Carbohydrate metabolism in silver perch and barramundi

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Summary

Practical diets for fish contain between 21 and 60% protein. Given that the protein composition of fish is similar for different species, this large difference reflects species differences in the ability to utilize non–protein macronutrients (lipid and carbohydrate) for energy. Fish may be classified on this basis into three groups: fish that are unable to utilize either lipid or carbohydrate efficiently (these fish 'require' the highest dietary protein), fish that utilize lipid efficiently but carbohydrate poorly, and fish that utilize carbohydrate well (these fish 'require' the least dietary protein). Examples from each group are presented. The assessment of carbohydrate utilization is a key method of understanding where new species being considered for aquaculture fit into this classification and can be a simple and rapid indicator of approximate dietary protein needs. Three methods of assessing carbohydrate utilization are described and data for two species presented. The species are silver perch (*Bidyanus bidyanus*), an omnivore that utilizes carbohydrate well, and barramundi (*Lates calcarifer*; also known as Asian sea bass), a carnivore that is inefficient at utilising both lipid and carbohydrate. The three approaches discussed include digestibility, uptake and clearance rate of carbohydrate from the blood stream and summit–dilution experiments to evaluate relative weight gain for diets with progressively increasing amounts of carbohydrate. The data explain why silver perch do well on low protein diets (e.g. 32–35%) while barramundi perform better on high protein diets (e.g. 40–50%). Barramundi have little metabolic capacity to efficiently utilize diets with high carbohydrate components and diets for this species are likely to always be more expensive than those for silver perch.

Keywords: aquaculture, finfish, carbohydrate utilization

Introduction

The most obvious difference between diets for aquaculture species and diets for terrestrial farm animals is that aquaculture diets tend to be much higher in protein. This is because fish have much lower energy requirements as they are cold–blooded, and energy needs for excretion and locomotion are lower than for warm–blooded terrestrial animals (Lovell 1989). So, the protein to energy ratio is much higher.

However, the differences between different species of fish can also be large. For example, NRC (1993) tabulated "estimated dietary protein requirements for maximal growth of juvenile fish" and reported values that ranged from 30% to 55%. As protein is generally the most expensive macronutrient, this has a big impact on the cost of feeds and feeding. It is also an important consideration in selecting aquaculture species for farming. In general, high–value species are selected for aquaculture because of their attractive market price. However these species are, almost without exception, also carnivorous and need to be fed diets with high contents of expensive protein.

Why is there such a big difference in the protein content of diets for different fish? The overall protein content of different species of fish is actually very similar at around 60–70% dry basis (Anon 1992) and 16–18% wet basis. This appears to suggest that actual 'tissue' requirements are similar. The large differences in the 'optimal' protein content of diets is primarily due to differences in the ability of different species to utilize non–protein energy sources, lipid and carbohydrate. This is reflected in differences in reported protein retention efficiency values (100 x protein retained/ protein ingested) for different species. Bowen (1993) tabulated values for fish from a number of studies and reported values ranging from 21–48%.

Table 1 lists most of the fish species included in a new book on Nutrient Requirements and Feeding of Finfish for Aquaculture (CABI 2002). For this book, each chapter author was asked to list nutrient requirements and give information on practical diets for particular species. The 'optimum' dietary protein content, whether derived from extensive research trials based on optimum performance or found to be acceptable through practical trials with diets of different

Species	Optimum protein content (%)	Comments on content or utilization		Reference
		Lipid	Carbohydrate	
Japanese flounder *Paralichthys olivaceus*	55–65	Commercial diets contain 6–12%. Inefficient as energy source	Inefficient. No protein sparing effects	Kichuchi and Takeuchi 2002
Yellowtail *Seriola quinqueradiata*	>50	Optimum 9%	Inefficient. Low amylase activity	Masumoto 2002
Red sea bream *Pagrus major*	52 (optimum performance when 60% energy comes from protein)	Optimum 15%; 20% reduces performance	Inefficient	Koshio 2002
Gilthead sea bream *Sparus auratus*	55	Commercial diets contain 12–24%	Inefficient. Low amylase activity	Koven 2002
European sea bass *Dicentrachus labrax*	43–52	Up to 19% beneficial; 30% detrimental	Contents above 30% reduce growth	Kaushik 2002
Barramundi *Lates calcarifer*	40–45	Optimum 15–18% for fingerlings	Inefficient	Boonyaratpalin and Williams 2002
Altantic halibut *Hippoglossus hippoglossus*	56–60	Commercial diets contain up to 27%	Inefficient. Low amylase activity	Grisdale–Helland and Helland 2002
Eel *Anguilla* spp.	45–47	Efficient. 20% spares protein	Inefficient	Satoh 2002
Summer flounder *Paralichthys dentatus* and Southern flounder *Paralichthys lethostigma*	48–56	Commercial diets contain 10–15%		Daniels and Gallagher 2002
Winter flounder *Pseudopleuronectes americanus*	40–45	Commercial diets contain 10–15%		Daniels and Gallagher 2002
Atlantic salmon *Salmo salar*	35–55	Very efficiently. Commercial diets contain up to 40%	Inefficient. Low amylase activity. Commercial diets contain 6–15% gelatinised starch	Storebakken 2002

Rainbow trout *Oncorhynchus mykiss*	Practical diets contain 42–48	Practical diets contain 16–24%		Hardy 2002
Sturgeon *Acipenser* spp.	40–50	Efficient. Up to 36%		Hung and Deng 2002
Hybrid striped bass *Morones saxatilis x M. chrysops*	41	Efficient	Efficient. Up to 25% utilized	Webster 2002
Red drum *Sciaenops ocellatus*	35–45	7–11% produced maximum weight gain. 28% led to excess lipid deposition in body	Not adversely affected by up to 35%	Gatlin 2002
Milkfish *Chanos chanos*	Practical diets contain 23–27	Optimum 7–10%	Efficient. Commercial diets can contain >45%	Lim *et al.* 2002
Common carp *Cyprinus carpio*	30–35	Increasing lipid from 5–15% did not improve growth but increased lipid deposition	Efficient. 30–40% optimum	Takeuchi *et al. 2002*
Indian major carps Catla *Catla catla*; Rohu *Labeo rohita*; Mrigal *Cirrhinus mrigala*	Practical diets contain 25–28	7–8%	Efficient. 22–30% optimum	Murthy 2002
Tilapia *Oreochromis* spp.	28–35 Practical diets contain 24–28	5% satisfactory; 12% optimum. >12% reduced growth	Efficient. Up to 40% used	Shiau 2002
Channel catfish *Ictalurus punctatus*	25–35	Practical diets contain 5–6% lipid. Additional lipid led to excess lipid deposition in body	Efficient. Practical diets contain 25–31%	Robinson and Li 2002
Silver perch *Bidyanus bidyanus*	25–29	Practical diets contain 6–10%. Additional lipid led to excess lipid deposition in body	Efficient. Up to 30% utilized	Allan and Rowland 2002

protein contents, ranges from 23–65%.

Fish may be categorised according to their ability to utilize lipid and carbohydrate. Some interesting trends are apparent. Several species appear to be inefficient at utilising either lipid or carbohydrate and therefore perform better on diets with 'high' protein contents. These species include Japanese flounder, yellowtail, red sea bream and gilthead seabream. Then there are species that appear to utilize lipid efficiently but not carbohydrate. For these species, 'optimal' dietary protein (lowest protein content for maximum performance) is lower than the first group. These species apparently include halibut, sea bass, summer, southern and winter flounder and Atlantic salmon. Salmon appear the most efficient at lipid utilization and commercial diets for this species often contain 40% lipid and only 35% protein (Storebakken 2002). The final group in this system include those species that utilize carbohydrates well, but either utilize lipid poorly or excess lipid leads to undesirable fatty fish. This group includes milkfish, channel catfish, tilapia, silver perch, and common and Indian carps. Those species can perform well with the lowest protein in their diets, with contents as low as 25% or less being satisfactory.

Although the preferred lipid source for aquaculture diets is fish oil, there are problems with this commodity; production is static and price is increasing. Approximately 56% of global supplies already go into aquafeeds, and this percentage is predicted to rise to 79% by 2010 (Pike and Barlow 2003); the longer–term outlook for fishmeal use and price is poor. In addition, for many species, high contents of dietary lipid leads to excess lipid deposition and this can reduce market acceptability.

The ability of a species to digest and utilize carbohydrate is therefore a critical component in the assessment of the nutritional requirements of new species for aquaculture and will have a major bearing on the likely cost of aquaculture diets and the overall economics of farming.

Three methods of assessing carbohydrate utilization will be described and data presented for an omnivorous species, silver perch (*Bidyanus bidyanus*), and a carnivorous species, barramundi (*Lates calcarifer*; also known as Asian sea bass, Boonyaratpalin *et al.* 2002).

Assessment of carbohydrate utilization

Digestibility

Digestibility is the critical first step in understanding the utilization of any nutrient. Because fish are cold–blooded, there is less difference between digestible energy and metabolizable energy than there is for warm–blooded terrestrial animals. This is just as well because measuring metabolizable energy for free swimming aquatic animals is quite a challenge.

Measurement of digestibility in fish is also much more difficult than for terrestrial animals. Faeces must be either removed from the fish before excretion, raising the possibility of under–estimating digestibility because of incomplete digestion, or removed from an aqueous environment after excretion, raising the possibility of over–estimating digestibility because of leaching.

For silver perch, faecal pellets are fairly intact and losses to leaching are minimal. *In vivo* digestibility coefficients were calculated following settlement of faeces (Allan *et al*. 1999). For barramundi, faecal pellets are often very loosely bound and to reduce leaching the faeces were removed before excretion by 'stripping' (the faeces were obtained by applying gentle pressure on the abdomen; McMeniman 2002).

Notwithstanding quite different methods used to measure digestibility, the actual values for identical carbohydrate sources (taken from the same batch) were very different (Table 2). It should be noted that the actual test ingredients (carbohydrate) and diet ingredients and formulations were identical, that is the test diets were identical except for pellet size. Barramundi appear very inefficient at digesting carbohydrate compared with silver perch.

Gelatinization of starch has been reported to improve digestibility for several fish species including channel catfish, carp and rainbow trout (Stone *et al*. 2003b). In matched experiments with silver perch

Table 2 Energy digestibility coefficients for ingredient inclusion at 30% in the same fishmeal based reference diet for silver perch and barramundi.

		Apparent digestibility coefficient (%)	
Ingredient	**Gross energy MJ/kg**	**Silver perch[1]**	**Barramundi[2]**
Raw wheat starch	16.9	83.4	7.6
Gelatinised wheat starch	16.9	93.4	–6.5
Dextrin	16.9	95.7	56.2
Glucose	13.1	92.5	40.0
Pea starch	16.5	69.9	36.9

[1]Data from Stone *et al.* 2003b
[2]Data from McMeniman 2002

and barramundi, gelatinization improved energy digestibility for silver perch but not for barramundi (Stone *et al*. 2003b; McMeniman 2002). For barramundi, gelatinization actually appeared to reduce energy digestibility of wheat (Table 2) although it should be noted that the errors associated with measuring digestibility of 'indigestible' ingredients can be quite high.

While digestibility is the essential first step in ingredient evaluation, once digested the ingredients may or may not be utilized. Wilson (1994) and Hutchins *et al*. (1998) suggested that differences in utilization of well–digested carbohydrates might be explained by differences in absorption rates.

Carbohydrate absorption

A rapid and inexpensive method for assessing carbohydrate absorption is to measure uptake and clearance of carbohydrates introduced orally or by injection into the peritoneum. For silver perch and barramundi the results of experiments where glucose, 1 g/kg body weight, was injected into the peritoneum and measured in the bloodstream over 24 h are presented in Figure 1. Differences between the species are clearly apparent. Glucose was absorbed into the bloodstream much more efficiently and rapidly by silver perch compared with barramundi and then clearance rates, indicating efficient absorption was quicker. These differences indicate major differences in facilitated glucose transport mechanisms and probably differences in metabolic enzyme activities.

Similar experiments with galactose and xylose indicated that both species were intolerant of these carbohydrates (Anderson 2002; Stone *et al*. 2003a).

Utilization of carbohydrates for growth

Even if carbohydrates are digested and absorbed, relative differences between digestion and absorption of proteins might reduce fish performance. Growth studies, preferably followed by analysis of carcass composition, are needed to quantify the protein sparing potential of carbohydrates. For silver perch and barramundi, fish were fed a fishmeal based reference diet or that diet substituted with either 15 or 30% of wheat starch. Once again, the actual test ingredients and diet ingredients and formulations were identical except for pellet size. Relative weight gain is presented in Figure 2. The linear reduction in growth of barramundi as the diet was substituted with wheat starch is clear evidence that wheat starch acted as a diluent with no indication of any protein sparing effects. In contrast, with silver perch, weight gain was not significantly affected by either 15 or 30% wheat starch presenting clear evidence of a protein sparing effect.

Conclusion

Utilization of carbohydrate for energy is a desirable characteristic for an aquaculture species as it effectively reduces the need to provide energy through protein and or lipid, both more expensive macronutrients than carbohydrates.

Silver perch, an omnivorous freshwater fish, is able to efficiently utilize carbohydrate as starch as indicated by high digestibility, rapid uptake and clearance of glucose from the bloodstream and evidence that starch can be used to spare protein in growth studies. This information has been crucial in the development of

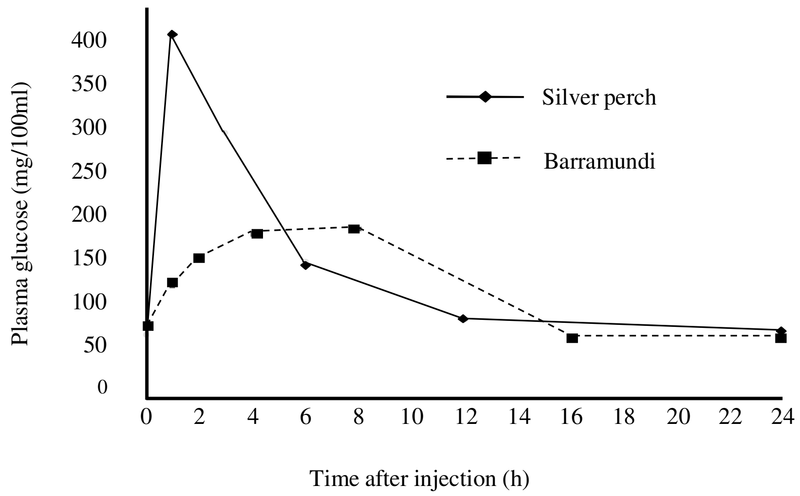

Figure 1 Plasma glucose concentration in silver perch and barramundi following an intraperitoneal injection of glucose at a dose rate of 1 g glucose/kg body weight (data for silver perch from Stone *et al.* 2003a and for barramundi from McMeniman 2002).

low–cost, high performance diets for silver perch. Silver perch perform well on low protein diets (digestible protein contents of <30%; Allan and Rowland 2002) and diets for that species are now the cheapest of any diets for fish or shrimp cultured in Australia.

In contrast, barramundi, a carnivorous catadromous fish, is inefficient at digesting carbohydrates, relatively inefficient at uptake and clearance of glucose from the bloodstream (compared with silver perch) and apparently unable to utilize starch to spare protein in growth studies. Diets for this species contain high dietary protein contents (>45%), and though it has high performance it is relatively expensive.

The three methods used to assess carbohydrate utilization provide an effective and relatively straight forward method of assessing the nutritional status of new species for aquaculture and give a reliable indication of the type of protein content likely to be needed for intensive production.

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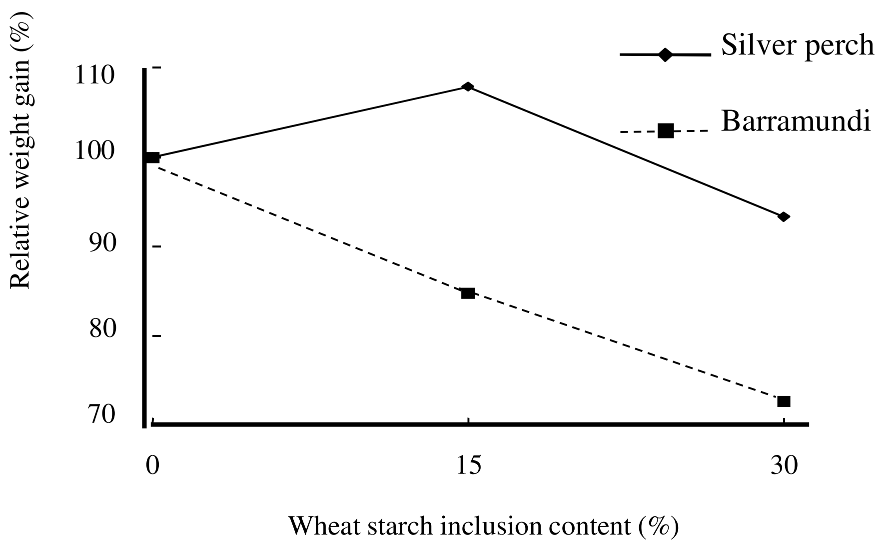

Figure 2 Relative weight gain of silver perch and barramundi fed the same fishmeal-based reference diet (0% wheat starch inclusion) or that diet substituted with either 15 or 30% wheat starch (for silver perch from Stone *et al.* 2003c and for barramundi from McMeniman 2002.)

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