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The effect of type of carbohydrate (starch vs. nonstarch polysaccharides) on nutrients digestibility, energy retention and maintenance requirements in Nile tilapia

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ABSTRACT

For Nile tilapia, the energetic value of non-starch polysaccharides (NSP) was compared to starch. It was assessed if carbohydrate type (NSP vs. starch) affected the energetic utilization for growth (K_{gDE}) and the energy requirements for maintenance (DEm). Eighteen groups of fish were assigned in 2 × 3 factorial design: two diets, with either a high NSP or high starch content; and three feeding levels (low, medium or satiation). The NSP diet contained 70% of the starch diet supplemented with 30% dried distillers grains with solubles. Nutrients digestibility, nitrogen and energy balances were measured. All nutrients digestibility decreased with increasing feeding level ($P < 0.001$). Diet type (NSP vs. starch) affected the digestibility of all nutrients except for dry matter and fat. NSP of both diets were digested and the NSP digestibility ranged between 23% and 73%. Averaged over feeding levels, 5% and 17% of the total digestible energy originated from NSP at the starch and NSP diet, respectively. Although the digestible energy intake was similar, the contrast in type of carbohydrates between the diets resulted in lower energy retention with the NSP rich diet ($P < 0.05$). Despite this impact on energy retention, both DEm and k_{gDE} were not significantly influence by diet. However, DEm was numerically higher (96 vs. 110 kJ $kg^{-0.8}$ BW d^{-1}) and k_{gDE} was numerically lower (65% vs. 58%) at the NSP diet compared to the starch diet. In conclusion, NSP are digested by Nile tilapia. Digested NSP are less well utilized for growth, which is reflected by a lower energy retention in fish and is due to the slightly higher DEm in combination with a slightly lower k_{gDE}.

Statement of relevance: Scarcity of fishmeal and -oil combined with the fast growing aquaculture sector, result in diversification of feed ingredients in fish-feeds. Plant ingredients as protein source become more important, which also increases the dietary carbohydrate content including non-starch polysaccharides (NSP). This paper provides information on the nutritional value of NSP in tilapia. This will eventually lead to improved fish-feed formulations.

1. Introduction

For all animals, nutrients are essential for growth, reproduction and sustaining their vital life processes (i.e., maintenance). Proper diet formulation in terms of energy requires information on nutrient digestibility, energy requirements for maintenance (DE_m), and the efficiency of utilization of digestible energy (k_{gDE}) for growth, both for fish and other animals (Schrama et al., 2012). Digested nutrients are used for ATP production or/and for anabolic processes (NRC, 2011). Energy requirements for both growth and maintenance can be met by the digested nutrients: protein, fat and/or carbohydrates. The relative importance of these digested nutrients for meeting energy requirements differs between species (e.g., herbivorous, omnivorous vs. carnivorous) (Halver and Hardy, 2003). Compared to terrestrial farm animals, in fish relatively little information (Anderson et al., 1984; Bergot, 1979; Hemre et al., 1989; Jafri, 1995; Kim and Kaushik, 1992) is available on the potential of carbohydrates to meet the energy requirements.

The substitution of fishmeal in fish diets will result in more types and higher levels of plant ingredients (Glencross et al., 2007a). Consequently this will enhance the variability in dietary nutrient composition, particularly regarding carbohydrates. Carbohydrates can be classified into: low molecular sugars and starch, being digested by endogenous enzymes; and non-starch polysaccharides (NSP) (NRC, 2011). Mammals, birds and fish lack endogenous enzymes to digest NSP (Choct and Kocher, 2000). Whereas, through the production of volatile fatty acids (VFA) by intestinal bacteria, fermentable NSP can still be a substantial energy source for humans and rats (Castiglia-Delavaud et al., 1998), pigs (Schrama et al., 1998) and poultry (Choct and Kocher, 2000). In fish, some studies showed qualitatively that fermentation of NSP occur

Abbreviations: NSP, non-starch polysaccharides; BW, body weight; DE, digestible energy; DEm, digestible energy requirements for maintenance; ME, metabolizable energy intake; RE, retained energy; k_{gDE}, utilization efficiency of digestible energy for energy gain; FCR, feed to gain ratio; DDGS, dried distillers grains with solubles.

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in the intestine, which is indicated by the presence of VFA (Amirkolaie et al., 2006; Schrama et al., 2005). Some studies in fish have addressed the qualitative impact of NSP on digestion processes and their interference with the digestion of other nutrients (Leenhouwers et al., 2006, 2007a, 2007b; Refstie et al., 1999). However, quantitative data on NSP digestibility and the impact of digestible NSP on energy retention in fish is lacking.

Like in mammals (Pullar and Webster, 2007) and birds (Emmans, 1994), in fish it is shown that the energetic efficiency for growth depends on the composition of growth (fat to protein gain), with fat accretion being more efficient than protein (Lupatsch et al., 2003; Rodehutscord and Pfeffer, 1999) and on the nutrient composition of the digested energy (protein, fat and carbohydrates) (Noblet et al., 1994; Schrama et al., 1998, 2012). In pigs and humans, NSP generate a lower energetic efficiency for growth (Noblet et al., 1994; Schrama et al., 1996, 1998). In fish, such information on the impact of the type of carbohydrates (NSP vs. starch) on K_{gDE} is absent.

In fish, the digestible energy requirement for maintenance (DEm) is dependent on environmental factors, such as: water temperature (Lupatsch and Kissil, 2005); water oxygen concentration (Glencross, 2009; Tran-Duy et al., 2012) and stocking density (Lupatsch et al., 2010). In Nile tilapia (*Oreochromis niloticus*)(Saravanan et al., 2013)and African catfish (*Clarias gariepinus*)(Dersjant-Li et al., 2000, 2001)dietary mineral composition affects also DEm. In various fish species, the impact of dietary macronutrients composition on DEm was often small and not consistent (Glencross et al., 2007b, 2008; Rodehutscord and Pfeffer, 1999; Schrama et al., 2012). This might be due to the use of marine based experimental diets in the past; i.e., low dietary carbohydrates content. In pigs, the type of carbohydrates (enzymatically digestible vs. fermentable) in a diet can alter maintenance requirements for energy through changes in physical activity (Schrama et al., 1996, 1998). Information on the impact of dietary NSP on DEm in fish is lacking.

In this paper, the energetic value of NSP for Nile tilapia is compared to starch. In other words, how does the type of carbohydrates influence the energy balances of Nile tilapia? It addresses the impact of the type of carbohydrates (NSP vs. starch) on: 1) the digestibility of nutrients; 2) the energetic utilization of digestible energy for growth (K_{gDE}); and 3) the energy requirement for maintenance (DEm).

2. Materials and methods

2.1. Diets and feeding

Eighteen aquaria were randomly assigned to one of six experimental treatments, which were arranged in a 2 × 3 factorial design: two diets (NSP vs. starch) and three feeding levels. The two diets were aimed to have an identical crude protein and fat content, but being different in the type of carbohydrate composition, i.e., NSP and starch content. Dried distillers grains with solubles of wheat origin (DDGS) was used as NSP source, because of the high NSP content and the expected high NSP digestibility. In pigs relatively high NSP digestibility of DGGS are reported (Jakobsen et al., 2015; Tanghe et al., 2015) The NSP diet was a mixture of 70% of the starch diet with 30% DGGS. (Table 1). In order to keep crude protein and fat content similar between diets and based on the predicted protein and fat content of DDGS, the starch diet was formulated to have the same protein and fat content as NSP diet. Consequently inclusion of 30% DDGS resulted in two isonitrogenous and isolipidous experimental diets. The analysed chemical composition of diets in Table 1 confirms this. When formulating the diets, both the starch and NSP diets were checked whether the amount of essential amino acids was meeting the requirements of Nile tilapia according to the recommendation of NRC (1993). Both diets were supplemented with, lysine, methionine and threonine to ensure that none of the essential amino acids were limiting. Yttrium oxide (Y_2O_3) was used as inert marker to measure nutrient apparent digestibility coefficients. The experimental feeds were extruded and obtained from Research Diet Services B.V. (Wijk bij Duurstede, the Netherlands) and the pellets of both feeds were floating pellets (2 mm). The dietary ingredients were mixed and hammer-milled (Condux LHM20/16; Hanau) through a 1 mm screen. The diets were processed by extrusion using a Clextral BC45 laboratory scale twin-screw extruder (Clextral) with a 3 mm die, resulting in about 2 mm pellet size. After extrusion, pellets were dried in a tray dryer at 70 °C for 3 h and cooled to ambient temperature and then stored at in bags at 4 °C.

Table 1
Ingredients and analysed chemical composition of the experimental diets.

	Diets	
	Starch	NSP
Test ingredients (%)		
DDGS (from wheat)	–	30
Maize	23.5	16.0
Wheat	24.0	16.4
Wheat Bran	10.0	6.8
Wheat gluten	10.0	6.8
Fish meal[a](CP > 68%)	10.0	6.8
Soya bean meal (RC < 50)	15.0	10.2
Fish oil[b]	2.0	1.4
Monocalciumphospate	0.78	0.78
L-Lysine HCl	0.3	0.3
DL-Methionine	0.3	0.3
L-Threonine	0.1	0.1
Ytrium oxide[c]	0.02	0.02
Dialmol[d]	2.00	2.00
Premix[e]	2.00	2.00
Chemical composition on dry matter (DM)basis (g kg^{-1})		
Dry matter (DM, g kg^{-1} diet)	959	962
Crude fat	73	73
Crude protein	333	328
Ash	69	72
Total carbohydrates	525	528
Starch	331	232
NSP	194	296
Gross energy (KJ g^{-1} DM)	19.7	19.9
Crude protein/gross energy (mg KJ^{-1})	16.9	16.5
Digestible protein/digestible energy (mg KJ^{-1})	18.0	17.9
Dietary viscosity (cP)	2.29	2.67

DDGS, dried distillers grains with solubles. Südzucker Bioethanol GmbH, Germany.
Total carbohydrate calculated as DM- crude protein − crude fat –ash content.
NSP,non-starch polysaccharides = 1000-crude protein- crude fat- ash − starch.
[a] Fishmeal LT (90% blue whiting and 10% sprat; crude protein content 72%) Triple Nine Fish protein. Esbjerg, Denmark.
[b] Triple Nine Fish oil. Esbjerg, Denmark.
[c] Inert marker for calculation of apparent digestibility.
[d] Diamol GM; Franz Bertram.
[e] Mineral and vitamin composition of premix identical to Tran-Duy et al.(Tran-Duy et al., 2008).

Three feeding levels were applied to create contrast in digestible energy intake (DE) in order to estimate the linear relation between DE and retained energy (RE). From the relation between RE and DE, the utilization efficiency of DE for growth (k_{gDE}) and the energy requirements for maintenance (DEm) was derived. The 3 applied feeding levels were: 2.0 times maintenance “low”, 3.5 times maintenance “Mid” and apparent satiation “Sat” (being about 45%, 80% and 100% respectively of the ad libitum intake). The first two feeding levels are restrictive and were based on previous experiment with Nile tilapia (Schrama et al., 2012). The “Sat” treatments were hand-fed for one hour twice a day (at 9:00 and 16:00). The “Mid” treatments were fed half of the calculated daily ration twice a day (at 9:00 and 16:00), “Low” treatments were fed the complete daily ration once a day (at 9:00). The daily feeding ration per aquarium was calculated based on the mean initial fish weight, the feeding level of the treatment (in g $kg^{0.8}$ BW d^{-1}) and the expected growth of the fish. The expected daily growth was estimated using an expected feed to gain ratio (FCR) of 1.5 which was assumed equal for all treatments.