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Critical variability exists in the digestible value of raw materials fed to black tiger shrimp, *Penaeus monodon*: The characterisation and digestibility assessment of a series of research and commercial raw materials

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ABSTRACT

The digestibility of a suite of raw materials was determined when fed to black tiger shrimp (*Penaeus monodon*) in a series of three experiments. A total of 29 commercial and research raw materials were evaluated using the diet replacement digestibility method. Each of the reference and test diets were fed to tanks of shrimp for one-week prior to commencing faecal collection. The collected faecal samples were kept separate from any feed residue through using a discrete feeding period, after which uneaten feed was removed before a separate faecal collecting period. The same reference diet and soy protein concentrate diet were used across each of the three experiments and demonstrated consistent digestibility using this method. Most raw materials demonstrated some utility for use in diets for shrimp, with digestible protein or energy values > 0.800. However, there were some raw materials (e.G. *camelina* meal) that provided very little nutritive value for shrimp. This study presents data on the digestibility and digestible nutrient content of a wide variety of raw materials, providing a clear basis for progressing to formulating shrimp diets on a digestible protein and energy basis, thereby optimising dietary formulation, maximising ingredient utilisation and reducing impacts of uneaten feed.

1. Introduction

Progress in the use of raw materials, other than fishmeal and fish oils, in diets for shrimp has resulted in significant advancements in the ability to utilize a range of different terrestrial derived grain and animal resources (Davis and Arnold, 2000; Davis et al., 2002; Alvarez et al., 2007; Cruz-Suarez et al., 2001, 2007; Smith et al., 2007; Luo et al., 2012; Carvalho et al., 2016). However, the capacity to effectively utilize raw materials in diets for any aquaculture species, including shrimp, relies on an ability to formulate diets to consistent digestible nutrient and digestible energy specifications (Glencross et al., 2007). Failure to formulate on an equivalent digestible nutrient and energy basis can result in a misleading interpretation of the value of a raw material through a failure of diet specifications, not a failure in the raw material per se. However, in many cases, the assessment of alternative raw materials has occurred with excess nutrient supply masking any potential deficiencies through the formulation of diets to crude nutrient and gross energy specifications only and as such the variability in the nutritional value of those alternatives is missed because of that over supply of nutrients (Glencross et al., 2008a).

Over the past twenty years there have been a suite of studies that have evaluated the digestibility of specific raw materials (Merican and Shim, 1995; Brunson et al., 1997; Glencross and Smith, 1997; Smith et al., 2007; Cruz-Suárez et al., 2007, 2009; Yang et al., 2009; Carvalho et al., 2016). Most of these studies have focused on specific ingredients. However, very few studies have examined the digestibility of a comprehensive suite of raw materials, with those that do focused on *Litopenaeus vannamei* (Lemos et al., 2009; Yang et al., 2009; Carvalho et al., 2016). In the study by Lemos et al., 2009, the authors compared the digestibility of protein against the in vitro digestibility of protein but did not report any of the other nutritional parameters (e.g. digestible dry matter, energy or lipid). The study by Yang et al., 2009 assessed a range of plant and animal meals without assessing their specific origin or the effects of post processing. Whereas the study by Carvalho et al. (2016) had a focus on the use of various animal and vegetable meals but did also include an analysis of the effect of inclusion level and reported variable effects of inclusion level across those raw materials studied. Such databases on the digestible value of ingredients remain highly useful resources to underpin future formulation of both practical and research diets and form the basis of understanding the key raw material

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attributes that affect nutritional quality of raw materials.

In the present study, a series of digestibility experiments were undertaken with black tiger shrimp (*Penaeus monodon*) to define the digestible nutrient and energy values of a suite of raw materials for use in shrimp diets. It was postulated that shrimp would exhibit different capacities to digest this range of different raw materials. We considered that the generation of this data is an essential step to improve the basis by which shrimp diets are formulated. The variation in chemical and digestible composition of the different raw materials is discussed, as are some of the key observational determinants of variability in digestibility values encountered in this study.

2. Materials and methods

2.1. Raw material preparation

A suite of raw materials with potential for or currently being used in the shrimp feed sector were sourced from a commercial feed company (Ridley Aquafeeds, Narangba, QLD, Australia) and raw material producers throughout Australia. A mixture of plant protein and rendered animal by-products were obtained. Some additional raw materials for use in research diets were also evaluated (e.g. vitamin-free casein). Each of the raw materials was milled using a Retsch mill (ZM200 Centrifugal Mill; MEP Instruments, Brendale, QLD, Australia) with a 750 µm screen to create a consistent flour from each product. After milling, all raw materials were held at −20 °C pending diet manufacture. Details and composition of all raw materials used in this study are presented in Tables 1 and 2.

2.2. Diet manufacture

A diet design strategy based on the diet-substitution ingredient digestibility method was used as the basis for this study (as reviewed by Glencross et al., 2007). As the basis for this strategy a reference diet was developed using a formulation specification of 42% protein and 7% lipid which was a mimic of the commercial feeds typically used in the Australian shrimp farming industry and which also acts as our industry equivalent performance benchmark (Glencross et al., 1999). A large (100 kg) batch of reference mash was prepared with a subsample pelleted to make the reference diet. Test diets were made by blending a sample of the test ingredient with a subsample of the reference mash in a 30:70 ratio on an as is basis (Table 3). Each diet was prepared by mixing samples of the test raw material and reference mash in an upright planetary mixer (Hobart, Sydney, NSW, Australia). Water was then added during the mixing to form a dough which was subsequently screw-pressed (Dolly, La Monferrina, Castell'Alfero, Italy) through a 1.5 mm die and cut to pellet lengths of about 6 mm. The pellets were then steamed using a commercial steamer (Curtin & Son, Sydney, Australia) at 100 °C for 3 min before being oven dried at 60 °C for 24 h. Diets were kept at −20 °C when not being fed.

2.3. Shrimp collection and trial management

Several hundred individuals (~3.0 g/shrimp, subsample weight of $n = 40$) of black tiger shrimp were collected from two commercial farm grow-out ponds (Truloff's Prawn Farm, Alberton, Qld 4207 and Melivan Pty Lt, Kurrimine Beach, Qld 4871) by cast-netting and transferred to a holding tank (10,000 L) where they were held pending allocation to trial tanks. During the holding period (~7 days) they were fed a standard commercial grower diet (Prawn Enhance™, Ridley Aquafeeds, Narangba, QLD, Australia).

For the faecal collection part of the study, five shrimp were allocated to each of 60 × 100 L circular (60 cm D × 45 cm H) tanks in an indoor laboratory system. Each of the tanks of shrimp were maintained with flow-through seawater at a rate of 1 L/min. The temperature (assessed daily) across all tanks was 28.9 ± 1.0 °C and dissolved oxygen at 6.4 ± 0.14 mg/L over the experimental period. Light was maintained on a 12:12 light:dark cycle for the duration of the study. All work undertaken in the laboratory was done using red-light to ensure the shrimp were not disturbed. For each treatment, each tank was used as

Table 1
Composition and origin of the experimental raw materials. Indicated also is which of the three sub-experiments each ingredient was evaluated in.

Ingredient	Source	Experiment	Dry Matter	Protein	Lipid	Ash	CHO	Energy
Blood meal	AJ Bush, Beaudesert, QLD, Australia	1	93.2	93.4	1.6	1.2	–	23.4
Dried Fish Solubles	Aquativ, Elven, France	2	93.5	71.8	13.9	14.2	0.1	22.4
Fishmeal (Anchoveta)	Ridley, Narangba, QLD, Australia	1	90.9	70.5	12.5	16.4	0.6	22.3
Fishmeal (Jack Mackerel)	Ridley, Narangba, QLD, Australia	3	92.7	74.3	11.4	15.5	–	21.6
Fishmeal (Tuna By-Product)	Ridley, Narangba, QLD, Australia	3	96.4	67.1	10.5	21.9	–	20.3
Krill meal	Akerbiomarine, Lysaker, Norway	3	94.9	64.4	21.1	11.8	–	24.5
Meat and bone meal 1 (Low temp)	CSF, Laverton, VIC, Australia	2	93.6	51.3	12.3	27.7	8.7	19.2
Meat and bone meal 2 (High temp)	CSF, Laverton, VIC, Australia	2	96.0	53.2	13.5	24.6	8.6	20.0
Hydrolysed feather meal	Camilleri, Maroota, NSW, Australia	1	94.8	82.3	7.3	5.3	–	22.6
Poultry offal meal (FAQ)	Camilleri, Maroota, NSW, Australia	3	94.7	69.7	16.6	15.1	–	23.3
Poultry offal meal (HQ)	CSF, Laverton, VIC, Australia	1	95.7	72.2	13.7	13.5	0.6	22.2
Poultry offal meal (LQ)	CSF, Laverton, VIC, Australia	1	96.5	65.9	15.0	14.6	4.5	22.6
Vitamin free casein	Sigma-Aldrich, Syndey, NSW, Australia	1	94.7	82.2	0.8	8.0	9.0	22.4
Camelina meal	Aus-Oils, Kojonup, WA, Australia	1	92.1	27.2	29.3	5.2	38.3	26.2
Canola meal - Expeller	Riverland Oilseeds, Pinjarra, WA, Australia	1	94.8	36.2	9.6	7.3	47.0	21.2
Canola meal – Solvent Extracted	Riverland Oilseeds, Footscray, VIC, Australia	1	89.6	37.5	6.6	8.4	47.5	20.9
Corn gluten	Arrow Commodities, Surrey Hills, NSW, Australia	2	92.3	65.1	6.0	1.6	27.3	23.7
Faba bean - extruded	Ridley, Narangba, QLD, Australia	2	96.3	29.9	1.5	3.3	65.3	18.9
Faba bean - raw	Ridley, Narangba, QLD, Australia	2	90.5	30.3	1.8	3.6	64.3	19.0
Field peas - extruded	Ridley, Narangba, QLD, Australia	2	96.0	25.2	1.4	3.1	70.3	18.9
Field peas - raw	Ridley, Narangba, QLD, Australia	2	90.6	24.9	2.1	3.3	69.7	19.0
Lupin kernel meal (cv. Coromup)	Coorow Seeds, Coorow, WA, Australia	3	91.8	46.0	8.2	4.1	33.6	21.0
Pregelled starch	Manildra, Auburn, NSW, Australia	3	85.6	0.2	0.0	1.2	98.6	20.5
Soybean meal (Hifeed)	Ridley, Narangba, QLD, Australia	3	92.5	48.5	11.8	8.2	31.5	23.4
Soybean meal (Trifecta)	Ridley, Narangba, QLD, Australia	3	92.1	69.3	2.6	4.3	23.8	21.7
Soy Protein Concentrate	Selecta, Araguari, Brazil	1, 2, 3	90.2	69.8	2.4	7.3	20.5	21.9
Soy Protein Isolate	ADM, Decatur, IL, United States	1	93.7	89.7	5.3	5.0	–	23.3
Wheat flour (Plain)	Manildra, Auburn, NSW, Australia	3	87.5	15.3	1.9	1.7	81.2	21.5
Wheat gluten	Manildra, Auburn, NSW, Australia	3	92.1	86.5	0.7	1.5	3.4	24.1

All values are percent dry basis. Except for Dry matter, which is on a percent as received basis and for Energy which is on a MJ/kg dry basis.