers in bulk feed, they also have the potential to create localized heating, moisture migration and molding. External infesting species, however, are more frequently the cause of problems in complete feeds. These include Indian meal moths and flour beetles, which prefer to obtain nourishment from processed grain products, along with carpet beetles that feed on meat meal, feather meal and other ingredients of animal origin.

Most of these insects thrive on food containing 12 to 14% moisture. They are capable of completely developing from an egg to a reproductively active adult within 30 days when temperatures are between 20 and 30°C. At 16°C most of these species cease to lay eggs. They usually become dormant at about 4.5°C. Under optimal environmental conditions, propagation of tremendous numbers of insects can occur in a very short period of time because of their short maturation time and relatively high fecundity.

With the knowledge and ability to recognize conditions that promote insect infestation and rapid population growth, it is easy to see that effective control requires sustained and concerted effort on several prevention and housekeeping tasks. Rapid inventory rotation is perhaps the most important control process. However, regular inspection of feed and early detection of bugs along with good sanitation in storage areas are proactive practices that can greatly reduce the incidence of feed contamination with bugs. As a final resort, insecticides can be used to eliminate a persistent infestation.

In the United States all chemicals used as insecticides must be registered for this purpose, and be properly labeled according to Environmental Protection Agency (EPA) regulations. Fumigants such as hydrogen phosphide (phosphine gas), methyl bromide and chlorpyrifos-methyl require application by individuals that are certified by controlling state agencies. These insecticides are highly effective and leave no residue in the feed. However, the vapors are very toxic. Fumigant insecticides should always be used with extreme caution, and only according to the manufacturer's recommendations for treatment of feed.

Rodents

Populations of rats and mice that become established in storage areas obviously consume some amount of feed. However, the losses that they cause through packaging damage and the resultant feed spillage and exposure to insects and molding conditions are probably far greater. They also pose a substantial health hazard to workers handling the feed.

As with insect pests, several methods of control must be employed in a concerted manner in order to be effective. The basis for a rodent control program should always be good housekeeping, both inside the warehouse as well as around the exterior perimeter. Combining this with maintenance of physical barriers that limit entry and an aggressive trapping effort will noticeably minimize feed loses caused by rodents.

Use of poisons should only be considered as a last resort to control rodent populations in feed storage areas. Baits containing strychnine or other acute rodenticides, in close proximity to stored feed, impose an increased risk of feed contamination and dangerous contact with humans or pets. These same risks exist with the use of anti-coagulant rodenticides such as warfarin, even though they are much less dangerous.

HANDLING

Movement of feed on the farm can only be considered as a necessary evil. Some amount of feed or nutrient loss occurs each time that it is handled in the processes of receiving, storing and feeding. These chronic losses are usually small, but they accumulate over time. A good general control strategy is to identify the causes of greatest loss, and make any practical modifications necessary to handle feed as gently and as little as possible.

Both pelleted and extruded dry feeds have excellent handling characteristics. Pellet durability of both types of dry feed is usually quite good. However, variability in the consistency of feed ingredients may cause some batches of feed to be softer and more fragile. Feed manufacturers reduce the incidence of soft feed by using ingredients with good binding characteristics, and by the inclusion of feed additives that help increase pellet hardness. The cylindrical or spherical particle shape of pellets also reduces breakage, and allows dry feed to flow easily from trucks, bins and feeders.

The physical characteristics of dry feeds are so well suited to the handling and distribution requirements of aquaculture that inherent limitations are often challenged. It is easy to overlook the fact that even the most durable crumbles and pellets can break down into dust and fines when subjected to sufficient amounts of compression and abrasion. It is important to give ample consideration to moving the feed as little as possible and as gently as possible.

With bagged feed the challenge is to reduce the amount of particle size attrition that occurs when pellets or crumbles are forced to rub against each other. Use of forklifts and pallets, or hand-trucks and mini-pallets, allows bags to be handled in multiple units. This minimizes the amount of feed movement within each bag and reduces the creation of dust and fines. When it is necessary to handle single bags, the process should be done as gently as possible. Obviously rough treatment such as throwing or walking on sacks of feed should be avoided.

Pellet-against-pellet abrasion in bulk feed is more difficult to control. The very nature of this method of storing and handling feed requires that pellets flow from the delivery vehicle to a bin, and from the bin throughout the farm. It also necessitates the use of conveying equipment. These mechanical devices are often the source of, or solution to, most problems with excessive levels of dust and fines in bulk feed.

Among the types of conventionally used feed conveying equipment, bucket elevators, belt conveyors and drag conveyors are the least destructive (17). These work well because they control movement of feed against feed, and minimize the potential of shearing or pinching pellets in conveying mechanisms. Pneumatic, oscillating and vibratory conveyors cause only slightly more abrasion. However, they almost eliminate losses from pellet breakage when properly maintained and operated.

The most potentially destructive conveyance mechanism for feed is the auger. Tube type screw conveyors as well as flexible augers are widely applied in feed handling systems on farms because of their low cost and simplicity of operation. Their most frequent use is in unloading bulk bins. In this application the equipment design is usually more appropriate for handling mash feeds or whole grain, where the auger turns at a high rate of speed and has an inclined discharge. Most are also “choke-loaded”, meaning that feed completely covers the inlet to the conveyor, causing compression and breakage as pellets enter the tube. While proper equipment design can minimize many of these problems, the added expense usually ends up favoring selection of conveyors that are more appropriate for use with feed.

SUMMARY

Aquaculture feeds, like most food products, have a finite shelf life and special handling requirements. In order to realize full economic and nutritional value of these feeds, it is necessary to store and handle them properly. Deterioration of feed quality during storage can be minimized by frequent rotation of the inventory and a concerted effort to maintain good housekeeping and environmental conditions that discourage the growth of mold and infestation by insects and rodents. Proper handling techniques can also reduce nutrient loss and pellet breakage just prior to feeding.

The importance of careful attention to the specific requirements for proper storage and handling of aquaculture feeds can not be overstated. At most farms that raise fish or shrimp, feed cost is the largest single expense item. Therefore, even a small reduction in wasted feed can significantly affect production cost and directly impact bottom line profitability.

REFERENCES

1. E. Leitritz, and R. C. Lewis, Trout and Salmon Culture - Fish Bulletin No. 164, University of California, 1980.

2. M. Gadient, in R. A. Erdman, ed, Proceedings Maryland Nutrition Conference for Feed Manufacturers, University of Maryland, 1986, pp. 73-79.

3. M. B. Coelho, *Feed Management*, Vol. 42, No. 10, pp. 24-35, (1991).

4. BASF, Keeping Current KC 9138, 5th ed, BASF Corporation, Mount Olive, NJ, 1994

5. L. G. Fowler, W. M. Thorson, W. L. Wallien, G. R. White, and P. E. Martin, *USFWS Technology Transfer Series*, No. 89-1, (1990).

6.National Research Council, Nutrient Requirements of Trout, Salmon, and Catfish, Nat. Acad. of Sci., Washington, D. C., 1973.

7. K. W. Chow, in K. W. Chow, ed, Fish Feed Technology, UNFAO, Rome, Italy, 1980, pp.216-224.

8. G. J. Rokey, J. R. Krehbiel, K. E. Matson, and G. R. Huber, in R. R. McEllhiney, ed, Feed Manufacturing Technology III, American Feed Industry Association, Arlington, VA, 1985, pp. 222-237.

9. L. M. Ashley, in J. E. Halver, ed. Fish Nutrition, Academic press, New York – London, 1972, pp. 439-530.

10. L. Friedman, and S. I. Shibko, in J. E. Halver, ed. Fish Nutrition, Academic press, New York – London, 1972, pp. 182-239.

11. W. Jantrarotai, and R. T. Lovell, J. Aquat. Anim. Health, 2:248-254, (1991).

12. M. D. Wiseman, R. L. Price, D. V. Lightner, and R. R. Williams, Applied Environmental Microbiology, 44:1479-1481, (1982).

13. D. V. Lightner, in C. J. Sindermann, and D. V. Lightner, eds. Disease Diagnosis and Control in North American Marine Aquaculture, Elsevier, Amsterdam – Oxford – New York – Tokyo, 1988, pp. 96-99.

14. H. T. Ostrowski – Meissner, B. R. LeaMaster, E. O. Duerr, and W. A. Walsh, Aquaculture, 131:155-164, (1995).

15. R. W. Hardy, Aquaculture Magazine, Sep./Oct., (1998).

16. J. R. Pedersen, in R. R. McEllhiney, ed, Feed Manufacturing Technology III, American Feed Industry Association, Arlington, VA, 1985, pp. 380-389.

17. D. Falk, in R. R. McEllhiney, ed, Feed Manufacturing Technology III, American Feed Industry Association, Arlington, VA, 1985, pp. 167-190.