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SHORT COMMUNICATION

Apparent digestibility coefficients of protein, lipid and carbohydrate in practical diets fed to paddlefish, *Polyodon spathula* (Walbaum)

Richard J Onders[1], Steven D Mims[1], Carl D Webster[1] & Ann L Gannam[2]

[1]Aquaculture Research Center, Kentucky State University, Frankfort, KY, USA

[2]US Fish and Wildlife Service, Abernathy Fish Technology Center, Longview, WA, USA

Correspondence: R J Onders, Aquaculture Research Center, Kentucky State University, Frankfort, KY 40601, USA. E-mail: rick.onders@kysu.edu

The paddlefish, *Polyodon spathula* (Walbaum), shows promise as an aquaculture species because, as a sturgeon relative (Bemis, Findeis & Grande 1997), its roe is processed into black caviar. In addition, the boneless white meat has shown high potential for consumer acceptance of both fresh and value-added products (Wang, Mims & Xiong 1995). Paddlefish can be trained to accept a prepared diet, although they are obligate filter feeders of zooplankton in nature (Rosen & Hales 1981). Feed training is necessary for intensive culture of phase II juveniles (Mims & Shelton 2005) for stocking in ponds or reservoirs. Currently, commercially available trout or catfish feeds are fed to paddlefish in ponds or tanks (Onders, Mims, Wilhelm & Robinson 2005). However, no data have been published on the ability of paddlefish to utilize nutrient sources from prepared diets. The objective of this preliminary study was to determine the digestibility of protein, lipid and carbohydrate in practical diets containing three different protein and carbohydrate levels by paddlefish.

Diets were formulated from readily available ingredients with chromic oxide added as an indigestible indicator (Austreng 1978) (Table 1). Ingredients were supplied by Rangen (Buhl, ID, USA). The ingredients were ground using a pin mill (Alpine, Hosokowa Micron Powder Systems, Summit, NJ, USA), and then screened to remove particles >0.5 mm using a Rotex screener (Rotex, Cincinnati, OH, USA). Aliquots of each ingredient were then weighed to produce 50 kg of each diet. Diets were prepared as follows: wheat midds and soybean meal aliquots were placed in a No. 4A Buffalo mixer (John E. Smith's Sons, Buffalo, NY, USA) along with chromic oxide and mixed for 6 min. The remaining ingredients were then added and mixed for an additional 6 min. The mixture was fed into a pilot-scale Wenger X85 extruder (Wenger, Sabetha, KS, USA), fitted with a 1.6 mm die. Extrusion parameters were: preconditioner – 7.5 min at 43 °C, extruder barrel – 30 s at 93.5 °C and 6.8 atm. The resulting pellets were dried in a variable circulation batch drier (Proctor and Schwartz Division, Wolverine (MA), Horsham, PA, USA), and then air cooled. Finally, the pellets were top coated with lipid.

Age-0 paddlefish of mean weight ($\pm$ SE) 155 ± 5 g were randomly selected from a holding tank and stocked 12 fish tank^{-1} into three 2700 L circular tanks (2.4-m-diameter $\times$ 0.6-m-depth), supplied with flow-through dechlorinated municipal water (5.7 L min^{-1}, 23 °C). Dissolved oxygen was maintained above 75% of saturation using air stones. The experiment was conducted in three trials of one diet each with a different set of paddlefish used for each trial. The paddlefish were starved for 2 days before each trial to clear the digestive tract. The feeding response to the chromic-oxide-coated pellets was poor; therefore, to ensure that paddlefish consumed the diets, the pellets were ground in a coffee grinder, mixed with water to form a paste and loaded into a 50 mL syringe. The syringe was fitted with a

Table 1 Formulations (g kg^{-1}) for determining ADC of nutrients in practical diets fed to paddlefish

	Diet		
Ingredient (protein)	**1**	**2**	**3**
Menhaden fish meal (64%)	60	50	40
Soybean meal (47.5%)	356	226	109
Distiller's grains with solubles (28%)	149	149	149
Wheat midds (16.7%)	179	179	179
Wheat flour (12%)	141	281	410
Corn gluten meal (42.6%)	50	50	50
Menhaden fish oil	20	20	20
Dicalcium phosphate	8	8	8
Vitamin mix	20	20	20
Mineral mix	5	5	5
Stay C (35%) active	2	2	2
Choline chloride (70%)	3	3	3
Chromic oxide	7	7	7

ADC, apparent digestibility coefficient.

6-cm-length plastic tube and the fish were fed by injecting the diet into the oesophagus. Feeding was performed at 08:00 and 16:00 hours. Before each feeding, faeces were collected by stripping (Venero, Miles & Chapman 2007) by application of thumb pressure to the area immediately anterior to the anus. Faecal material was collected until 100 g wet faeces was accumulated from each replicate tank. Faecal samples were stored at -15 °C.

The diets and faecal samples were analysed by a commercial laboratory (Woodson-Tenent Laboratories Division, Eurofins Scientific, Des Moines, IA, USA). The laboratory measured protein, lipid, moisture, ash and chromic oxide. Carbohydrate was calculated by difference (Barrows & Hardy 2001); however, fibre was not determined. Therefore, reported carbohydrate levels are inflated by the fibre content. Available energy values for the diets were estimated according to the procedure described by King (2004); (Table 2).

The apparent digestibility coefficient (ADC) for each diet was calculated according to

$$\mathrm{ADC}\ (\%) = 100\left[1 - \left(\frac{N_\mathrm{f}}{N_\mathrm{d}} \times \frac{I_\mathrm{d}}{I_\mathrm{f}}\right)\right]$$

where N_f is the nutrient in faeces, N_d is the nutrient in diet, I_d is the indicator in diet and I_f is the indicator in faeces. The mean values for ADC of protein, lipid and carbohydrate were compared by ANOVA. *t*-Tests were used when multiple comparisons were required.

There was no significant difference in ADC ($P > 0.05$) for protein among diet treatments, which averaged 84.2%. For lipid, ADC was also not significantly different ($P > 0.05$) among the diets, averaging 59.8%. For carbohydrate, ADC was not significantly different ($P > 0.05$) between diet one (34.1%) and two (30.9%); however, diet 3 was significantly lower ($P < 0.05$) than the other two diets at 22.9% (Table 3).

Table 2 Proximate composition (% wet weight) of three practical diets fed to paddlefish in order to determine ADC of nutrients, and calculated available energy from protein, lipid and carbohydrate

	Diet		
Diet component	**1**	**2**	**3**
Moisture	8.6	9.4	9.7
Protein	34.2	29.3	24.8
Lipid	8.0	7.8	7.7
Ash	7.2	6.5	5.8
Carbohydrate	42.0	46.9	52.1
Available energy (MJ kg^{-1})*	12.7	12.2	11.9

*Estimated using the following available energy values: protein 17.6 MJ kg^{-1}, lipid 34.5 MJ kg^{-1}, carbohydrate 9.4 MJ kg^{-1}(King 2004).
ADC, apparent digestibility coefficient.

Table 3 Apparent digestibility coefficients (ADC) for protein, lipid and carbohydrate from three practical diets fed to paddlefish*

	Diet		
Component	**1**	**2**	**3**
Protein (%)	83.8 ± 1.7^{a}	84.8 ± 1.4^{a}	83.9 ± 0.7^{a}
Lipid (%)	66.3 ± 1.8^{a}	66.0 ± 4.3^{a}	47.7 ± 25.6^{a}
Carbohydrate (%)	34.1 ± 0.1^{a}	30.9 ± 3.3^{a}	22.9 ± 2.9^{b}

*Values are means (± SD) for three replications. Means in the same row with different superscripts are significantly different ($P < 0.05$).

Zooplankton, the natural food of paddlefish, is high in protein and lipid. Mischke, Li and Zimba (2003) reported proximate compositions of zooplankton collected from ponds that averaged 65% and 8.8% for protein and lipid, respectively, on a dry matter basis. However, paddlefish have been shown to survive and grow on diets much lower in protein and lipid. In a study comparing commercially available feeds, Onders *et al.* (2005) reported no significant differences in growth or survival when paddlefish were fed either a commercial trout feed (45% protein, 16% lipid) or a commercial catfish feed (32% protein, 4.5% lipid). In addition, the paddlefish fed either feed were of condition factor similar to paddlefish reared in ponds on zooplankton exclusively (Mims & Knaub 1993); however, fillet lipid and abdominal fat levels were significantly higher in the paddlefish fed the trout feed, indicating that available energy exceeded the requirement.

The diets used in this study contained between 2.6% and 3.8% protein derived from fish meal; however, the high ADC for protein (84.2%) indicates efficient use of plant-based protein ingredients as well. Degani (2002) investigated the digestibility of soybean meal and fish meal by adult hybrid sturgeon; Russian sturgeon, *Acipenser gueldenstaedtii* (Brandt) × *Acipenser bester* (female beluga sturgeon, *Huso huso* L × male sterlet, *Acipenser ruthenus* L) and reported that ADC for soybean meal and fish meal were not different at 82% and 81% respectively. These values are similar to the average ADC for protein (84%) obtained in the present study, in which soybean meal accounted for 53%, 41% and 24% of the total protein in the three diets respectively. Sturgeon and paddlefish have similar digestive tracts, including an intestine with an attached pyloric caecum, a spiral valve intestine and a short rectum, and these results suggest similar levels of protease activity as well.

Paddlefish lipid digestibility became highly variable (Table 3) as carbohydrate increased from 42% to 52% (Table 2). In a study by Médale, Blanc and Kaushik (1991), lipid digestibility by Siberian sturgeon, *Acipenser baerii* (Brandt), decreased as diet lipid increased from 12% to 20% of wet weight proximate composition, and as crude starch increased from 0% to 10% of the diet composition. These authors suggested a possible association between crude starch in the diet and decreased lipid digestibility, while pointing out that increased lipid content did not decrease lipid digestibility in other carnivorous species, such as rainbow trout, *Oncorhynchus mykiss* (Walbaum) (Takeuchi, Yokoyama, Watenabe & Ogino 1978). In the present study, the wheat flour content was adjusted to increase total carbohydrate, increasing crude starch as well, while lipid remained constant. This may indicate a requirement for limiting sources of crude starch in practical diets for paddlefish, and investigating alternate ingredients to limit interference with lipid digestibility.

Paddlefish do not appear to utilize carbohydrate well, as would be expected for a species adapted to nutrients of animal origin. However, grain-based practical fish diets contain carbohydrate necessarily and may also provide an economical energy source. Kaushik, Luquet, Blanc and Paba (1989) reported that Siberian sturgeon do not utilize complex carbohydrate well. However, they also reported that processed carbohydrate sources, such as extruded or gelatinized corn starch or extruded whole corn, could be used as an energy source in Siberian sturgeon diets, limited by adverse liver effects at high levels. Similarly, Flynn-Aikens, Hung and Hughs (1993) reported that white sturgeon, *Acipenser transmontanus* (Richardson), were able to utilize D-glucose and with higher body weight gain and feed efficiency when compared with fish fed diets containing dextrin and cellulose or cellulose alone. Although the practicality of using purified digestible carbohydrate in commercial feeds for sturgeon or paddlefish is questionable, it may be useful to investigate further the digestibility of various carbohydrate forms by paddlefish, in conjunction with liver and lipid digestibility effects.

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