The objective of feeding fish is to provide the optimum nutritional requirements for good health, growth, yield while minimizing wastage to optimize profits. Though natural feed forms the main source of nutrition, supplemental feeding is necessary to obtain increased production in ponds. Therefore, a good artificial feed not only facilitate in meeting nutritional requirements but also help to maintain good water stability and acceptance by the fish. To produce supplementary feed with the desired physical characteristics, feed processing and technology has a major role to play for quality feed production. Commercial feed is mainly used by few advanced and progressive farmers while the high cost is prohibitive for the small and marginal farmers. Moreover, non-conventional ingredients are normally not used for fish feed production by aqua feed industry, resulting into increased cost of the feed in the market. Some of the limitations in using non-conventional ingredients are poor utilization by fish either due to presence of anti-nutritional factors or insufficient processing. Furthermore, the scientific information on fish feed technology of conventional and non-conventional feed ingredients are limited. Production of feed as per the requirements essentially involves industrial processing that needs to be marketed in the form highly preferred by the end-users. Hence, the entrepreneurs need to access and use technical information and technology available at the research institutes to produce the desired commercial demand. The combination of the technical knowledge, technological package and business skill would certainly ensure establishment of the successful venture of feed production to cater the demand.

INTRODUCTION

India is the second-largest aquaculture producer in the world dominated by carps. About 80% of India's aquaculture production is composed of carps of Indian and Chinese origin. Feed is a vital input which greatly influences the production cost and sustainability. Similarly, production of feed of desired characteristics like minimum feed wastage, lower handling cost, easier storage and improved feed efficiency have role in improving aquaculture production.

India produces enormous quantities of feed materials derived from crops. These include a wide variety of oil cakes, pulses, mill byproducts of seeds and grains. Smaller quantities of byproducts from the meat, fish and dairy processing industries are also available in the market. Amalgamation of these types of feed ingredients could form good quality supplemental feed to provide balance nutrition to the cultured fish.
Unlike natural foods which normally are present as discreet living forms and therefore are biologically stable until consumed, artificial feeds undergo rapid nutrient loss through normal deteriorative processes and leaching by water unless quickly consumed. Moreover, when feed aggregates tend to disintegrate and separate into their ingredients components, thus losing their original nutritional properties. So a successful artificial feed apart from meeting nutritional requirements should have good water stability and acceptance by the fish.

FISH FEED TECHNOLOGY IN INDIA

The concept of feed technology in India started about 30 years ago. In 1967, the compounded livestock Feed Manufacturers Association of India (CLFMAI) was set up to represent the interest of manufacturers in the government, cooperative and private sectors with an estimated designed capacity of 1.73 million tonnes/annum. However, the production of compounded feed was for livestock and poultry. At that time, there was no commercial production of fish feed. Few mills gradually produced pelleted feed by using old pelleting technique suitable for producing large size pellets for livestock and Poultry; it was inadequate for making small sized pellets of sufficient hardness and compactness suitable for fish feeding. Small size pellets are required for fish feeding that not only possess hardness but also remain water stable when fed to fish. A laboratory size feed pelleting machine manufactured by California Pellet Mills Co. in USA was installed long back at ICAR-CIFA, Bhubaneswar, India for production of laboratory size feed pellets producing about 100 kg feed per hour. However, it was having number of limitations and feed manufacturers started producing fish feed on commercial scale. Now, many states have feed mills producing fish feed on commercial scale, both sinking and floating type. ICAR-CIFA installed the extrusion machine under the Division of Fish Nutrition and Physiology and started producing both sinking and floating pellets for carp and prawn feeding.

BASIC STEPS OF FEED MANUFACTURING AND TECHNOLOGY

Raw material collection

The first operation for feed manufacturing is the collection of raw materials. Initially the raw materials are checked by physical observation and chemical analysis to ascertain the quality. Good quality locally available feed ingredients like maize, soyabean meal, ground nut cake, till oil cake, rice bran, rice polish, fish meal and mustard oil cake are procured from the market that arrive in bags or small containers are stored in dry location preferably in specially designed feed store. Proper storage temperature and humidity are maintained during storage, so the nutrient losses are minimized. Liquid ingredients like oil and molasses are generally stored in bulk tanks.

FEED FORMULATION

It is a process which has to address two principal objectives. The first is nutrient requirement of fish based on which feed formulation is performed to achieve an optimal
production. The second is the calculation to find the types and amounts of ingredients to be mixed to produce complete feeds.

a. Hand formulation

A simple method in hand formulation is ‘Pearson square’ which can be simply applied for mixing one, or two groups of ingredients considering the requirement (usually protein). Fig 1. shows a simple application of Pearson’s square to fish meal (65.3% protein) and rice bran (12.2% protein) to formulate 35% protein supplementary feed. Application becomes more complex for more ingredients and requirement considerations for which worksheet are needed.

Fishmeal  
(65.3% protein)  
35–12.2=22.8  
22.8/(22.8+30.3)x100=42.94%

Rice bran  
(12.2% protein)  
65.3–35=30.3  
30.3/(22.8+30.3)x100=57.06%

The solution is 42.94 % fish meal + 57.06% rice bran

**Fig:** Pearson Square model

**Fig.1.** Harvesting of freshwater IMC in ICAR-CIFA pond
b. Linear programming computerized formulation

Linear programming is a class of mathematical programming models concerned with the efficient allocation of limited resources to known activities with the objective of desired goals such as maximizing profit or minimizing cost when there are alternate uses for their sources. Basically linear programming works by solving of a number of linear equations. A series of equations which describe in mathematical terms the conditions of requirements of the formula is established. These requirements are to be measured in numerical terms. These are fairly easy to accomplish for some items like protein, fat, calcium etc., but difficult for other factor like palatability. Such a programme would allow a number of constraints, maximum or minimum levels of nutrient requirements and ingredient inclusion to be set based upon cost and nutritive values. The primary advantage of using linear programming (LP) in the formulation of feed is that it can rapidly and accurately determine combination of feedstuffs that will meet specific nutritional and physical requirements at lowest possible cost and not have any bias towards any ingredient. But there are limitations also.

c. Quadratic programming formulation

Nutrient requirements used in linear programming feed formulation are usually for fixed maximum rate of growth. This may not be the best decision from economic point of view. Nutrient constraints may be relaxed to bring down feed cost while still achieving acceptable lower growth. Quadratic programming takes into account the growth response within a range of nutrient constraint. A good understanding of biological response functions from actual feeding trials is therefore, essential in the use of quadratic programming.

Grinding

Grinding or particle size reduction is a major function of feed processing. Grinding generally improves feed digestibility, acceptability and increases the bulk density. Different types of grinders are used for grinding the feed ingredients like hammer mills, attrition mills, roller mills, cutters etc. Hammer mills are mostly impact grinders with swinging or stationary steel bars forcing ingredients against a circular screen or solid serrated section designed as a striking plate. The material is held in grinding chamber until it is reduced in size of the opening in the screen. Attrition mills use the hammer mill principle to a certain extent. Grinding is done between two discs equipped with replaceable wearing surfaces. One or both of these discs is rotated, if both they rotate in opposite directions. In roller mill, a combination of cutting, attrition and crushing occurs. These are smooth or corrugated rolls rotating at the same speed set at a predetermined distance apart with material passing between the two.

Mixing

This is a process in which each small unit of the whole is the same proportion as the original formula. Only when all ingredients as per the formula are thoroughly mixed, the feed
will prove worthy. Various types of mixers are available in the market like vertical and horizontal type. Feed mixing include all possible combinations of solids and liquids.

Extrusion cooking

Extrusion processing has become the primary technique used for fish feed production, mainly because of the high physical and nutritional quality of the feed (Hilton et al., 1981). Basically, an extruder is a long barrel with one or two rotating screws (single - or twin screw extruder) which is specially designed to subject feed mixtures to high heat and steam pressure. When feed exits the die at the end of the barrel, trapped steam blows off rapidly, the soft warm pellets expand, and a low density floating pellet is produced. The system is also equipped with a preconditioner as well as an accompanying machine control system. The preconditioner is a high speed mixing unit designed for the purpose of mixing water and steam into the blend of dry ingredients. The overall goal with preconditioning is to supply the extruder barrel with an evenly moistened and preheated mix. Preconditioning allows more efficient transfer of heat through friction in the extruder barrel, and also reduces the extruder barrel wear and energy. Most materials require milling prior to extrusion, especially large granular ingredients like maize or soya. After extrusion, cooling is required to remove excess moisture. A moisture content of 12-14% should be achieved to prevent fungal activity. Moreover, aquatic animals cannot digest starch effectively resulting in excessive excrement which causes physiological problems such as excessive gas, bloating diarrhoea and these apart from affecting the growth of the fish also lead to water pollution. So starch in the feed are effectively utilised by extrusion for preparation of floating feed. Extrusion processing has become the primary technique used for fish feed production, mainly because of the high physical and nutritional quality of the feed (Hilton et al., 1981).

Extruded feed may be of sinking type or floating type. A part of the supplementary feed for fish in sinking form goes waste as it sinks to bottom and fish cannot consume it. This wastage is less in floating feed and farmer can directly observe the feeding requirements and adjust feeding rates accordingly. The advantages of feeding floating feed are less waste, higher feed intake, improved feed efficiency, lower handling costs, easier storage, and less bacterial contamination. Floating feed for fish has become very common for feeding of fish including fresh water fish. Extruded floating feed after incorporation of fish hydrolysate (Bind-Add+) increased growth rate and feed utilization in Oreochromis niloticus (Sahu et al., 2017).

Benefits of extrusion

1. In extrusion, raw material is expanded, starch is gelatinized and oil cells are ruptured. So the digestibility of nutrients is increased. Denaturation exposes sites for enzyme to attack and may thus make the protein more digestible. So it increases the nutritional value of protein-containing ingredients.

2. Extrusion can destroy harmful organisms like salmonella. Heat labile proteinaceous anti-nutritive factors such as trypsin inhibitors and lectins may be destroyed.
3. The heat and pressure deactivate destructive enzymes such as those that cause rancidity.
4. Increase availability of carbohydrates.
5. It neutralizes growth inhibitors.
6. There is increase availability of sulphur containing amino acids.
7. There is also improvement of palatability.

Cooling and drying

The temperature imparted to pellets after extrusion cooking assists the removal of moisture by the air drying process. Generally, within ten minutes after extrusion, hard pellets are cooled to ambient temperatures and brought to moisture content slightly above that of the entering soft feed. This may be done by spreading pellets in a thin layer on the floor and blowing air over them. Commercially, it is done by passing the hot pellets through a vertical or horizontal chamber designed to bring air at ambient temperature into intimate contact with the outer surface of the pellets. The cooling and drying operation are of vertical type or horizontal type. Heated air may be used in the cooling and drying process. Pellets after preparation may also be dried by using dryer fitted with electrical heaters.

Packing, storage and distribution

Most feed are sacked. The sacking operation includes weighing, sacking, taping, coding and sewing. The sacked bags are then sent for distribution. The bulk products are stored in large bins.
EFFECTS OF EXTRUSION PROCESSING CONDITION ON NUTRIENT QUALITY

Temperature

Effects of extrusion temperature on digestibility and utilization of the diets by rainbow trout were examined. In one experiment, a fishmeal-based diet was extruded with a twin-screw extruder at three temperatures (100, 125 and 150 °C) and in another experiment; fishmeal-based diet was extruded using a single screw extruder at two temperatures (100 and 140 °C). In two experiments, it showed that extrusion processing with temperatures in the range from 100 to 150 °C did not affect digestibility of protein, individual amino acids or energy. Similarly, feed conversion and net accumulation efficiency (retention) of protein and energy were not significantly different in trout fed diets extruded at 100 and 140 °C. In line with these results, Barrows et al. (2007) found no significant effect of extrusion temperature on apparent digestibility coefficients of protein, organic matter, lipid, energy or carbohydrate in diets containing soybean meal for rainbow trout. The feed produced from high extrusion temperature (127°C) resulted in improved FCR of fish compared to feed produced from low extrusion temperature (93°C) (Barrows et al., 2007). This indicates that feed extruded at the highest temperature of this experiment was better utilized either due to improved availability or utilisation of the nutrients or favourable feed structure. Effect of extrusion temperature on physical quality was investigated by Aarseth et al. (2006). Feed produced at the lowest temperature, 100°C, showed a significantly higher durability and hardness compared to feed produced at 140°C.

In our experiment in ICAR-CIFA, the effects of quality of floating feed from locally available ingredients on different extrusion temperatures were studied. There was no significant difference in floating time, sinking time and proximate composition of feed when the temperature of extrusion was 130°C with pressure 10 kg/cm² (Das et al., 2018).

Moisture

In general, low moisture content, especially in combination with severe heating; have shown to cause reduced digestibility of nearly all amino acids in fish meal, especially cysteine (Andorsdòttir, 1985). Reduced digestibility of cysteine was also shown in rainbow trout when water addition to the extruder was restricted, compared to when the diet was produced at elevated moisture conditions (Sørensen et al., 2002). Cysteine reacts readily during heat treatment to form disulphide bonds between cysteine units. The reduction in cysteine digestibility in heat treated proteins has been explained by introduction of SS bonds, assumed to be resistant to proteolytic cleavage. The improved performance of shrimps fed diets extruded at elevated moisture contents also emphasizes the significance of moisture during processing (Obaldo et al., 2000). From this, it can be concluded that “dry” extrusion conditions should be avoided. In order to prevent losses of essential nutrients, a moisture content of 25-30% during wet extrusion of diets for fish and pets has been recommended (Rokey, 1994). In our feed mill, moisture content of 20% was maintained for preparation of
quality floating feed for carp.

**Protein source and starch level in ingredients**

Various protein-containing ingredients in combination with starch affect expansion of the extrudate differently. It has been reported an increase in expansion when soy protein isolate was added to pure starch, whereas gluten protein caused reduced expansion (Faubion *et al.*, 1982). The results also showed that expansion increased linearly as the starch level was increased. Increasing the starch content from 0 to 10% did not result in any significant increase in expansion, but the expansion increased significantly at higher starch inclusion levels. Starch gelatinization increased significantly with increasing amount of starch in the SBM diet, whereas the FM-diet showed decreased starch gelatinization with increased starch level. There was a significant difference in expansion due to protein source. The highest expansion was observed for the fish meal diet. As starch level increased, the differences in expansion among protein sources became more pronounced. In the Feed Mill at ICAR-CIFA, it was observed that, increasing the maize level in the diet produced better quality floating feed compared to low level of maize.

**Quality of feed ingredients**

The qualities of feed ingredients affect the quality of floating feed. High physical quality of the feed pellet is necessary in order to minimize feed wastage and thereby maximizing feed intake and feed conversion. The pellet must be durable and remain in one piece until eaten by the fish, since dust and small fractures of the feed are not ingested and will result in poor feed conversion ratio. Fish do not physically disrupt the feed in the oral cavity but gulp the pray whole (Steffens, 1989). If the feed is too hard, the pellet may stay intact during passage through the gastrointestinal tract, and the nutrients may be unavailable for enzymatic degradation. The ingredient compositions affect physical quality of the feed. Moreover, physico-chemical properties of different ingredients seem to affect extrusion processing parameters, and thereby pellet quality. In one of the experiments at ICAR-CIFA, Bhubaneswar, it was indicated that, the floating feeds developed by replacement of soyabean meal with ground nut oil cake and till oil cake are superior to floating feed prepared by inclusion of only soyabean meal and this may be economic for the farmers (Das *et al.*, 2016; 2018).

**Other conditions**

Other conditions like screw speed and rate of flow of ingredients to the extruder affect the quality of floating feed.
EVALUATION OF FLOATING PELLET

The floating feed must be evaluated in order to ascertain quality. The evaluation may be of physical or chemical.

Physical evaluation

a. Strength of rupture

Hardness or strength at rupture, defined as the maximum force needed to crush a pellet, is commonly determined using a texture analyser. This method assesses resistance to breaking when pellets are exposed to external pressure, and can be used to mimic the force on pellets during storage in bins or silos, crushing of pellets in a screw conveyor, and crushing of feed pellets between animal teeth (Kaliyan and Morey, 2009). Despite, the reliability of the test, there is a lack of standardization for analyzing the texture of feed pellets. The result of the test may also vary with the various probes and attachments used. Hardness may be reported as shear force if a knife is used or pellet hardness if a flat ended probe is used. Hardness of the pellet varies with degree of expansion, ingredients and processing conditions.

b. Water stability

Water stability of feed is an important quality trait for slow eating aquatic animals. Feed has to be soaked in water for hours with minimum leaching of nutrients. The water stability was calculated as the difference in DM weight before and after incubation in water.
divided by DM weight of the feed before incubation. A procedure to determine water stability over time was described by Baeverfjord et al. (2006). In general, the feed having better water stability is preferred even for fast eating carp. Floating and sinking pellets of higher water stability are selected for feeding of fish specific for a particular species.

c. **Bulk density**

Bulk density is an important property that determines floatability or sinking velocity of pellets and is directly related to the degree of expansion during extrusion. A floating pellet is more expanded and has a lower bulk density compared to a sinking pellet. Bulk density of pellet needs to be adjusted according to feeding management practices and feeding habits of the target species, and usually a bulk density greater than 525 g/L is needed for sinking pellets in seawater 35 g/L. Bulk density is analyzed by filling up a measuring cylinder of known volume. Pellets are carefully poured into a tared cylinder until a pile of feed has developed on top. A scraper is used to remove the excess feed by pulling once gently over the edge of the cylinder. The content of the full cylinder is then weighed on a balance. In order to standardize the procedure, pellets should be poured from a funnel, preloaded with feed, and the cylinder should not be tapped prior to weighing. Each measurement should be carried out in triplicate, and bulk density for each replicate is calculated as mass of the sample to the unit volume of the sample (g/L). Volumetric displacement methods can also be used to measure specific density of the pellets with improved accuracy.

d. **Durability**

Durability is the amount of fines produced from a sample of pellets after being subjected to mechanical or pneumatic agitation. Pellet durability simulates forces on pellets taking place during filling of bins, during transportation from the feed factory to the farm, and during distribution in the feeding system at farms. Pellets with high durability form fewer small particles and fines during bagging and storage and finally, show low degradation in feeding devices when fed to fish. Different devices have been developed to assess durability of pellets; however, most of these cannot be used on oil-coated high energy extruded feed.

e. **Fat absorption**

Oil absorption is determined as weight increase of sample (g) divided by initial weight of sample (g) and they multiplied by 100. Oil leaking can be determined as the loss of oil from pellets. Leaking of oil from high energy diets is a problem because of lowered energy content and different nutritional profile. Oil leaking from the pellet should be avoided. Research has shown that oil leaking is affected by choice of ingredients and processing conditions. Sørensen et al. (2010) found that oil leaking was not associated with oil level in the feeds, but was related to feeds with low absorption capacity. Neither was oil leaking correlated with expansion of the pellet or other physical quality parameters. Most likely oil leaking is related to microstructure of the pellet. Expansion of the pellets is correlated to oil absorption capacity.
**Chemical evaluation:**

The floating pellets can also be evaluated by chemical evaluation. The chemical evaluation may be of different types.

*a. Proximate composition*

It is based on the separation of feed components into groups or fractions in accordance with their feeding value. These nutrients are known as proximate principles of feed or proximate analysis of feed. The various fractions are water, crude protein, crude fat or ether extract, crude fibre, nitrogen free extract and mineral matter or ash. Proximate composition is very common practice for feed evaluation. The gross energy (GE) is calculated by using bomb calorimeter.

*b. Amino acid and Fatty acid composition*

The primary function of protein is to supply the amino acids. Therefore, the requirement of protein is essentially the same as requirement for amino acids. The quality of protein depends upon the amino acids makeup of the feed. All the amino acids can be analysed by using amino acid analyser. The ingredients are initially hydrolyzed by 10 N HCl after which the amino acid composition is characterized by HPLC. In practical condition, the most limiting amino acids like lysine and methionine are also analysed by indirect method.

The dietary sources of lipid in feed are estimated through Gas Chromatography for qualitative fatty acid analysis. The feed materials are initially cold extracted with organic solvents i.e. chloroform and methanol and the extracted lipid were esterified and then analyzed by using gas chromatography where it is compared with standard fatty acid mixture.

*c. Mineral and vitamin composition*

Minerals are analysed in the laboratory both for major or macro minerals and minor or micro minerals. Atomic absorption spectrophotometer is routinely used for estimation of mineral in feed stuffs. However, by using near Infrared spectroscopy, all the minerals can be analyzed in very short period of time. The fat soluble vitamins namely Vit A, Vit D, Vit E and Vit K are analysed by the saponification process.

**Bioavailability/digestibility**

The potential value of feed for supplying a particular nutrient can be determined by chemical analysis, but the actual value of the feed can be arrived only after making allowances for the inevitable losses that occur during digestion, absorption and metabolism. These losses can be very correctly measured in nutrient digestibility laboratory to know the digestibility of feed stuffs. In the Fish Nutrition and Physiology Division of ICAR-CIFA, nutrient digestibility laboratory was set up and the digestibility of newer and nonconventional feed stuffs are measured in this laboratory. In this laboratory, the culture practice is conducted in a re-circulatory aquaculture mode where cylindro-conical tanks of 200 litre water capacity are used for collection of faecal matter of fish in order to calculate the digestibility of nutrients.
CONCLUSION

Lots of technologies have been developed in this area, some technologies are meant for farmers and some are of academic interest. Extruded feeds have many advantages like less waste, higher feed intake, improved feed efficiency, lower handling costs, easier storage and less bacterial contamination. The feeding of extruded feed for fish need to be popularized among the farmers of all regions of India where farmers are still using the mass feed.

Fig. 4. Different types of fish feed produced in the feed mill of ICAR-CIFA

ACKNOWLEDGEMENTS

Authors are thankful to the National Fisheries Development Board for undertaking a project (Upscaling and demonstration of nursery and grow-out carp feeds) under which this work was conducted and Director, ICAR-Central Institute of Freshwater Aquaculture, Bhubaneswar, India for providing logistic facilities to conduct this study.

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