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Cost-effective use of feed ingredients is fundamental to the profitability of any livestock industry, including the aquaculture sector. To effectively utilize limited feed resources, it is essential that we identify those factors that can influence ingredient quality and develop techniques for the assessment of the ingredients prior to inclusion in compound feeds. To date, our ability to achieve this has been restricted. Measurement or prediction of chemical composition of feed ingredients, and/or book values based on in vivo measurements were the only means available to feed manufacturers. Given the variation that exists in the nutritional and physical quality of feed ingredients, these approaches are far from adequate. Alternative techniques for the rapid assessment of nutritional quality must be identified.

Near infrared spectroscopy (NIRS) represents a rapid, cost-effective, repeatable and accurate means of assessing the nutritional quality of feed ingredients and, in some cases, complete feeds. The procedure is based on the fact that when exposed to specific wavelengths of infrared light, components within a foodstuff, such as protein, moisture, starch and oil, have characteristic NIR absorption bands (Figure 1). Using this principle, calibrations between characteristic NIR spectra and nutritional quality for any ingredient can be developed.

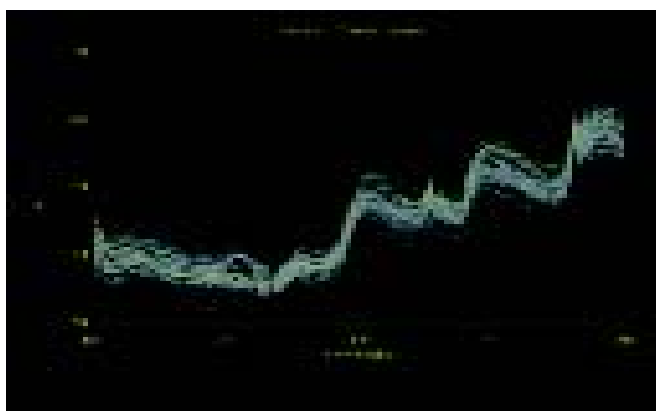
The application of NIRS for the assessment of the nutritional quality of feed ingredients for aquaculture species is not as advanced as it is for pigs and poultry. This is due to the fact that we have less nutritional knowledge about aquatic animal species, and there are other factors that must be considered when producing aquatic feeds such as water stability and binding capacity.

The aim of this paper is to identify where the greatest gains are to be made through the application of NIRS in aquafeed

Rapid, accurate and cost-effective analysis of feed ingredients using NIRS represents a useful way to monitor ingredient quality by the aquafeed sector. The technology helps prediction of macro-nutrients such as protein, fat and moisture, and key components of feed ingredients such as starch and oil. It can also be used to detect heat damage and other changes due to thermal processing. Another potential application is the detection of contaminants in feed ingredients.

Application of Near Infra-Red Spectroscopy (NIRS) to Manage the Nutritional Quality of Aquafeed Ingredients

Figure 1. NIRS spectra can be used to detect differences in the composition of aquafeed ingredients which can vary significantly for ingredients of apparently consistent quality.



production and to highlight some recent developments in the application of NIRS that may help improve the production of aquafeed.

Defining nutritional quality of ingredients for aquafeeds

The “nutritional quality” of aquafeed ingredients reflects their comparative ability to supply specific nutrients to the target species via a specific diet form (eg. semi-moist, steam, or extruded pellet) while being free of chemical, physical and microbiological contaminants. Our capacity to measure the nutritional quality of an ingredient prior to diet manufacture will influence:

- The matching of diet specifications to the nutrient requirements of the target fish species;
- Variation in fish performance through variability in nutrient supply over time;
- The overall quality of the processed diet in terms of product integrity and the influence of processing on nutrient supply;
- The health status of the fish through elimination of feed contaminants.

Further to this, measurement of key macro-nutrients (protein, moisture, fat) in complete feeds can represent an important quality assurance tool that ensures all ingredients have been correctly assembled and that the processing conditions did not compromise overall diet quality.

Table 1. Typical variation in the composition and quality of baitfish fed to southern bluefin tuna.

Parameter	Range
Crude protein (% DM)	49.4-75.3
Crude fat (% DM)	1.9-36.5
Free fatty acids (% DM)	2.9-53.4
Peroxide value (meg/kg, DM)	<0.1-598.0

Measurement of macro-nutrients or components using NIRS

Macro-nutrients such as crude protein and ingredient components such as starch content (often critical to pellet binding and the capacity of a processed feed to float or sink) represent a useful means of assessing ingredient consistency, and hence the “complimentary additivity” of that ingredient when it is incorporated into a processed feed. In addition, they provide a useful guide to the supply of nutrients from that ingredient. While definition of “available” or “digestible” nutrients provides a more accurate match of diet specifications to fish requirements, in most cases gross chemical composition is adequate for aquafeed production. This will be discussed in more detail later in this paper.

NIRS calibrations for ingredient components such as crude protein, moisture, fat and starch can be developed relatively inexpensively. Only *in vitro* wet chemistry is required (as opposed to *in vivo* experiments with target fish species), and NIRS is well established in the measurement of these parameters in a wide variety of feed ingredients. In cases where there are few changes to the combination of ingredients in a processed feed, NIRS can be applied to measure processed feed quality as well as ingredient quality.

An example of where NIRS can be applied to maintain the supply of nutrients and to maintain manufactured feed quality is the farmed southern bluefin tuna industry. Farmed tuna are currently fed baitfish as their primary source of nutrients while manufactured diets that are under development also incorporate a fresh baitfish component (Figure 2). As the quality of baitfish used in tuna production varies significantly, our

capacity to measure quality is important if we are to improve the efficiency of farmed tuna production. A survey of baitfish being used to feed farmed tuna revealed large variation in the crude protein, crude fat, free fatty acid and peroxide value of the baitfish on offer (Table 1). To account for this, van Barneveld (2001a) demonstrated that the crude protein, moisture, crude fat and free fatty acid content of bait fish can be adequately screened using NIRS on samples of processed frozen, processed thawed and processed freeze-dried bait fish, the latter being the most accurate (Table 2).

Figure 2. Unprocessed fish products used as a source of nutrients in aquafeeds will vary significantly in composition and benefits will arise from NIRS analysis prior to incorporation into diets.



Measurement of available nutrient supply

In mature livestock sectors such as the pig and poultry industries, measurement of available nutrient supply is critical to optimizing production efficiency because it accounts for losses that occur during digestion and metabolism. Diet specifications and available ingredients change on a daily basis, and a wide range of ingredients are utilized to produce the diets. Compared with the terrestrial livestock sectors, there is less information on the nutrient requirements of many aquaculture species, or we have less capacity to change the performance of the fish during the production cycle through a diet change. As a consequence, the need for NIRS calibrations that allow the prediction of nutrient supply on a routine basis is diminished.

Table 2. Calibrations statistics for chemical constituents of baitfish (1100-2500 nm)

	N	Mean	RSQ	SECV	1-VR
Moisture (%)	72	73.13	0.98	0.64	0.96
Crude protein (%)	75	17.99	0.85	0.58	0.73
Crude fat (%)	73	2.07	0.96	0.68	0.88
Free fatty acids (%)	71	6.61	0.84	1.49	0.69

RSQ, r-squared; SECV, standard error of cross validation; VR, variance ratio.

Assessment of processing responses using NIRS

In animal (fish meals, meat meals) and vegetable proteins (soybean meal, canola meal) that have undergone processing, heat damage can result in an overestimation of nutritional quality due to reactions between the α -amino group of lysine with other compounds. Rutherford et al. (1997) developed the digestible reactive lysine assay as a means of assessing heat damage in feed ingredients and it was subsequently demonstrated by van Barneveld et al. (1999) that reactive lysine per se could be used as a measure of heat damage. To assess the potential for NIRS to measure total and reactive lysine in heat treated protein sources, van Barneveld (2001b) subjected samples of canola meal to a structured range of dry and autoclaved heat treatments to create sample sets of 60 for each protein source. In addition to this, random samples of canola meal were included in the sample set, prior to development of NIRS calibrations for both total and reactive lysine (Table 3).

Based on the above data, there is no reason why NIRS calibrations could not be developed for both heat-treated feed ingredients commonly used in aquafeed production and processed aquafeeds themselves. This routine quality assurance procedure could significantly enhance the consistency and quality of aquafeeds.

In addition to heat damage, development of NIRS capacity for the measurement of changes in starch properties (gelling temperatures etc) with increased heat application could be very useful in defining the capacity to incorporate a new ingredient into extruded aquafeeds.

Measurement of contaminants

NIRS is routinely applied in the pharmaceutical and other industries for the detection of contaminants. Provided that the contaminant in question has a characteristic NIR absorption spectra, accurate calibrations can be developed relatively easily using “spiked” samples.

A bigger issue associated with the measurement of contaminants in aquafeeds and aquafeed ingredients is the accuracy of the sampling procedure. Unless a representative sample can be routinely collected, little value will be gained through rapid and objective analysis using NIRS. In particular, it is unlikely that an adequate sampling protocol for molds and mycotoxins will be practically feasible in a commercial feed mill or ingredient receiving point. With this in mind, it appears that prevention of these contaminants through correct storage and the strategic application of mould inhibitors is by far the best course of action, and where this has proved diffi-

Table 3. Performance indicators for NIRS calibrations developed for the prediction of total and reactive lysine (g/kg, as received) in cold-pressed and solvent-extracted canola meal samples (van Barneveld, 2001b).

Constituent	SEL	SECV	SD	SECV/SEL	SECV/SD
Total lysine	0.40	0.42	4.64	1: 1.05	0.09
Reactive lysine	0.60	0.76	4.46	1: 1.27	0.17

SEL, Standard error of laboratory reference; SECV, Standard error of cross validation; SD, Standard deviation.

cult to achieve or frequently ineffectual, then application of effective mycotoxin binders should be considered.

Conclusions

In aquafeed production systems, primary contributors to the management of nutritional quality of feed ingredients include the assessment of macro-nutrients such as protein, fat and moisture, and key components of feed ingredients including starch and oil. Capacity to detect over-processing or heat damage, changes in starch properties with heat application and contaminants will also contribute to reduced variation in feed quality. In the longer term, as knowledge of nutrient requirements for target species improves, as the capacity to manipulate the composition of diets increases, and as the capacity to control the intake of individual fish in a commercial production system increases, the need to measure the “available” or “digestible” nutrient supply using NIRS will increase. ■

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