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EFFECT OF DIETARY CARBOHYDRATE OF DIFFERING MOLECULAR COMPLEXITY ON THE TILAPIA (*SAROTHERODON MOSSAMBICUS*)

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Feeding trials were carried out on Tilapia. Experimental diets containing glucose, sucrose, dextrin, starch and α-cellulose at three different levels (10, 20 and 40 %) were given to the fish for eight weeks. Growth improved as the inclusion level of carbohydrate increased from 0 % to 40 %. There was significant correlation between carcass fat and condition. At the 40 %, inclusion level, protein retention was highest on dextrin and starch and lowest on the glucose diet. At 20 % glucose spared more, and at 40 % spared less protein energy in the diet than dextrin starch or sucrose at corresponding levels. The effect of these carbohydrates for substituting protein energy in feed for tilapia is discussed. Inclusion levels were adjusted with polypropylene powder. As α-cellulose was increased from 0 % to 40 %, growth, FCE, NPR, carcass fat and condition factor declined and were lower than in control fish. The negative physiological effect of α-cellulose as an inert bulking agent in fish feed is discussed.

Key words: Carbohydrate, Molecular complexity, Tilapia.

INTRODUCTION

Supplementary feeding is one of the most important components of intensive fish culture. Fish feed contains three times as much protein as conventional live-stock feed Jauncey [1]. In fish nutrition protein is important not only as an amino acid source providing the enzymatic and structural components of cells, but also as an energy source. It is wasteful to use dietary proteins in order to satisfy the energy requirements of fish since, per kilo, caloric protein is an expensive energy source.

An alternate approach is the use of carbohydrate as a protein sparing source. Many carbohydrates, which are inexpensive and naturally abundant, can be used as energy sources in fish diets. The specific type and amount of carbohydrate that should be included in the diet of a particular species is also important to determine. Although no specific recommendations for carbohydrate levels in fish diet have been suggested, it has been found that excessive carbohydrate can lead to dangerous levels of liver glycogen in trout, NAS [2]. However, relatively high levels of carbohydrate in catfish diets do not lead to glycogen problems Wilson [3]. The present laboratory study was undertaken to determine the efficiency of carbohydrates of differing molecular complexity on survival, growth, food conversion and quality of fish flesh in terms of protein, lipid and ash contents.

MATERIALS AND METHODS

The fish used in the present study were 2-week-old tilapia which weighed 1.69-2.1 g. They were maintained in 55 L glass aquaria at an ambient temperature range of 25–28^{o} and under natural photoperiod with diffused sunlight through laboratory windows. A semi-closed system was used with water constantly recirculated by air lift through a gravel filter situated inside each aquarium. Excreta were siphoned out periodically and about one half of the water volume in each aquarium was replaced with tap water each week. A series of three feeding levels of five different carbohydrates was offered to the experimental fish for eight weeks. Experimental diets were prepared by a formula that was the same as that used for the control diet with geometrical increase of supplemented carbohydrate added to the premix (Table 1).

Pure forms of glucose, sucrose, dextrin starch and α-cellulose were included at three different levels viz. 10, 20 and 40 % w/w. The inert bulking agent used in the diet was polypropylene. Gross energy values were calculated according to Anderson *et. al.* [4]. Fish were fed at a rate of 3 % of their body weight per day (dry matter diet/live weight fish) and this ration was evenly divided into two portion over 24 hr. The fish were fed six days a week and the weight of food given was adjusted after weekly fish weighings. At the end of the experiment, the fish were sacrified, weighed and measured.

Chemical analyses were based on samples taken from 5 different fish and all the analyses were performed from duplicate samples from each individual. A.O.A.C. [5] methods were used for crude protein, moisture and ash content. Lipids were determined by the method of Bligh and Dyer [6].

Data analysis: The index of fatness or leaneness, the condition factor K, was computed by the formula:

K = 100 X weight (g)/length (mm)

Food conversion efficiency was calculated by the formula.

FCE = weight (g)/food given (g).

The efficiency with which fish are able to utilize dietary protein was measured by the formula, Osborne *et. al.* [7].

PER = live weight gain (g)/protein consumed (g).

Specific growth rate was calculated as.

SGR = 100 X increase in weight (g)/time (days)

Net protein retention was calculated by formula.

NPR = 100 X increase in carcass protein (g)/protein fed (g).

SGR, FCE, PER, NPR and condition factor were calculated each week and the mean value for each week computed. Data were analysed by single factor analysis of variance and difference between the means was tested using the multiple comparison technique of Duncan [8].

RESULTS

For most carbohydrates there was improvement in SGR as the level of inclusion was increased from 0 to 40 %. However increase in the level α-cellulose inclusion showed decreased SGR. Final fish weights were significantly greater than the control for all levels of carbohydrate except for α-cellulose for which increased level of inclusion in fish diet from 0 to 40 % resulted in progressive growth retardation (Fig. 1).

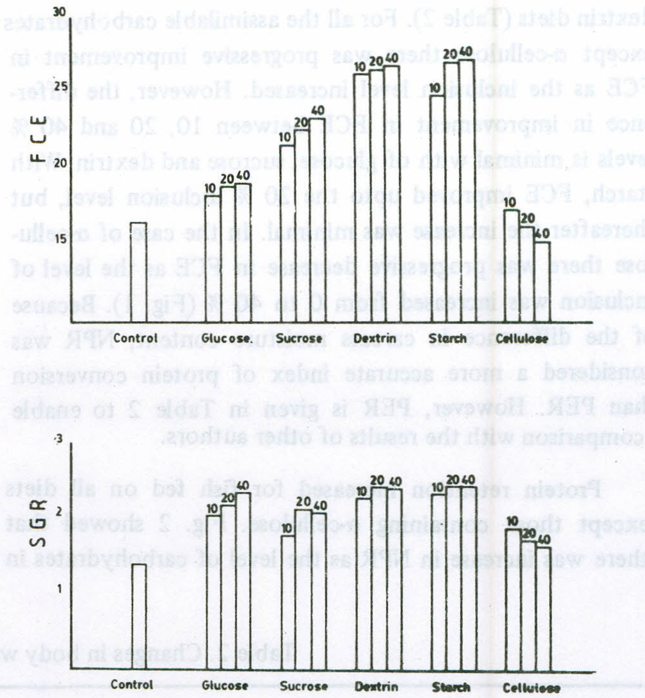

Fig. 1. SGR and FCE of *S.mossambicus* fed on diets containing different levels of carbohydrate.
(Figures above bars indicate percentage inclusion).

At the end of the experiment there were significant differences in carcass moisture content between the group ($P < 0.2$). The carcass moisture content was generally higher for glucose and sucrose diets than for starch and

Table 1. Diet formula and chemical composition (g/100g).

		Percentage inclusion of different carbohydrates														
Ingredients	Control	Glucose			Sucrose			Dextrin			Starch			α-Cellulose		
Premix	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
PVP	40	30	20	–	30	20		30	20		30	20		30	20	
Glucose	–	10	20	40	–	–	–	–	–	–	–	–	–	..	–	–
Sucrose	–	–	–	–	10	20	40	–	–	–	–	–	–	–	–	–
Dextrin	–	–	–	–	–	–	–	10	20	40	–	–	–	–	–	–
Starch	–	–	–	–	–	–	–	–	–	–	10	20	40	–	–	–
α-Cellulose	–	–	–	–	–	–	–	..	–	–	–	–	–	10	20	40
Proximate analysis of diet (dry basis)																
Ash	6.5	4.4	4.2	4.5	5.0	5.9	5.3	5.8	5.1	4.8	5.1	4.9	4.5	5.8	5.7	6.1
Crude protein	33.75	34.12	34.75	34.78	35.78	34.91	35	35	35	35	35.16	35.15	34.15	35	35	35
Fat	15.4	17.4	17.5	17.7	16.5	17.8	17.0	17.1	17.6	17.3	16.7	17.8	18.8	15.78	15.0	14.15
Moisture	23.7	18.5	18.4	18.1	21.5	18.2	17.3	25.8	26.1	26.7	28.9	30.1	30.5	29.3	28.7	26.8
Gross energy MJ/Kg	14.0	14.87	15.06	15.14	14.91	15.21	14.92	14.96	15.15	15.04	14.84	15.27	15.62	14.44	14.14	13.80

(a) Premix contained 40 % crude protein, 5.0 % crude fat, (b) All the carbohydrates are of BDH; (c) Mean of 5 determinations.

dextrin diets (Table 2). For all the assimilable carbohydrates except α-cellulose there was progressive improvement in FCE as the inclusion level increased. However, the difference in improvement in FCE between 10, 20 and 40 % levels is minimal with of glucose, sucrose and dextrin. With starch, FCE improved upto the 20 % inclusion level, but thereafter the increase was minimal. In the case of α-cellulose there was progressive decrease in FCE as the level of inclusion was increased from 0 to 40 % (Fig. 1). Because of the difference in carcass moisture content, NPR was considered a more accurate index of protein conversion than PER. However, PER is given in Table 2 to enable comparison with the results of other authors.

Protein retention increased for fish fed on all diets except those containing α-cellulose. Fig. 2 showed that there was increase in NPR as the level of carbohydrates in the diet was increased upto 20 %, further increase decreased the NPR. The presence of non protein energy in the diet

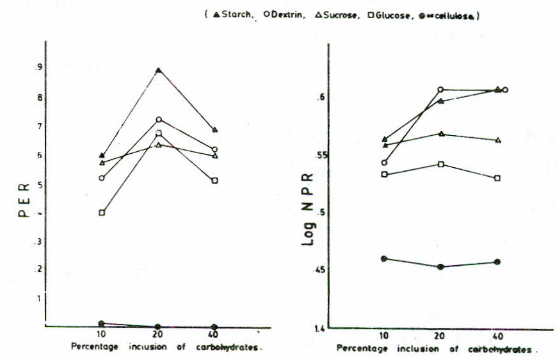

Fig. 2. Showing the effect of various levels of dietary carbohydrates on PER and NPR.

Table 2. Changes in body weight and carcass composition.

Ingredients	% Inclusion of different carbohydrates	Initial mean weight (g)	Final mean weight (g)	Mean % increase (g)	PER	NPR	Condition factor K	Protein	Fat	Moisture	Ash
Control	0	1.91	7.02cde	267.53	2.07	29.19	2.32bcde	16.21	4.31	78.33ab	3.85
Glucose	40	1.90	8.98abcd	367.36	2.51	34.51	2.36bcd	15.71	5.31	77.83abcd	3.55
	20	2.05	8.50abcde	314.63	2.62	35.08	2.46abc	15.55	5.45	77.80abcd	4.21
	10	1.95	8.16bcde	318.46	2.39	34.27	2.50abc	15.51	5.73	76.90cde	3.87
Sucrose	40	1.83	10.12abc	453.00	2.60	37.03	2.53abc	15.31	6.21	77.21cde	3.75
	20	1.75	10.06ab	474.05	2.61	37.35	2.58ab	15.92	6.35	77.58abcd	3.72
	10	2.13	11.01ab	369.95	2.58	36.55	2.60a	15.97	5.65	77.60abcd	4.21
Dextrin	40	2.21	11.56a	323.07	2.62	40.21	2.59ab	16.15	6.37	75.21cde	4.35
	20	2.03	11.06ab	444.82	2.73	39.57	2.58ab	16.01	6.26	75.51cde	4.24
	10	1.98	8.97abcd	353.03	2.52	35.00	2.62a	16.00	5.33	76.00cde	3.88
Starch	40	1.93	11.03ab	471.50	2.69	40.75	2.62a	16.33	7.05	74.11e	4.11
	20	2.11	11.06ab	424.07	2.91	39.41	2.62a	15.99	6.99	74.66de	4.05
	10	2.19	9.40abcd	329.22	2.60	35.23	2.59ab	15.66	3.86	78.88a	4.45
α-Cellulose	40	1.69	5.57e	288.75	2.00	28.31	2.27e	15.65	3.95	78.35ab	3.31
	20	2.03	7.14cde	251.72	2.00	28.25	2.36bcd	15.21	4.25	78.01abc	4.20
	10	2.00	7.21cde	260.05	2.01	29.00	2.35bcd	16.35	4.35	77.95abc	4.32
Initial* Group.	—		—		–	–		16.35	4.35	77.95abc	3.85

*Group sampled for analysis at the beginning of the trial. Mean. wt. 1.87g (n=5). Figures with common superscript in each row are not significantly different (P >0.05).

clearly improved the efficiency with which dietary protein was converted to fish protein. In the case of α-cellulose FCE and NPR values fell as the level of inclusion increased.

All carbohydrates except α-cellulose produced fish with significantly higher condition factors than the control diet ($P < 0.02$). However diets with 10 % carbohydrate inclusion levels showed significantly increased condition with respect to the 20 % and 40 % inclusion levels. The carcass analysis in Table 2 shows that fat content of fish fed on diets containing assimilable carbohydrate was higher, whereas that of fish on 20 % and 40 % α-cellulose diets was lower than the control.

Starch and dextrin at all inclusion level produced fish with a significantly higher fat content than the sucrose and glucose inclusion diets, though the fat content of all the inclusion levels of sucrose and glucose was higher than the control. Carcass fat was related to condition, and regression analysis revealed significant correlation between the two variable ($r=0.58$ $P < 0.02$). Starch and dextrin when included from 0 to 40 % produced fish with significant higher carcass protein. Carcass ash was unaffected by the level or type of carbohydrate fed.

DISCUSSION

Balarin and Haller, [9] reported that warmwater fishes have no requirement of dietary carbohydrate. However the present investigation and that of Anderson *et. al.* [4] demonstrate that carbohydrates can have value as energy source for tilapia. The growth of fish fed on diets containing glucose, sucrose, dextrin and starch was superior to that of fish fed on a carbohydrate free diet and as the inclusion level of each of these carbohydrates was increased to 40 % both the gross energy of diets and fish weight increased (Table 2). Carnivorous species such as salmonids develop high levels of liver glycogen and suffer mortality when fed excess carbohydrate, Philips *et. al.* [10] Buhler and Halver [11], suggested that 20 % should be the miximum level for chinok salmon. It is now recognized that carnivorous species are less able to metabolise carbohydrates than are herbivorous species, Furuichi and Yone [12], Cowey and Sargent [13]. Predominantly herbivorous species such as carp are more capable of utilizing dietary carbohydrate than are carnivores, but carbohydrate levels as high as 40 % have been shown to retard growth even in carp, Furuichi and Yone [14]. In the present study, 40 % inclusion carbohydrate did not retard growth. The use of such high levels of non-protein energy in production diets of tilapia could be an effective means of reducing feed cost.

Diet affects carcass quality and growth, so when developing diets for fish the resulting carcass quality and growth must be considered. In this study, condition was found to improve with increasing dietary carbohydrate for all levels, except in the case of α-cellulose, and significantly correlated with carcass fat. Carcass fat was higher in fish fed on diets containing assimilable carbohydrates than in the control group. However, the fat content of the control remained at a similar level to that of the initial group sampled prior to the feeding trial, indicating that the accumulation of fat was due to the greater energy content of the diet containing carbohydrate. According to Balarin and Hatton [15] the total live weight fat content of tilapia is typically 5-6 % which does not reduce consumer acceptance. The maximum fat levels recorded in the present study were 6.99 and 7.95 % in 20 % and 40 % starch respectively and for most diets was between 5 and 6.78 %.

When the NPR is plotted against the inclusion level of different carbohydrates (Fig. 2) it is apparent that all the carbohydrates had a protein sparing effect which is related to the complexity of the carbohydrate molecule. As more energy was provided by the carbohydrate the proportion of protein energy in the diet decreased and this led to an increase in carcass protein retained per unit protein fed. At low carbohydrate inclusion levels, when approximately 50 % of the total energy was provided by protein, the amount of protein sparing appeared to be related to the complexity of the carbohydrate molecule. Thus, the simple sugars glucose and sucrose had a greater sparing effect than dextrin, starch and α-cellulose. As the level of carbohydrate increased and the proportion of protein energy in the diets decreased, the order changed and starch produced the most sparing, while glucose produced the least. Sucrose showed better retention than glucose in that there was improvement in protein retention by increasing the inclusion level indicating that disaccharides have greater potential than monosaccharides.

Increasing the level of starch from 20 to 40 % improved NPR, but the gain remained the same regardless of increase in the amount of dextrin. The same increase in the amount of glucose and sucrose depressed NPR. Pieper and Pfeffar [16] reported similar results in the replacement gelatinized maize starch with 30 % glucose in the basic diet spared dietary protein in rainbow trout. They suggested that the poor performance of the glucose diet might be due to negative physiological effects caused by glucose saturation. As a monosaccharide, glucose requires no digestion and is rapidly assimilated across the gut, whilst starch and sucrose must undergo enzyme hydrolysis before assimilation. Hence glucose appears at gut absorption sites more rapidly than disaccharides or polysaccharides hydrolysis products and the rate of appearance of glucose is more closely related to its concentration in the diet. Glucose is known to inhibit the transport of amino acids at the absorption sites in the gut membrane of higher vertebrate (Alvarado and Robinson [17]) and the same effect has been recorded in fishes (Hokazono *et. al.* [18]).

It is possible, as indicated by the results of present study, that the efficiency of energy retention is greater in diets of starch and dextrin than in diets containing glucose. It is postulated that the slower influx of monosaccharides from the digestion of dextrin and starch might be beneficial. The inhibition of amino acid transport accounts for the decrease in protein retention of tilapia fed on diets containing glucose at levels greater than 20 %.

As all the carbohydrate inclusion levels increased from 0 to 20 % there was improvement in SGR, whilst slightly poorer FCE was recorded at the inclusion level of 40 % for sucrose, dextrin and starch. It is possible that levels of disaccharides and polysaccharides higher than 20 % could reduce growth, where as 40 % glucose inclusion improved FCE. When α-cellulose was included in the diets at 10 % there was no reduction in growth with respect to the control, indicating that low levels of fibre are acceptable in diets for tilapia. However, at higher fibre levels, FCE and SGR were reduced while condition and carcass fat were similar to corresponding measures for the control (Fig. 1, Table 2. Hilton *et. al.* [19] reported similar results for the growth of rainbow trout fed on a high-fibre diet. Based on data the obtained in the present study it appears that α-cellulose, which is often used as an inert bulker in experimental diets, retards growth. This reduction in growth is associated with a decrease in gut passage time (GPT) and diet digestibility. Polypropylene, which may be a better bulking agent was used instead of α-cellulose in the present study. It probably would have less active effect on GPT than a fibrous material since it does not absorb water.

In summary, there seems to be potential for using complex carbohydrates upto a level of 40 % as an energy sources in the feed of tilapia. Further work is in progress to assess the long-term effect of feeding carbohydrate on fecundity, breeding and flesh quality.

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