Factors Affecting Metabolic Waste Outputs in Fish

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Nitrogen (N) and phosphorus (P) metabolic wastes produced by fish are at the origin of most dissolved N and P waste produced by intensive aquaculture operations. Dissolved N and P wastes impose constraints on productivity of the operations and may lead to environmental degradation problems. Reducing outputs of these dissolved wastes is considered a key element for the long-term sustainability of aquaculture in many parts of the world.

The output of N and P metabolic wastes by fish is determined by numerous endogenous (biological) and exogenous (dietary, environmental) factors. Nutrition and feeding obviously have determinant effects on amounts of metabolic wastes produced. However, endogenous factors, such as fish species and size/age, may also have very significant impacts. It is necessary to improve our understanding of the basis and relative contribution of these various determinants in order to develop nutritional and breeding strategies aimed at minimizing waste outputs from fish culture operations.

1. Determinant of Nitrogenous Metabolic Wastes

Approximately 80-90% of N metabolic wastes excreted by fish is as ammonia. Urea generally only represents 10 to 15% of dissolved N waste outputs (Kaushik and Cowey, 1991). Other soluble nitrogenous compounds are also excreted but these only represent as very small proportion of nitrogenous metabolic wastes

The main factors affecting N metabolic waste outputs are those that influence the catabolism and deposition (retention) of amino acids (protein) by the fish. Amino acid composition of the diet is consequently a factor with a very significant effect on amount of ammonia produced by fish. Feeding amino acids in excess of requirement will result in the catabolism of these amino acids with associated excretion of ammonia. Diets formulated with protein sources of poorer amino acid profile will generally result in greater ammonia excretion.

The balance between digestible protein (DP) and digestible energy (DP) of the diet (DP/DE ratio) is another key factor. Numerous studies have shown that decreasing the dietary DP/DE ratio resulted in an increase in N retention efficiency and a decrease in dissolved N waste outputs of numerous fish species. The improvement in N retention and decrease in N metabolic wastes is due to the utilization of non-protein energy sources for meeting energy requirements, resulting in a reduction of catabolism of amino acid, in what is commonly referred to "protein sparing". Protein-sparing by dietary lipids has been shown to occur in most fish species. Protein-sparing by digestible carbohydrate has also been demonstrated but may be limited especially when the diet already contain a high level of lipids and/or a relatively low DP/DE ratio. Digestible N retention efficiency (N retained/digestible N intake), nonetheless, rarely exceeds 50% in rainbow trout and 60% in Atlantic salmon fed diets with low DP: DE (16-18 g DP/MJ DE). It is not clear to what extent this significant catabolism of amino acids, despite ample supply of non-protein energy (indicated by high lipid deposition), is related to inevitable losses (maintenance requirement, inevitable catabolism) of amino acids or catabolism of amino acids that are in excess of requirement. Recent studies with rainbow trout have shown that preferential catabolism of essential amino acid for energy may be important even when intake of these amino acids is limited (Encarnação et al., 2004).

Water temperature is frequently assumed to have a significant impact of metabolic N waste excretion by fish. However, studies with rainbow trout reared at different temperature showed that water temperature from 6 to 15ºC had no effect on digestible N retention efficiency (Azevedo et al., 1998). Increasing water temperature results in increasing feed intake, growth and N waste outputs per fish per unit of time but do no appear to have any effect on the ratio of N waste produced to digestible protein or N consumed.

An increasing number of studies also indicates that catabolism of amino acids is very sensitive to a number of biological factors. Azevedo et al. (2004) observed that Atlantic salmon retained a greater proportion of digestible amino acids consumed than rainbow trout of similar size, growing at similar rates, and fed similar diets. This translates into much lower N outputs for Atlantic salmon compared to rainbow trout (Figure 1). Fish size also appears to have a very significant impact on efficiency of amino acid utilization in some species (Figure 1). These results highlight the need for detailed investigations into the regulation of the main metabolic pathways of amino acid utilization. This could then be translated into the development of approach for genetic selection or metabolic modulation.

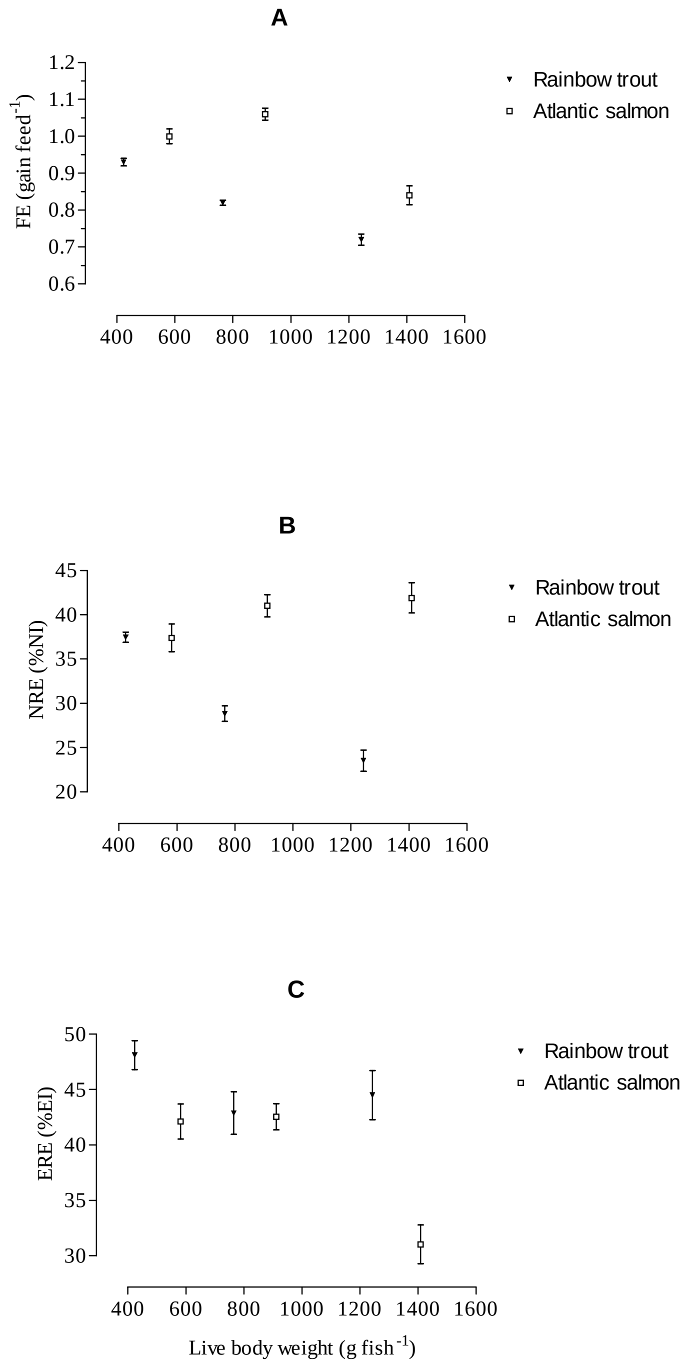

Figure 1 – Feed, N and energy utilization responses (average ± standard error mean across diets, n = 12) of rainbow trout and Atlantic salmon fed four diets with different protein/ lipid ratios as fish grew during a period of 308 days at 8.5^{o}C in freshwater. A) Feed efficiency (FE, mean ± standard error mean (SEM), n = 12); B) N retention efficiency (NRE, mean ± SEM, n = 12); C) Energy retention efficiency (ERE, mean ± SEM, n = 12); NI = nitrogen intake; EI = energy intake; Live body weight calculated as the average live body weight between two consecutive sampling periods; Mean values of FE, NRE and ERE were calculated based on ratios of feed, N and energy gains, respectively

and feed, N intake (NI) and energy intake (EI) between two consecutive sampling periods. Source: Azevedo et al. (2004).

2. Determinant of P Metabolic Wastes

Metabolic P wastes are excreted mostly as phosphate via the urine. In mammals, urinary phosphate excretion is determined mostly by plasma phosphate concentration. A threshold plasma phosphate concentration exists below which phosphate excretion is minimal and above which phosphate excretion is proportional to the increase in plasma phosphate. This type of relationship between plasma phosphate and urinary phosphate excretion was recently confirmed with rainbow trout (Bureau and Cho, 1999).

Both digestibility and quantity will determine the fate of P fed to fish. The undigested fraction of the P of the diet is excreted in the feces by fish. The fraction of P digested by the animal is absorbed where it is deposited in the body of the fish. Experimental evidence suggests that there is a requirement to maximize growth and maximize P deposition and bone mineralization. P requirement of rainbow trout for maximum growth was 0.37% digestible P (0.19 g/MJ DE) and 0.53% (0.27 g/MJ DE) for maximum phosphorus deposition (Rodehutscord, 1996). Fish receiving only the digestible P amount required to meet requirement for growth excrete only minute amounts of metabolic P (ca. 5 mg P kg-1 BW d-1) indicating that digestible P intake of the fish is directed almost completely toward deposition (Rodehutscord, 1996; Bureau and Cho, 1999). There is evidence that efficiency of P utilization tends to decrease as digestible P level increase from the level required for maximum growth to the level required for maximum P deposition. Given the existence of such a threshold relationship, it might be reasonable to conclude that a digestible P level producing a plasma phosphate concentration near renal P excretion threshold concentration should be acceptable from a biological (the fish) point of view and optimal from a waste management point of view. Recent experimental evidences suggest that this level is around 0.4% digestible P (0.2 g/MJ DE) for rainbow trout.

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