Technical Article:

Aquaculture- Producing aqua feed pellets- R V Malik CEO Malik Engineers, Mumbai

As more of world's natural fisheries are depleted and demand of fish continues to rise, aquaculture will continue to grow, thus raising demand for healthy, commercially prepared fishes. Mostly, Aquaculture relies upon Extrusion cooking to produce feeds that are good mix and nutritionally available, but also in a form that is capable of moving through water column very slowly (floating) to be ingested. Thus the big dependency in aquaculture is selecting ingredients that when extruded will possess just right buoyancy, not migrate nutrients into water, with high palatability for specific fish species.


Fig 1) 2mm Floating Fish Feed Pellet produced on Extruder

Fish feed pellets are prepared either by pressed cut sheets or by Extrusion methods. This article will discuss about Ingredients and Extrusion process for producing the pellets.
Main ingredients include 1) Fish & Bone Meal 2) Soy protein (though it is not preferred by farmers being not easily digestible by many fish species) 3) Wheat 4) Starch 5) Blood Meal. Other ingredients like Vitamins, Minerals and Lipids (Fat Oil) are also added in producing pellets.

Fish meal
Fish meal is a well-known source of proteins which is strongly demanded by the animal feeds industry. This is due to its balanced amino acid content, which makes it an ideal feed for many domestic animals. Moreover, its use to adjust (improve) the amino acid content of other dietary protein sources also contributes to increase demand for fish meal.
As its name points out, fish meal is derived from captured fish, including whole fish, fish scraps from fillets, and preserves of industries. Most of the main capture fishery producers devote the main part of this activity to fish meal production.

The raw materials used in fish meal manufacture come almost entirely from species which are not often used for human consumption (either due their size, or because they are very abundant).

The fishmeal processing system consists of preserving initial fish proteins by means of a controlled dehydration, which extracts around 80% of the water and oils contained when fresh from fish. This leads to the production of a dry product, easy to preserve and easier to transport than the initial product.Fresh fish entering the manufacturing plant is first ground and then cooked in a continuous heating oven at 90-95 %, which in-turn coagulates proteins and lose their water-holding capacity. The hot mash is then transported to an endless screw or oil expeller,that presses it and squeezes out most of the remaining water and oils.

Pressed fish coming out of the press (press cakes)t hen cut into smaller portions and placed into a dryer on a steam heated surface. During the drying period, the mash is in constant motion and subject to an air jet which removes all the steam emitted.

The dried mash obtained is now called 'fish meal' and contains from 8 to 10% of water. However, if the moisture level is more than 11 -12%, there is a risk of the fish meal developing moulds. Generally, antioxidants are added when fish meal is introduced and taken out of the dryer, and by so doing ensuring the stability of the oils remaining within the fish meal.

Soy Protein:

Not all fish species have easy digestibility of soy protein, primarily due to increased carbohydrate content fraction. It is usually used as supportive additive with other easily digestible protein like fish meal which is rich in fish proteins.

Bean processing consists essentially of extracting the oil so as to concentrate the proteins. This process provides a very important by-product, namely soya oil, which is widely used as a raw material and oil for human consumption. This process also contributes to the elimination of certain anti-nutritional factors present in the raw bean.

The first step in processing involves the removal of the shell (cellulose) from the grain. The “bare” beans are then heated, on the one hand to reduce the activity of certain enzymes, and on the other to break the cellulose strands and facilitate the following steps. The heated beans are then mashed to form thin paste-like slices, which further facilitates the destruction of the cellulose structure and oil extraction. The product, now termed ‘whole soya cake’, still contains its oil and has around 40% protein, and as such is sold directly for animal feeding.

Next, the oil can be extracted from the whole cake by means of a solvent (such as hexane). After total evaporation of the solvent, there remains the solvent extracted soya cake, which in turn is widely used for animal feeding, and contains 45 to 50% protein.

Bloodmeal

Abattoirs or slaughterhouses produce many important by-products, such as blood

and bones, etc. which are often difficult to commercialize. Nowadays however, these by-products constitute the basic raw material of the bone and blood meals widely used in industry for animal feeding.
Considerable amounts of blood are produced by abattoirs, and this product is usually transported to drying ovens and converted into blood meal. Blood from different origins such as, sheep, goat, and poultry are usually stored and processed separately. However, so as to comply with basic sanitary measures, it is generally compulsory to store blood within cooling chambers and to ensure that the level of bacteria is kept within prescribed maximum limits.

The manufacture of bloodmeal

Fresh blood is kept cool at the factory, and sizeable particles filtered and the blood mass stirred so as to separate the fibrillar phase from the liquid mass. The fibrin is then heated up to coagulation and the coagulated mass divided and dried through a hot air stream (i.e. by spray drying). This method is particularly gentle (spraying a product in a hot airstream) and does not denature the proteins because the water evaporation cools down the hot air very quickly, thereby preventing overheating.

Wheat flour

Wheat is one of the most important cereals worldwide, and is used for making bread and for many other produces. It is also an essential raw material for livestock feeding, including fish.

Wheat in fish feeding

Starch products, especially wheat, are frequently used as binders for the manufacture of pellets; the gelatinizing property of starch when water-heated being useful for this purpose as the starch absorbs water and forms a gel. Moreover, when starch is gelatinized its digestibility improves considerably. Various starch types (wheat, barley, rice, maize or potatoes) can gelatinize but each one will have its own characteristics. In addition, all three starch types generally have the capacity to form a stable structure when subjected from high to low pressure during the extrusion process. It is this property which is used for feeds that must have a high lipid content, during the extrusion process the starch forms a cell structure with alveoli that can then be filled with oil instead of air and/or steam.
For carnivorous fish feeding purposes the starch must be considered as a supporting structure that gives the pellets their texture and together with the other dietary ingredients allows the formation of a binded diet. However, since the natural feeding habits and foods of seabass and/or seabream usually contain very small proportions of carbohydrates (ca. 3% glycogen, animal starch - glucose polymer). If excessive quantities of digestible starch are provided in the feed this may result in the accumulation of excess liver glycogen, which in turn may trigger a liver dysfunction.

Lipids:

Fish oils are a Co-product of the fish meal industry. Their nutritional characteristics regarding fatty acids make them indispensable for fish feed manufacture, and in particular their characteristic high content of n-3 unsaturated fatty acids (first double bond linkage in position 3), which are essential for a well balanced food formula for carnivorous fish species.
A large amount of fish oil arising from fish meal manufactures is re-processed in specialized facilities for diverse purposes; part of it being hydrogenated and mixed with other lipids, and transformed into margarine, mayonnaise and bakery compounds, and the other part used directly by the feed industry.

Minerals:
Minerals are measured as ash in the recipe. Though they serve no functionality in extrusion (on the contrary their abrasive nature will accelerate wear & tear of working parts in extruder), these are usually added in proportions < 5%. They include phosphorous, calcium (from calcium carbonate or ground lime stone), sodium chloride (salt), magnesium, potassium, Etc.
Vitamins:
They can be water soluble or soil soluble. Vitamin B&C are water soluble, A,D,E, &K are fat soluble. They are added in proportions < 0.5-0.6% in diet, but due to harsh processing conditions inside the extruder, these get destroyed, hence they are added well in excess of min requirements.

Apart from above, the feed may contain, Flavors/Aromas, Antioxidant (preservative) & antimicrobials, Dyes & Pigments (for human appeal and distinction, rather than for fish itself), Etc. It is important to use Certified ingredients that does'nt affect health of fish. Pigments are usually added as a coating step, to minimize losses during harsh extrusion processing conditions.

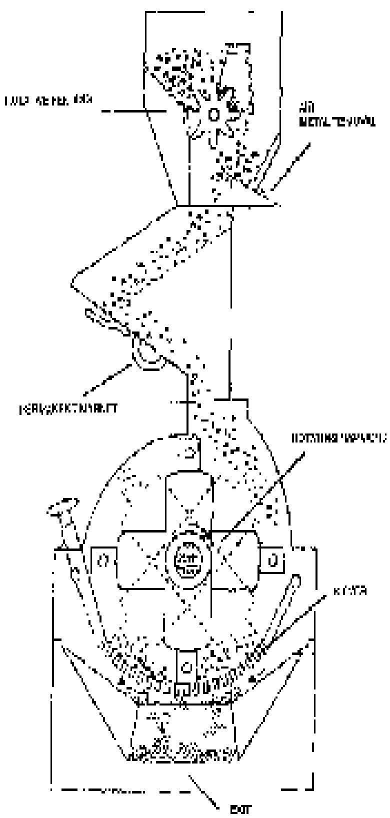
Formulation of Fish Feed:
As we have seen, feed formulators can resort to a wide assortment of raw materials to make up a food mixture so as to meet the nutritional requirements of the fish for energy, amino acids, fatty acids, carbohydrates, vitamins and minerals.
These raw materials are generally used in flour or liquid form, and will have to undergo binding by means of a technological process to obtain a food mixture in the form of dry pellets, which are easy to use and preserve.
As a guide, Salt Water marine aquaculture is dependant upon high levels of proteins with high digestibility. The fresh water aquaculture relies upon more carbohydrates, i.e high levels of grains coupled with modest to high quality proteins, minerals, vitamins with little or no fiber.
The first factor to be considered for feed formulation is the total energy and protein/energy ratio of the final product. After this, the protein content must be calculated according to the amino acid balance desired, and the lipids included to satisfy the best fatty acid profile for the species concerned and the energy level desired. All this must be considered taking into account the vitamin and mineral

requirements of the cultured species.
This formulation is not easily reached and so computerized linear programming techniques must be used. Furthermore, it is also necessary, after covering all the nutritional requirements of the species within the formula to also produce a range of tasty feeds of different pellet sizes for the different age classes.

Manufacturing stages

Storage

The raw materials coming into the feed manufacturing plant are generally stored in silos with an ideal height calculated so as to allow the raw material flow to be conveyed downwards, during the manufacturing process, until the final product is produced. This is in order to avoid having to pull the products up by vertical conveyors that usually cause breaks and dust in the final product.



Grinding

Grinding raw materials reduces particle size and increases ingredient surface area, thus facilitating mixing, pelleting and digestibility. The most commonly used grinders are hammer-mills, for fish feed manufacture, as plate-grinders do not generally produce fine enough ground materials.
The Extrusion cooking process utilizes wide variety of ingredients that can have varying particle sizes. It is desirable, but not necessary that all ingredients be of uniform particle sizes, to prevent segregation during mixing and transport prior to extrusion. Uniform particle size of ingredients promotes better mixing and uniform moisture uptake by all particles during the preconditioning step.
If the particle size of raw ingredients is too large, the final product may contain particles which are improperly cooked, which degrade product appearance and palatability. Also, if particle size is larger than die orifice used at extruder discharge, it may cause plugging of some orifices affecting capacity and appearance. As rule of thumb, it is necessary to maintain size of raw ingredients one third of the die opening die. Hence the need of size reduction equipment and sifting.
In hammer-mills, the grinding chamber consists of a series of mobile hammers on a rotor. The hammers, by centrifugal force, position themselves forming a star on the rotor and split the incoming feedstuff apart, which is then forced by depression through a metal grid composed of appropriately sized meshes.

Mixing
The ground ingredients must be mixed according to the desired proportions to obtain a homogeneous mixture. If the grinding process is correctly developed, the particles are homogeneous in size and the mixture produces pellets which statistically have the same formulation.
Generally, the dry ingredients (flours) are first mixed, followed by the liquid components. Continuous mixers are designed so that the feedstuff moves along the mixer as it mixes. There are many different types of mixers, including horizontal band-mixers, vertical mixers, conical screw-mixers, and turbine mixers, etc.
During this mixing process, the vitamin “premix”, the binding agents and other additives are added; they must in turn contribute to one or other particular desired quality of the pellets during the pelleting process.
Pelleting
Two different types of pellets are generally prepared for aquafeeds, namely pressed and extruded pellets. A third type, designed as ‘expanded feed’, is also marketed by some manufacturers.
The main difference between a pressed and an extruded feed is the cooking of the feedstuff in the case of extrusion, with the added mechanical and biological advantages previously described, especially with regard to starch gelatinization

Extruded Feeds:
The Extruder can be described as a Bio-Reactor with(mostly) a single, multiple flighted screw (Rotor) rotating at high speed inside a stationery hollow tube (stator). The Raw-materials fall from top at one end on the rotating screw which has multiple flights and varying pitches along its length. The barrel (tube) is externally heated/cooled by steam and cold water externally around. Due to this arrangement, a high pressure of around 40-70 bars (Kg/.cm2) is developed on the ingredients, temperature of ingredients varies from 110 C to 160 C, which ensures cooking of ingredients into plastic mass which is extruded out of multiple die openings/orifices and cut to produce porous pellets for fish feed.

Pre-Extrusion: Dry ingredients after having been mixed & ground thoroughly in desired proportions, are usually transported to the Single screw Extruder (Cooker) provided with a Pre-conditioner at top.

The Feed Delivery System: It consists of a “Live Hopper” or Bin with a horizontal conveying screw to convey dry ingredients to the Preconditioner from above. The Bin is provided with device which avoids bridging of material (since raw ingredients have low bulk density and poor flow through a normal Hopper) and ensures continuous flow of materials to the Preconditioner below, hence the name “live” bottom bin. It should hold adequate volume to support the extruder operation for minimum 5-8 min., as a buffer time for the operator and auto control network to respond and allow recharging the bin from top. The screw is provided with variable speed motor to properly adjust the flow as per production capacity of the Extruder.

Preconditioning: This step ensures the dry ingredients are constantly added with moisture (water) in desired proportions (25-30%) and steam is also added, at 5-6 bar, for pre-cooking the wet ingredients. As the ingredients move forward towards the Extruder feed opening, they are held at temperature of approx. 100 C and atmospheric pressure. Preconditioning makes the ingredients soft by precooking and it reduces energy requirement in the Extruder. If Lipds are to be added, their proportion is limited from 5-7% in this stage.

Conventional Preconditioner had only one tank and single agitator, but modern preconditioners have special oval tanks with 2 agitating shafts with adjustable beaters to control residence time inside the tank. 2 Agitators results in better mixing of dry and liquid ingredients. Longer retention time approx. 2-2 ½ min. are desirable before feeding into the Extruder. Usually lipids are added not more than 5-7% by weight here, since it leads to excessive slippages inside the Extruder and poor mixing & expansion/texture of final pellets.

Extrusion

Usually single screw Extruders with single barrel and screw is used for cooking the preconditioned ingredients, but twin screw extruders are also used. The latter have limited use because of high initial capital costs compared to single screw extruder.
The action of Extruder allow the free flowing ingredients to bond to each other and remain in pellet form after exiting from shaping (pelleting) die. It does this by the action of rotating screw or spiral inside a stationery barrel by generating high mechanical shear and raised temperature on feed materials.

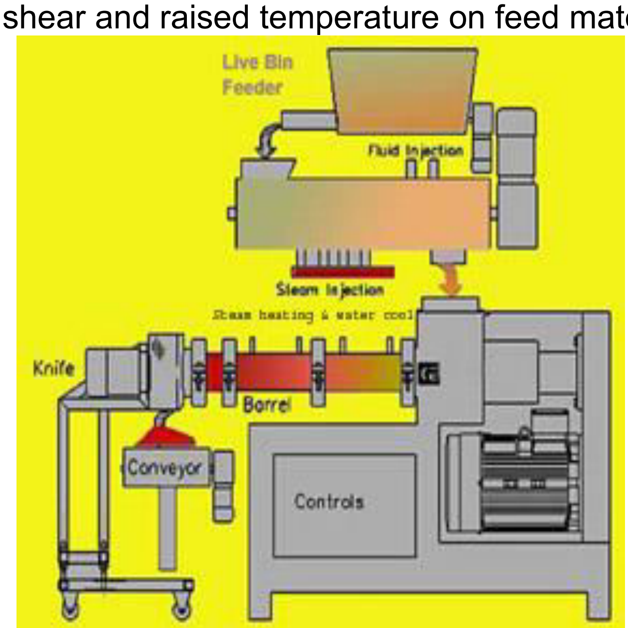


Fig 3) Schematic Diagram of Extruder with Preconditioner used for Fish feed production

Extruders for Fish Feed production have Mechanical Energy Input levels between 20-40 Kw-hr/ton of produce. Their screws run between 400-1000 RPM depending on sizes. Output capacities range between 1 t to 20 t per hour.
The Extruder usually employed is “Wet Extruder” since feed materials contain around 25% to 30% moisture (water). Both screw and the barrel are made up as separate segments so that individual components could be replaced when worn. Multiple flighted, varying pitch screw elements are usually employed to provide cooking and forward conveying of feed materials. The Volumetric capacity of screw is highest at Feed zone to account of low bulk density of ingredients. However, it reduces (lower pitch) towards the die, which causes compression and cooking of feed material. The final discharge end of screw is usually Conical to generate high pressure and attain maximum expansion of pellet when emerging from die opening. The barrel heads are provided with Steam Heating and water cooling Jackets around, for heating or cooling, as per process demand. The process temperature is held from 110 C to 160 C. gradient from Feeding Zone to Final Cooking Zone. Maximum conveyance & mechanical shear of material is ensured by action of multiple flighted screw elements and spirally grooved barrel segments .Water present inside the mixture is held as steam at high temperature and pressure. However, as soon as the cooked mass emerges out of die openings pressure drops to atmospheric and the product expands or “puffs”, being cut continuously by Rotating Die Knives working against the die Face, giving the pellet the specific rounded shape for extruded pellets.
Retention time inside Extruder is from 100-180 sec which ensures 70-85% starch Gelatinization and production of good shape and density.

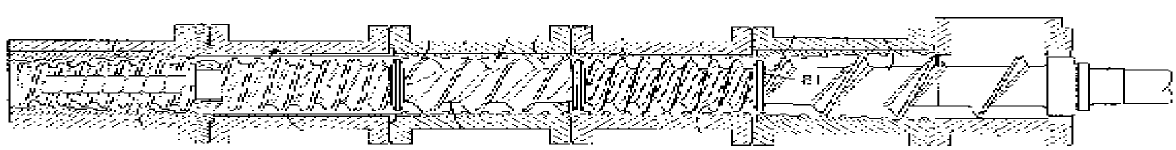


Fig 4) Screw & Barrel segments of Extruder for Aquafeed pellets

The above Extruder produces Floating Pellets with low bulk density, e.g 350-450g/l which are classified as “Floating” and sink very slowly into water column. Most Extruders have an arrangement, whereby the water vapour present in the mix is released by a vent opening on the barrel so that high density pellets or sinking pellets are produced for certain species of fish.

The following parameters will control the final pellet density: 1. Initial moisture content (usually 25-30% on wet basis)2. Process tempt. 3. Extruder back pressure. 4. Extruder RPM (residence time). 4. Drying conditions and temperature. 5. Quantity of Fats, vitamins & minerals applied post extrusion.

Drying
When added to Extruder, the ingredients contain around 25-30% moisture (wet basis). Extrusion process evaporates approx. 4-7% moisture thus still retaining considerable moisture inside the pellets. After the pelleting process, the pellets usually have a high moisture content (17 to 22%) that must be quickly reduced to avoid spoilage. This is usually achieved by using a hot-air drier, which lowers the moisture level to between 8 and 10% depending upon the manufacturing process.
Continuous Belt Dryers are commonly employed that provide heated air to remove excess moisture from wet product, as it travels on multiple decks of perforated steel belting. Since the Drying process is critical and determines the quality of pellets, it needs to be carefully monitored and controlled. The Air Temperature, Humidity and Residence time of products should be carefully adjusted to attain properly dried product that can absorb maximum fats and coatings in the Coating step.

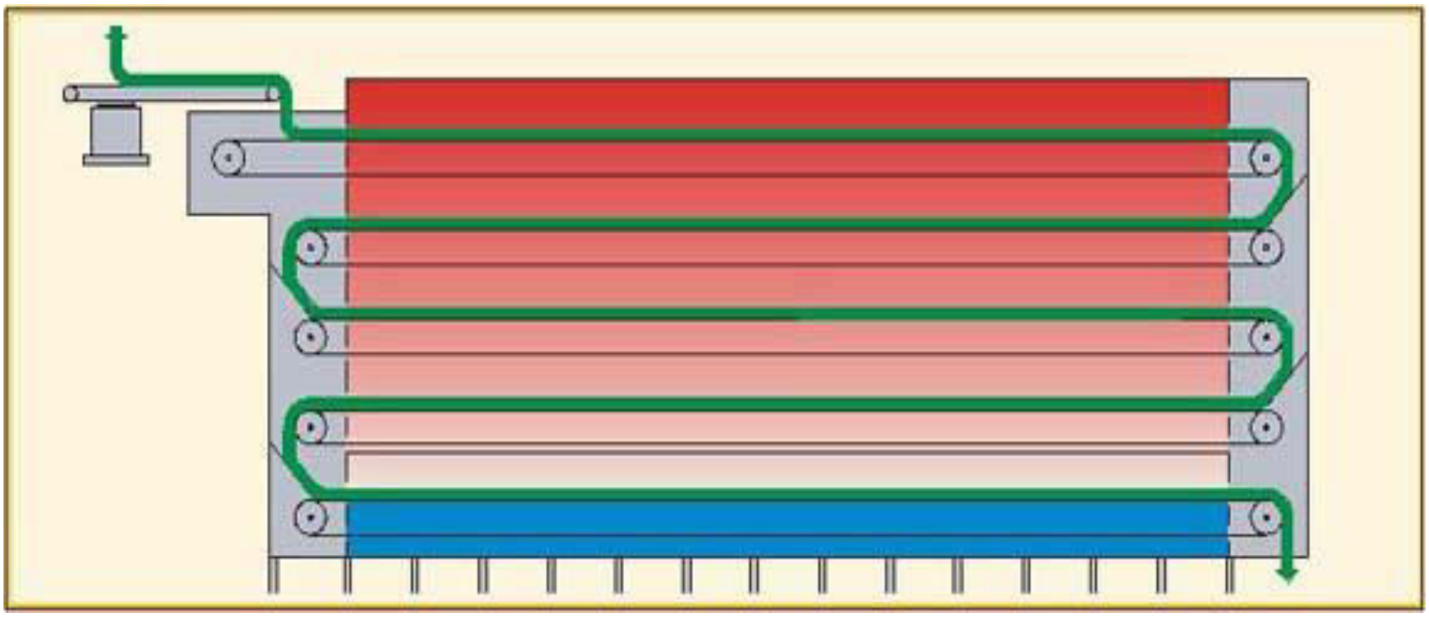


Fig. 5) Schematic Diagram of 3 pass Belt Dryer for Drying Fish feed pellets of excess moisture

Sifting
The mechanical manufacturing processes inevitably results in shocks and scorching that partially crumble the pellets at their surface and cause various breaks and dust that must be eliminated. This is achieved by sifting, a process that is generally applied at least twice before the final conditioning (sifting after drying and after coating/cooling).

Coating
The pellets emerging from the pelleting presses or extruders do not generally contain more than 7 to 10% lipid. To achieve higher dietary lipid levels (20-27%), coating is necessary with the appropriate oils, generally using heat. In the same manner, certain heat sensitive vitamins and/or drugs that would not normally withst

and the harsh extrusion processes (thermo labile products) can also be added later during the coating process. These ingredients are usually added through spray nozzles fed through dosing pumps which accurately control the weights deposited. They can be vacuum assisted for still more good results.
The Expansion that occurs as a result of extrusion processing, makes the product porous with low bulk density and air pockets, so that more oil is absorbed during the spray coating process. Fats could be added in the form of Animal fats, Fish Oil or Vegetable Oil.

Cooling

On completion of the coating process (generally undertaken with heated material) the pellets are then cooled and sieved before the final conditioning; cooling occurring in a cool-air flow generated by a cooling-machine. Again, this machine usually provides continuous flow of product on perforated steel belts, while cooling air is applied through bed of pellets to lower the temperature.
Cooling is important, since if packed in hot state, moisture will condense in the packing, wetting the outer surface of the pellets, allowing mold growth. It is desirable to cool down within 10 C of ambient air tempt. So that problem of condensation in packing doesn’t occur.

Bagging

Bagging usually produces different types of feed presentations within the same factory, namely either small bags (20 or 25 kg) on pallets covered with a plastic film, or big-bags (500 or 1000 kg) in bulk.

Viability of Extrusion process:

It follows from the higher temperatures and pressures used during extrusion processing that investment and energy costs will be higher than those of conventional pressed feeds. Despite this however, the use of extruded feeds may be more profitable.
Following Table (illustration) summarizes the theoretical results obtained with fish fed a pressed (A) or extruded (B) feed.
Table showing Justification for Extrusion Over Press Feed production method for Fish Feed.

	FEED A	FEED B	B / A Difference
(1) Growth	1	1.1	10%
(2) Conversion rate	2	2	*0%*
(3) Feed price / kg	*5*	6	+20%
(4) Selling price of fish	50	50	0%
(5) Feed expenditure for 1 kg of fish produced (2) x (3)	10	12	+20%
(6) Profit from fish sales (1) x (4)	*50*	*55*	+1 *0%*

(7) Gross margin for feed item (6) - *(5)*	40	43	+7.5%

It is clear from the example given that despite the fact that the price of the extruded feed is 20% higher, the feed which provides 10% additional growth provides a 7,5% additional gross margin.

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