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Evaluation of five carbohydrate sources for *Penaeus vannamei*

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ABSTRACT

Utilizing chromic oxide as an inert marker, apparent digestibility coefficients of five carbohydrate sources were evaluated in 8.8 g *Penaeus vannamei*. Test diets for each ingredient, wheat starch, whole wheat, Nutribinder®, sorghum and steam cracked corn, were prepared containing 70% semi-purified reference diet and 30% of the test ingredient. Apparent dry matter digestibility (ADMD) of steam cracked corn was 23.27% and was significantly lower than all other ingredients tested. The ADMD of Nutribinder®, whole wheat, wheat starch and sorghum were 56.87, 52.46, 50.62 and 38.39%, respectively. ADMD of Nutribinder® was significantly higher than that of sorghum but not significantly different from whole wheat and wheat starch. Apparent digestible energy (ADE) values for the test diets ranged from 90.82% for the reference diet to 78.09% for the test diet containing corn. ADE values for wheat starch (71.30%), whole wheat (67.73%), Nutribinder® (69.54%) and sorghum (57.93%) were significantly higher than the ADE of steam cracked corn (40.17%). ADE values for wheat starch, whole wheat, Nutribinder®, sorghum and steam cracked corn were estimated to be 2966, 2915, 3209, 2604 and 1610 kcal/kg. Consumption of the test diets appeared to be inversely related to the digestibility coefficients, indicating that consumption may be energy regulated. Based on the observed results, digestibility of the tested carbohydrate sources appears to vary with source and gelatinization. Additionally, a significant depression in the protein digestibility of the reference diet as compared to the test diet containing the same carbohydrate source (wheat starch) may indicate associative effects.

INTRODUCTION

The primary focus of shrimp nutrition research has been to evaluate diet quality in terms of growth parameters of the cultured shrimp (for reviews see New, 1976; Wickins, 1976; Kanazawa, 1982; Chuang, 1991; Akiyama, 1992). Although this information is essential, before an ingredient can be properly evaluated as an economically acceptable ingredient for a formulation, the bioavailability of the nutrients must be determined. With the establishment

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of the bioavailability of the nutrients, both economic and nutritional parameters can be evaluated to determine the most economical level of inclusion in a feed formulation. Various studies have utilized the indirect chromic oxide method for determining the bioavailability of formulated diets and individual ingredients with several species of shrimp (Smith et al., 1983, 1985; Lee and Lawrence, 1985; Seidman and Lawrence, 1985; Akiyama et al., 1989); however, little research has been conducted specifically to determine the energy availability of carbohydrate sources.

Carbohydrates are the most economical sources of dietary energy. They appear to be well utilized by shrimp, and feeds containing relatively high levels of carbohydrates appear to have acceptable palatability and support good growth (Pascual et al., 1983; Shiau et al., 1991; Catacutan, 1991; Shiau and Peng, 1992). Utilization of carbohydrates by shrimp appears to vary with complexity and processing of the carbohydrate (Chuang, 1991). With limited information on the bioavailability of energy from carbohydrate sources, the nutritional and economic value of these ingredients is difficult to properly evaluate. Hence, the objective of this research was to determine the apparent digestibility coefficients of five carbohydrate sources for *Penaeus vannamei*.

METHODS

Apparent digestibility coefficients for five carbohydrate sources were determined for *P. vannamei* (8.8 g mean weight). Prior to the initiation of the experiments, shrimp were acclimated to the experimental conditions and diets. Shrimp were maintained in a semi-closed recirculating system consisting of 12 circular culture chambers (120 l), rapid rate sand filter, foam fractionater and biofilter. Salinity and temperature were maintained at 30 ppt and 28–30°C, respectively.

To determine apparent digestibility of the test diets and ingredients, voluntary consumption of a test diet with chromic oxide as an inert marker was employed. Each feed ingredient was evaluated utilizing a 30% replacement in the semi-purified reference diet (Table 1). Apparent digestibility coefficients for the reference diet were used to calculate digestion coefficients for the feedstuffs of interest based on the substitution of 30% test ingredient (Wilson and Poe, 1985). Test diets for each ingredient: wheat starch, whole wheat (soft white: 40% hard kernel, 60% soft kernel), Nutribinder® (gelatinized partially pre-digested grain products, primarily sorghum), grain sorghum and steam cracked corn, were prepared containing 70% reference diet and 30% of the test ingredient. Prior to use the sorghum, whole wheat and steam cracked corn were ground through a hammer-type mill with a #24 mesh screen. Dietary ingredients were homogenized in a food mixer (Hobart Corporation, Troy, Ohio). Boiling water was then blended into the mixture until a consistency appropriate for pelleting was reached. Each diet was pelleted utilizing a meat

TABLE 1

Composition of reference diet

Ingredient[a]	g/100 g dry weight
Casein	44.5
Gelatin	9.0
Wheat starch	28.0
Menhaden fish oil[b]	3.0
Soy lecithin (oil not removed)	1.0
Cholesterol	0.5
Fish solubles[b]	1.0
Carboxymethyl cellulose	2.0
Cellulose[c]	4.4
Vitamin premix[d]	2.0
Stay-C (10.28% active vitamin C)[e]	0.1
Mineral premix[d]	4.0
Chromic oxide sesqui[f]	0.5

[a]United States Biochemical Corporation, Cleveland, Ohio, USA.
[b]Zapata Haynie Corporation, Reedville, Virginia, USA.
[c]Sigma Chemical Corporation, Cleveland, Ohio, USA.
[d]Equivalent to Davis et al. (1992).
[e]L-Ascorbyl-2-Polyphosphate. Hoffman-LaRoche Inc. Nutley, New Jersey, USA.
[f]Fisher Scientific, Pittsburgh, PA, USA.

grinder with a 3 mm die. After pelleting, the diets were dried by forced ambient air to a moisture content of 8–10%.

Each of the test diets was fed to four replicate tanks of shrimp (15 shrimp per tank) over a 3 day conditioning period followed by a 2 day collection period. Exuviae and feces were removed from the tanks before the shrimp were given an initial feeding. To ensure that previously consumed material (feces and exuviae) was cleared of the digestive system, feces from the first feeding were discarded. Shrimp were allowed to feed for 30–40 min after which the feces were collected and uneaten feed removed. Fecal samples were collected by siphoning the feces from the tank into a 48 μm sieve. To limit mineral contamination from saltwater, the samples were immediately rinsed with distilled water and then dried for subsequent analyses. Once all the tanks had been siphoned the feeding process was repeated. Fecal samples collected from the same tank/treatment were pooled, resulting in four samples/treatment.

Chromic oxide was determined by the method of McGinns and Kasting (1964), crude protein by micro-Kjeldahl (Ma and Zuazago, 1942) and gross energy by micro-bomb calorimetry (Parr adiabatic calorimeter, Parr Instrument Company, Moline, Illinois). Total starch and gelatinized starch were analyzed by the Ralston Analytical Laboratories (Checkerboard Square, Saint Louis, MO, USA) and are presented in Table 2.

To evaluate the palatability of the test diets, feed consumption was esti-

TABLE 2

Total and gelatinized starch content (%) of the test diets[1]

Test diet	Total	Gelatinized	Gelatinization
Reference (RD)	25.0	6.0	24.2
70%RD+30% wheat starch	45.8	10.5	22.8
70%RD+30% whole wheat	36.3	11.6	32.1
70%RD+30% Nutribinder®	38.1	25.9	67.9
70%RD+30% sorghum	38.9	10.6	27.3
70%RD+30% steam cracked corn	39.1	11.0	28.1

[1]Analysis conducted by a commercial laboratory by standard methods (Ralston Analytical Laboratories, Checkerboard Square, Saint Louis, MO).

mated utilizing 10 shrimp (15 g mean weight) per culture chamber. The system's salinity and temperature was maintained at 30 ppt and 28–30°C. Each diet was fed to four tanks of shrimp over a 3 day period. The shrimp were offered an excess of feed for three 1 h feedings per day. At the end of the feeding period, excess feed was removed and collected in a 48 μm sieve. The uneaten feed was then rinsed with distilled water, pooled by tank and dried to a constant weight. Daily feed consumption was then estimated arithmetically.

Data were analyzed using a one-way analysis of variance to determine significant ($P<0.05$) differences among treatment means. Student-Newman-Keuls' multiple range test (Steel and Torrie, 1980) was used to evaluate significant differences among treatment means. All statistical analyses were conducted using the Statistical Analysis System (SAS Institute Inc., 1988).

RESULTS AND DISCUSSION

Based on visual observations, the test diets produced a quick feeding response and were readily consumed by the shrimp. Feed consumption varied significantly between the dietary treatments (Table 3). Based on correlation analyses, percent consumption was negatively correlated to the digestibility coefficients of the test diets. These results may indicate that consumption rates were adjusted in response to nutrient bioavailability, presumably due to the availability of dietary energy. Sedgwick (1979) found that although there were no significant differences in the weights of *Penaeus merguiensis*, the shrimp's consumption of the test diets was inversely related to their energy content. Similar control of food consumption through dietary energy density has also been reported in fish (Palaheimo and Dickie, 1966; Page and Andrews, 1973; Poston, 1975).

Apparent digestibility coefficients for the diets are presented in Table 3. Digestibility values observed for the basal diet are in accordance with diges-

TABLE 3

Average daily consumption and apparent digestibility coefficients for dry matter (ADMD), crude protein (ACPD), and energy (ADE)

Test diet	Consumption	ADMD	ACPD	ADE
Reference (RD)	1.53[d2]	87.17[a]	98.40[a]	90.82[a]
70% RD+30% wheat starch	2.02[bc]	76.21[bc]	95.60[b]	85.78[b]
70% RD+30% whole wheat	1.94[bc]	76.76[bc]	95.00[b]	84.71[b]
70% RD+30% Nutribinder	1.90[c]	78.08[b]	92.06[c]	84.89[b]
70% RD+30% sorghum	2.23[ab]	72.53[c]	91.35[c]	81.82[c]
70% RD+30% steam cracked corn	2.32[a]	68.00[d]	89.30[d]	78.09[d]

[1] Based on three 1 h feedings/day.
[2] Data represent the mean of four replicates. Mean values in any column with the same letter are not significantly different ($P<0.05$).

tibility coefficients reported for single ingredients (Akiyama et al., 1989) and compounded diets (Shiau and Peng, 1992). Digestion coefficients for the test diets were significantly lower than those for the reference diet, indicating a poor digestibility of the carbohydrate sources. Decreases in apparent protein digestion of the test diets appeared to be related to the dry matter digestibility of the diets and/or quantity of feed consumed. The substitution of cellulose filler with bread flour at 5 to 35% of the diet did not result in significant changes in APD in *P. monodon* juveniles (Catacutan, 1991). Although a depression in growth rates was associated with the use of corn starch, Shiau et al. (1991) reported no significant differences in apparent digestibility coefficients for protein, dry matter, lipid or carbohydrates in *P. monodon* fed diets containing wheat flour or corn starch. Based on the results of the present study and limited information on potential associative effects, clear conclusions for the observed decrease in protein digestion can not be made. Consequently, further evaluation of the interactions of carbohydrates with other diet components appears justified.

Apparent digestibility coefficients for dry matter and energy of the tested ingredients ranged from 56.87% (Nutribinder®) to 23.27% (corn starch) and 71.3% (wheat starch) to 40.17% (corn starch), respectively (Table 4). ADMD and ADE coefficients of corn were significantly lower than values observed for all other test ingredients. The commercial processing of sorghum (Nutribinder®) resulting in an increased gelatinization value (Table 2) significantly improved the digestibility of the sorghum. Similar improvements in the nutritional quality of carbohydrates due to increased gelatinization have been reported for other aquatic animals such as the red sea bream, *Pagrus major* (Jeong et al., 1991), channel catfish (Cruz, 1975), and the rainbow trout (Kaushik et al., 1989). Based on these results, digestibility of the tested carbohydrate sources appears to vary with source and gelatinization. Appar-

TABLE 4

Apparent digestibility coefficients for dry matter (ADMD), energy (ADE) and the gross energy (GE) of the test ingredients

Ingredient	Percent		kcal/kg	
	ADMD	ADE	GE	ADE
Wheat starch	50.62[ab1]	71.30[a]	4160	2966[ab]
Whole wheat	52.46[ab]	67.73[a]	4302	2915[ab]
Nutribinder	56.87[a]	69.54[a]	4615	3209[a]
Sorghum	38.39[b]	57.93[a]	4496	2604[b]
Steam cracked corn	23.27[c]	40.17[b]	4008	1610[c]

[1]Data represent the mean of four replicates. Mean values in any column with the same letter are not significantly different.

ent digestible energy values for wheat starch, whole wheat and Nutribinder® appear similar and these carbohydrate sources appear to have a significantly higher bioavailability than corn and sorghum.

CONCLUSION

Under the conditions of this experiment the test diets appeared to have acceptable palatability. Consumption of the test diets appeared to be inversely related to the digestibility coefficients, indicating that consumption may be energy regulated. ADE values for wheat starch, whole wheat, Nutribinder®, sorghum and steam cracked corn were estimated to be 2966, 2915, 3209, 2604 and 1610 kcal/kg. Based on these results, digestibility of the tested carbohydrates appears to vary with source and gelatinization.

Based on the results of the current study and previously reported results with other species, further investigation into the effects of processing, source and level of inclusion on digestible energy values is warranted.

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