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Exploring the possibility of quantifying the effects of plant protein ingredients in fish feeds using meta-analysis and nutritional model simulation-based approaches

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ABSTRACT

Numerous studies have been carried out to test the effect of incorporating various protein sources in salmonid fish feeds at the expense of fish meal. Comparison and interpretation of the results from these studies are difficult given the wide differences in ingredients, feed formulations, experimental designs and achieved performance. The objective of this study was to contrast two approaches for analyzing and comparing the results of such studies: meta-analysis and nutritional model simulation. The meta-analysis indicated that compared to fish meal-based diets, low or moderate dietary incorporation of plant protein ingredients in general did not affect growth of salmonids, whereas fish growth was depressed at high dietary inclusion levels of plant protein ingredients even when the diets were apparently nutritionally adequate. Feed intake was not negatively affected as long as the diets were nutritionally adequate. Sources of plant protein ingredients also appear to have divergent effects on fish growth. The scope of the meta-analysis was limited due to measures to ensure the meaningfulness of the meta-analysis. Therefore a novel integrated growth and nutrient utilization model was developed and used as a simulation tool to achieve a broader and more rational comparison of studies. Overall the model adequately predicted growth of salmonids fed diets containing different levels of plant protein ingredients. The model simulation-based approach allowed a proper quantification of the effect of plant protein sources in salmonid fish feeds.

1. Introduction

Issues of economic and ecological sustainability are creating a significant pressure to reduce levels of fish meal in fish feeds. Many studies are carried out each year to test the effect of incorporating various protein sources in feeds for different aquaculture species. These studies encompass a great diversity of ingredients, diet formulations, and experimental designs. For salmonids, a number of studies have shown that a large proportion of fish meals could be replaced by plant ingredients without a deleterious effect on growth rate and feed efficiency provided high quality ingredients are used (Drew et al., 2007; Glencross et al., 2006; Thiessen et al., 2004; Watanabe and Pongmaneerat, 1993). The complete replacement of fish meal in salmonid diets has been achieved in a limited number of studies (Gaylord et al., 2006; Iwashita et al., 2008; Kaushik et al., 1995). Nevertheless, fish meal replacement has failed in a large number of studies despite the fact that experimental diets appeared to be nutritionally adequate (de Francesco et al., 2004; Gomez-Requeni et al., 2005; Kim et al., 1998; Mambrini et al., 1999; Pongmaneerat and Watanabe, 1992; Romarheim et al., 2006). The basis of these discrepancies among the results of different feeding trials remains elusive.

Analysis of the response of animals to dietary manipulations is a complex matter. Formulation of diets with lower levels of fish meals and increasing levels of plant protein sources results in significant modification of the nutritive value of the diet (digestible nutrient contents, levels of anti-nutritional factors, etc.), which in turn may affect efficiency of nutrient utilization, feed intake, and growth of the animals. Consequently, an adequate analysis of the effects of changes in diet composition generally cannot be based on simple inferential statistical comparisons (Fig. 1a). The problem is further compounded by the incomplete and unreliable information about the nutritive quality of most feedstuffs (e.g. amino acid (AA) composition, estimate of apparent digestibility of nutrients, anti-nutritional factors, etc.). Furthermore, estimates of nutrient requirements, sensitivity of animals to different factors (anti-nutritional factors, secondary metabolites or contaminants, etc.) and metabolic responses of animals to diets differing in nutrient composition are not always well defined or understood. For example, recent AA requirement recommendations by NRC (2011) are higher for some AAs than those by NRC (1993). The latter has been widely used as the basis of feed formulation in fish meal replacement studies. Moreover, information from different studies is often presented in an idiosyncratic manner and thus studies may not be directly comparable. A meta-analytic approach could be a useful tool

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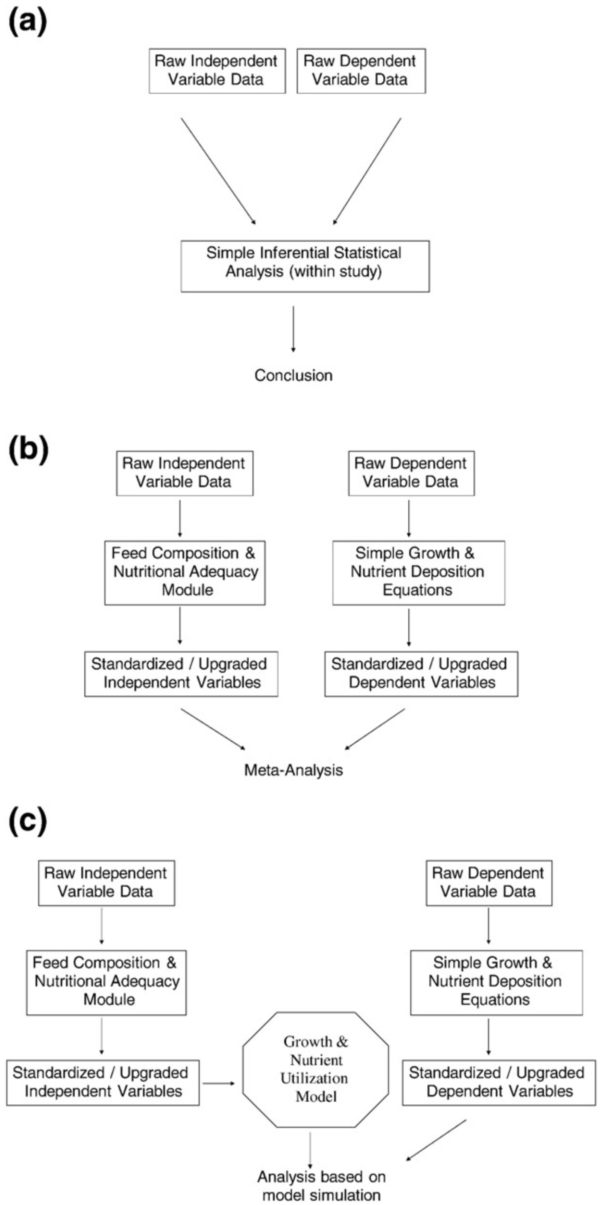

Fig. 1. Approaches to analyze the effects of replacing fish meal by plant protein sources in fish feeds: traditional approach for analysis of data from trials (a), meta-analysis based on upgraded & standardized data (b), and analysis based on simulation using growth and nutrient utilization model (c).

to extract and integrate information from different studies. This approach has been employed by Drakeford and Pascoe (2008) and Sales (2009) to examine the issue of fish meal replacement by different protein sources. On the other hand, meaningful comparison of the results from different studies through the meta-analysis should involve standardization of the experimental observations (Fig. 1b). Experimental observations should ideally be upgraded for missing information (e.g. dietary nutrient compositions) and the dependent parameters (e.g. growth rates, feed efficiency, etc.) standardized to ensure a meaningful integration and comparison of the results across studies. This is an issue that has often been overlooked in conventional meta-analysis studies.

However, a simple meta-analysis can only achieve limited results. Questions still remain as to how to meaningfully and objectively analyze and compare results if the experimental diets contain different digestible nutrient contents, when some experimental diets are expected to be nutritionally deficient, and if fish growth performance and feed efficiency differ widely. To solve these questions, a framework of a nutritional model is warranted. The experimental observations could be effectively organized and processed using nutritional models, and these structured experimental observations and model simulations could be compared (Fig. 1c). A nutritional model framework will not only help to integrate and analyze existing data, but also can help to optimize feed formulation and improve cost-effectiveness of feeds.

A number of nutritional models have been developed to predict growth, feed efficiency and waste outputs of various fish species based on bioenergetics frameworks (Bureau et al., 2002, 2003; Cho, 1992; Cho and Bureau, 1998; Cui and Xie, 1999; Glencross, 2008; Glencross et al., 2011; Kaushik, 1998; Lupatsch and Kissil, 2005; Zhou et al., 2005). These models are simple and practical, but the limitations of the bioenergetics approach are increasingly being recognized (Bureau and Hua, 2008). The current bioenergetics models are not sufficiently flexible to be applied to the wide range of conditions encountered in fish culture (Bureau and Hua, 2008). Perhaps the most significant limitation for bioenergetics models in the context of studying the effects of plant protein ingredients replacing fish meals is their incapability to take into account the metabolic role of specific nutrients, especially under conditions of nutrient inadequacy. For example, a deficiency of amino acids or phosphorus might occur when replacing fish meals by plant protein sources without dietary supplements. Therefore, there is a need for a greater use of mechanistic approaches to represent fish growth and nutrient utilization. A monogastric nutrient-based growth model has been successfully used in pig production (Brikett and de Lange, 2001a,b,c). This model explicitly describes the utilization of energy-yielding nutrients and metabolites for body protein and body lipid deposition at the whole animal level. Recently, Hua et al. (2010) adapted the model to fish by incorporating metabolic factors specifically pertinent to fish and re-determining the parameters for fish. However, the adapted model consistent with its original framework was found to be non-robust. It is becoming evident that it is not always possible to simply transpose concepts from mammals and birds to fish (Hua et al., 2010). Novel approaches are needed to develop more robust nutritional models for fish. Recent advances in the understanding of nutrient utilization by fish present a prime opportunity for developing such models to describe and predict how fish respond to a combination of dietary and environmental variables.

The objectives of the present study were to 1) conduct a meta-analysis of plant proteins replacing fish meal to examine the relationship between growth and dietary plant protein ingredient incorporation levels in salmonid diets, 2) develop an integrated nutritional model for salmonids and evaluate its reliability and predictability for fish fed varying macronutrient contents and feeding levels, 3) conduct an analysis of plant proteins replacing fish meal under the framework of the integrated growth and nutrient utilization model, and 4) further investigate the predictability of the integrated growth and nutrient utilization model for a wide variety of plant ingredients.

2. Materials and methods

The effects of replacing fish meal by plant protein sources were investigated through different approaches: 1) a meta-analysis based on upgraded and standardized data, 2) development of an integrated growth and nutrient utilization model, and 3) comparison of model simulations with experimental observations.

2.1. Meta-analysis of fish meal replacement with plant protein sources based on upgraded and standardized data

2.1.1. Modeling dataset

Published studies on replacement of fish meal by plant protein sources in rainbow trout (*Oncorhynchus mykiss*) and Atlantic salmon (*Salmo salar*) diets in the literature were carefully reviewed for the soundness of their experimental designs, ingredient quality, diet formulations, rearing conditions, husbandry practices, chemical analyses, and completeness of the information provided. The meta-analysis can only