Appropriate Trout Feed Protects Environment and Results in Valuable Human Foodstuffs

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SUMMARY

Development in research and production of trout feed during the last years led to a remarkable reduction of the environmental impact by improving the diet composition. Important steps were the minimizing of the phosphorus content, the use of extruded feed instead of pelleted feed and the increase of the energy (lipid) level. Lipid-enriched high-digestible diets with low phosphorus level are well utilized, enable rapid growth of trout and contribute to decrease of aquaculture waste by diminishing the excretion of phosphorus, nitrogen and organic matter. New considerations are related to stabilizing the trout faeces by adding guar gum to the feed. In future substitution of fish meal with vegetable meals will support the conservation of marine fish populations. Enrichment of trout feeds with fish oil results in marketable fish with substantial concentrations of eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). These n-3 polyunsaturated fatty acids are favourable for human health and have a beneficial effect especially in preventing cardiovascular diseases.

Key Words: Feed composition, lipid enrichment, digestibility, fatty acid composition, environment protection

1. INTRODUCTION

In general feed is a significant cost factor and calls for at least 40 % of overall expenses in aquaculture (PILLAY 1995). Therefore, feed quality and feeding need considerable attention in trout production.

Above all feed for trout and other fish species has to satisfy the following requirements:

- It must contain all essential ingredients e.g. indispensable amino acids, essential fatty acids, necessary vitamins and minerals;
- it has to meet the energy demand;
- it must be attractive to fish;
- it must be well digestible;
- it must support fish health;
- it must result in fast growth of the fish and good feed conversion ratio;
- it must guarantee reproductiveness of the fish;
- it must protect the environment;
- it must ensure the production of valuable human foodstuffs;
- it must be easy to obtain and cheap.

In the following paper I will discuss the possibilities for protection the environment by appropriate feed composition and the feasibilty of producing high-quality human foodstuffs.

2. ENVIRONMENT PROTECTION BY SUITABLE FEED COMPOSITION

2.1. Minimizing the phosphorus content

Phosphorus is an important body constituent (skeleton, nucleic acids, cell membranes) and essential for all energy-producing cellular reactions. The diet is a substantial source of this mineral (LALL 1991). However, since phosphorus discharge promotes eutrophication of waters it is necessary that the feed only contains the absolutely indispensable level of phosphorus to meet the nutritional requirements for growth and health. On principle trout can utilize dietary phosphorus very well and much better than e.g. common carp (OGINO et al. 1979, STEFFENS 1989).

Decisive aspect is the physiological availability of phosphorus. Feedstuffs of animal origin like fish meal are rich in bioavailable phosphorus. On the other hand in vegetable ingredients phosphorus often is present in the phytate form which is unavailable for most finfish. By adding microbial phytase the digestibility of phosphorus from plant ingredients can be improved considerably (RODEHUTSCORD and PFEFFER 1994, RICHE and BROWN 1996). But since phytase is sensitive to increased temperature the enzyme does not tolerate extrusion or expansion process.

Trout require more dietary P for bone mineralization than for weight gain (KETOLA and RICHMOND 1994). The physiological requirement of rainbow trout fingerlings for non-phytin phosphorus is about 0.54 to 0.61 % of the diet. Today in high-energy diets for rearing marketable rainbow trout the phosphorus content generally is less than 10 g/kg dry matter of feed.

Table 1 shows the feasibility of reducing the phosphorus excretion of rainbow trout by using high-energy feed with a low level of available phosphorus. Already several years ago investigations in Scotland have confirmed that improvement of feed composition and feed utilization resulted in reduced phosphorus pollution amounting to far less than 10 kg P/ t trout production (GAVINE et al. 1995).

Table 1. Calculation of phosphorus excretion by rainbow trout (g P/kg weight gain) depending on feed conversion ratio and dietary phosphorus content (PFEFFER 1989)

Feed conversion ratio (kg feed/ kg gain)	Dietary phosphorus content 20 g/kg	10 g/kg
1.50	26	11
1.25	21	8
1.00	16	6

2.2. Extruding

Manufacturing of pelleted feeds for trout and other species contributed considerably to the successful development of aquaculture and especially trout culture all over the world in the years after about 1960 (HARDY 1989). Since the last decade of the 20th century production of fish feed by extrusion was introduced. Thereby a new phase in fish feeding started.

The principle is as follows:

Ground ingredients were mixed and after adding some water conveyed by auger into a pressure cylinder. Then steam is injected and thereafter the mixture is extruded to atmospheric pressure (PILLAY 1995).

The benefit of extruded feed is:

- that raw starch is gelatinized by the hydrothermic break-up and by that means its digestibility is improved;
- that gelatinized starch has a good binding capacity for the feed particles which results in fewer fines, and floating and slowly sinking feed can be produced;
- that a supplementary addition of high amounts of lipid is possible in order to enlarge the energy content of the feed.

The intermediary utilization of starch by trout is limited and, therefore, the carbohydrate content of trout feed should not be to high. Nevertheless, gelatinized starch is better digested than raw starch (Table 2). This leads to a protein-sparing effect and a better feed conversion ratio which reduces the faecal wastes (STEFFENS 1993).

Table 2. Digestibility of native and gelatinized corn starch (dietary content 30 %) depending on the daily feed intake of rainbow trout (BERGOT and BREQUE 1983)

Daily feed intake (%)	Digestibility (%) native starch	gelatinized starch
0.5	55	90
1.0	38	87

2.3. Lipid enrichment

As already mentioned production of feed by extrusion enables a substantial lipid supplementation up to 25-30 %. Today especially fish oil is used, however, several plant oils can also be added for partial substitution of fish oil in trout feeds. Most oils are well digested by trout. Digestibility often comes to 90 % and more.

Lipids are nutrients with the highest energy content. Lipid-enriched high-energy diets generally result in excellent energy digestibility, fast growth and favourable feed conversion ratio.

An example of successful rearing of trout using high-energy diets containing high levels of fish oil is given in Table 3. Good results with regard to feed conversion ratio were received when the daily feed intake of the extruded feed with the highest lipid content was confined.

Table 3. Growth and feed conversion ratio (FCR) of rainbow trout (50 g initial weight) fed high-energy diets of different composition at 12 °C (ALSTED 1991)

	A	B	C	D	E	F
Feed composition (%)						
Protein	38	36	33	28	47	28
Lipid	19	24	29	38	24	38
Carbohydrates	27	25	24	21	11	21
Daily feed intake (%)	1.5	1.6	1.5	1.6	1.4	1.2
Specific growth rate (%)	1.53	1.85	1.61	1.58	1.40	1.33
FCR (kg feed/kg gain)	1.00	0.85	0.94	0.98	1.01	0.86

A – D: Extruded feeds differing in composition;
E: Pelleted commercial feed;
F: The same feed as D, but reduced feeding rate (70 %).

Experiments concerning the use of vegetable oils in trout feeds started already more than 30 years ago (STEFFENS 1977, 1989). Today we know that a substantial replacement (at least 50 %) of fish oil by plant oils is possible without compromising growth and feed conversion ratio (Table 4). In experiments with Atlantic salmon fed diets based on complete replacement of fish oil with plant oil no adverse intestinal stress could be observed (OLSVIK et al. 2007).

Table 4. Growth and feed conversion ratio (FCR) of rainbow trout (250 g initial weight) fed diets containing different lipid sources (CABALLERO et al. 2002)

	A	B	C	D	E
Dietary lipid content (%)	29.7	30.0	30.9	29.5	29.1
Lipid source (%)	100 capelin	50 anchovy 50 soybean	39 anchovy 61 rapeseed	10 anchovy 30 olive 60 lard	20 capelin 40 rapeseed 40 palm
Lipid digestibility (ADC, %)	92.5	92.0	93.9	79.2	90.9
Specific growth rate (%)	1.81	1.72	1.73	1.76	1.79
FCR (kg feed/kg gain)	0.73	0.72	0.73	0.79	0.76

However, digestibility of hard fat (e.g. pork lard) often is lower than that of vegetable oils and by that means feed conversion ratio is impaired. According to histological investigations an impact of dietary lipid source on the transport and/or metabolism of fat in the fish is suggested (CABALLERO et al. 2002). Thus a good balance of polyunsaturated fatty acids to saturated fatty acids in the diet is necessary. No negative effects on digestibility and growth even at low temperatures (7.5 °C) were observed when rainbow trout were fed diets with partial substitution of fish meal by beef tallow (BUREAU et al. 2008). In future it can be expected that e.g. the cultivation of soybeans containing enhanced levels of n-3 fatty acids is possible.

Elevated levels of non-protein energy (lipid + gelatinized starch) in the feed result in a protein-sparing effect, since less protein is utilized for energy purposes (STEFFENS 1981). Thus a balanced relationship between digestible protein and digestible energy contributes to the reduction of nitrogen excretion of the fish and to protection of water quality.

Improving of the feed efficiency ratio by using well digestible high-energy diets does not only result in minimizing the nitrogen load but also in remarkable reducing the organic load of the water (Table 5).

Table 5. Calculation of the organic load of water by trout faeces depending on different feed conversion ratio (PFEFFER et al. 1991)

Feed conversion ratio (kg feed/kg gain)	Digestibility of organic matter (%)	Expenditure of organic matter (g) for 1 kg gain	Organic matter (g) from faeces for 1 kg gain
1.2	75	1020	255
1.0	80	850	170
0.8	85	680	102

2.4. Stabilizing trout faeces

Land-based trout farms often use microsieve filtration for removing particle-bound waste load, mainly faeces, from the effluent water. By addition of a binder to the feed it is possible to enhance faecal stability and by that means to increase the separation of total suspended solids, total phosphorus and total nitrogen.

A suitable binder is guar gum. It is a linear polysaccharide (galactomannan) derived from the endosperm of the Indian cluster bean (*Cyamopsis tetragonolobus*). Inclusion of about 0.3 % of guar gum to the diet does not affect apparent digestibility of nutrients, growth rate and feed conversion ratio of the trout. No sign of pathological alteration in the intestine was observed (BRINKER et al. 2005, BRINKER 2007).

The inclusion of 0.3 % high-viscosity guar gum resulted not only in improved faeces stability but also in larger suspended particles from binder-stabilized faeces compared to the control. When using a 100 µm gauze a reduction in the post-microscreening residual load of about 50 % was obtained. Thus adding of this binder to the feed is a useful tool for diminishing the effluent load of land-based trout farms.

2.5. Substitution of fish meal

By reason of its amino acid composition fish meal is the best possible protein source of fish feeds. But it has to be considered that global marine fish catches are stagnating or decreasing and therefore fish meal will become scarce and more and more expensive in future. Conservation of fish populations is of general interest and fish should preferably be used for human nutrition directly.

Thus from the ecological and economical point of view it is necessary to replace the fish meal with other protein sources, e.g. poultry by-product meal, vegetable meals, yeast or bacterial biomass. Often in this connexion supplementation with synthetic amino acids, especially methionine and lysine, is inevitable. In some plant meals anti-nutritive compounds can be found which must be removed or reduced before using them as feed ingredient.

In March 2006 the project AquaMax "Sustainable Aquafeeds to Maximize the Health Benefits of Farmed Fish for Consumers" started in the EU Framework 6. In this project 32 participants in 12 European countries are involved. Goal of this four year programme is to replace as much as possible of fish meal and fish oil in fish feeds with sustainable terrestrial ingredients and to keep and maximize the health-promoting quality of farmed fish.

3. PRODUCTION OF VALUABLE HUMAN FOODSTUFFS

3.1. Lipid quality

Rainbow trout like many other fish species exhibit an excellent protein quality based on a favourable amino acid composition. They are also a good source for vitamins and minerals, and the flesh is well digestible on the strength of low amounts of connective tissue. Special attention must be payed to the high lipid quality of the flesh of rainbow trout.

Fatty acid composition of fish is markedly influenced by the lipid pattern of the diet (STEFFENS 1989, COWEY 1993, STEFFENS and WIRTH 1995). Rainbow trout and other freshwater fish are unlike marine fish able to desatiate and elongate larger quantities of dietary linoleic acid (18:2n-6) and linolenic acid (18:3n-3) to polyunsaturated fatty acids, such as arachidonic acid (ARA, 20:4n-6), eicosapentaenoic acid (EPA, 20:5n-3) and docosahexaenoic acid (DHA, 22:6n-3) (TOCHER 2003).

Rainbow trout fed modern high-energy diets contain high levels especially of n-3 polyunsaturated fatty acids. As shown in Table 6 the sum of eicosapentaenoic acid and docosahexaenoic acid is 15.8 % in fish which received a diet with 12.9 % lipid and 24.8 % in fish which received a diet with 23.8 % lipid on the basis of fish oil (STEFFENS et al. 1999, STEFFENS and WIRTH 2005). But rainbow trout fed diets with partial substitution of fish oil for vegetable oils up to 50 % also show a favourable fatty acid composition (Table 7).

Table 6. Lipid content (% of wet weight) and content of selected fatty acids (%) in the triacylglycerols of two commercial diets and of the dorsal muscle of rainbow trout (250 g) fed these diets (STEFFENS et al. 1999)

Lipid and fatty acids	Diet I	Rainbow trout muscle fed diet I	Diet II	Rainbow trout muscle fed diet II
Lipid content	12.9	4.6	23.8	4.9
18:3 n-3	9.3	11.0	7.4	9.2
20:5 n-3	6.7	3.9	13.8	8.8
22:6 n-3	11.9	11.9	12.8	16.0
18:2 n-6	11.0	8.6	5.8	4.4
20:4 n-6	7.5	10.1	8.1	9.9
Total n-3	32.1	28.7	39.7	36.9
Total n-6	20.5	19.9	16.3	15.7
n-3/n-6	1.6	1.5	2.4	2.4

Table 7. Lipid content (% of wet weight) and content of selected fatty acids (%) in the total lipids of the fillets of rainbow trout (750 g) fed different lipid sources (CABALLERO et al. 2002)

	A	B	C	D	E
Dietary lipid content (%)	29.7	30.0	30.9	29.5	29.1
Lipid source (%)	100 capelin	50 anchovy 50 soybean	39 anchovy 61 rapeseed	10 anchovy 30 olive 60 lard	20 capelin 40 rapeseed 40 palm
Lipid content	9.3	8.4	9.7	7.5	8.9
Total n-3	18.6	20.3	16.1	13.5	13.3
Total n-6	5.1	19.9	11.3	10.0	11.0
n-3 PUFA	16.1	17.1	11.5	11.3	10.1
n-3/n-6	3.3	1.0	1.4	1.4	1.3

To improve the lipid quality in the muscle of rainbow trout that were fed higher levels of vegetable oils or lard in their diets as human foodstuffs it is possible to revers the fatty acid composition of the fish by using a finishing diet containing only fish oil for some weeks. Satisfactory corresponding results were achieved e.g. in experiments with Atlantic salmon and red seabream (BELL et al. 2003, GLENCROSS et al. 2003).

3.2. Significance of n-3 polyunsaturated fatty acids for human health

For a long while we know that n-3 polyunsaturated fatty acids have antiatherosclerotic efficacy (TERANO et al. 1983, STEFENS et al. 1993, SINGER 1997, 2000, STEFFENS and WIRTH 2005). This is mainly based on:

- Inhibition of synthesis of the vasoaggressive low density lipoproteins (LDL);
- Acceleration of LDL elimination;
- No influence on the vasoprotective high density lipoproteins (HDL) or even enhanced HDL production;
- Decrease in the total serum triacylglycerols;
- Shifting the eicosanoid balance in favour of the antiaggregatory fraction;
- Reduction of the platelet aggregation and prolongation of bleeding time;
- Reduction of blood pressure.

There is evidence that long-chain n-3 polyunsaturated fatty acids also have beneficial effects on diseases other than those of the heart and of the blood vessels (STEFFENS 1997).

They include:

- Inflammatory diseases (HIGGS 1986);
- Arthritis (KREMER et al. 1987);
- Nephritis (THAIS and STAHL 1987);
- Lupus erythematosis (Kelley et al. 1985);
- Multiple sclerosis (BATES et al. 1989);
- Strokes (HIRAI et al. 1987);
- Cancer (KARMELI 1987);
- Skin diseases (RHODES 1984, SINGER and STÄNDER 1990);
- Asthma (LANDS 1986);
- Age-related macular degeneration (CHONG et al. 2008).

In a recent investigation from Japan former results were confirmed (SEKIKAWA et al. 2008). In all probability the low rate of atherosclerosis and heart disease in Japanese people compared to white American and Japanese American men is related to high fish consumption resulting in high blood levels of n-3 fatty acids and low coronary artery calcification.

Since rainbow trout fed modern diets is a good source of n-3 polyunsaturated fatty acids we can state that this species is a valuable health-promoting food for humans.

4. CONCLUSIONS

Modern high-energy trout feeds protect the environment especially by reduced release of phosphorus, nitrogen and organic matter.

Modern high-energy trout feeds guarantee the production of health-promoting fish which are valuable foodstuffs for humans.

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