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ISSN 0792 - 156X

PUBLISHER:
Israeli Journal of Aquaculture - BAMIGDEH -
Kibbutz Ein Hamifratz, Mobile Post 25210,
ISRAEL
Phone: + 972 52 3965809
http://siamb.org.il

DIGESTIBLE ENERGY IN DIETARY SORGHUM, WHEAT BRAN, AND RYE IN THE COMMON CARP *(CYPRINUS CARPIO* L.)

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(Received 18.4.05, Accepted 8.2.06)

Key words: common carp, digestibility, energy sources

Abstract

The digestibility of protein, fats, carbohydrates, and energy in three feed ingredients (sorghum, wheat bran, and rye) in common carp, *Cyprinus carpio,* was studied using the chromic oxide method. Three experimental diets were tested. Each contained 52.5% of a basal diet and 47.5% of the test ingredient. The carbohydrate levels in the test ingredients ranged 65-83% and the protein levels ranged 11-18%. Therefore, carbohydrates were the main energy source. Results showed that the digestibility of protein in rye (91.89%) was significantly higher ($p<0.05$) than in sorghum (71.86%) and wheat bran (80.64%), producing 12.4, 6.7, and 9.3 kJ/g digestible energy, respectively. The lipid levels in the test ingredients were very low, 1-4%. Lipid digestibility was 79.84%, 76.71%, and 82.01% in rye meal, sorghum meal, and wheat bran, respectively.

Introduction

In fish, as in other domesticated animals, digestibility is one of the most important aspects in evaluating the efficiency of foodstuffs (Forster, 1999). Relatively inexpensive energy-yielding nutrients, such as fats and carbohydrates, reduce oxidation of dietary proteins that would otherwise be used for energy, satisfy the energy requirements of fish, and improve dietary utilization. The beneficial effects of incorporating protein-sparing nutrients have been studied (Viola and Rappaport, 1979) and optimal protein:energy ratios have been proposed for many fish species (Cho and Kaushik, 1985). A surplus of dietary energy contributes to a high fat content in some fish. Carbohydrates and lipids are important sources of energy because of their ability to "store" protein. The amount of carbohydrates that can be included in fish diets depends on the ability of the fish to digest the particular carbohydrate source. Vegetable carbohydrates are usually the least expensive

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form of energy for animals, but their utilization efficiency varies among fish species. Carnivorous fish, especially trout, poorly digest grains. Eels, though carnivorous, convert wheat meal quite efficiently. Intensive feeds containing no animal protein have been developed for common carp and tilapia (Viola et al., 1982; Degani and Viola, 1987).

Chromic oxide (Cr_2O_3) is used in digestion trials and nutrient balance studies as an inert reference compound to determine the digestibility of nutrients in livestock. The digestibility of a nutrient component in a diet is calculated from the indicator and the ratio of the nutrient in the food and feces (Furakawa and Tsukahara, 1986; Hanley, 1987; Forster, 1999). This indicator has also been successfully used in fish.

Common carp, *Cyprinus carpio* L. is an important aquacultured fish. Extensive studies have been carried out on the nutrition and growth of carp and goldfish (Appleford and Anderson 1996, 1997; Xie et al. 2001). An apparent digestibility coefficient of protein sources (fishmeal, soybean meal, poultry meal) for carp has been reported (Degani et al. 1997a), and the digestibility of protein, fats, carbohydrates, and energy in three feed ingredients (wheat, barley, and corn) has been described in a study conducted in our laboratory (Degani et al. 1997b).

Fagbenro (1999) studied the apparent digestibility coefficients (ADC) of nutrients in cereal grain by-products in common carp. The lowest ADC gross energy was obtained in millet grain (46.3%), increasing to 52.6% in maize grain. The relative ranking of cereal grain by-products in descending order of ADC gross energy was very similar to that observed for ADC dry matter.

The purpose of this study was to examine the digestibility of energy derived from sorghum, wheat bran, and rye in the common carp.

Materials and Methods

Fish and culture system. Common carp (*Cyprinus carpio* L.; 500-800 g) were obtained from the Kibbutz Dan Fisheries. The culture system was developed in the Aquaculture Biotechnology Laboratory at MIGAL – the Galilee Technology Center in northern Israel. We used a recirculating system consisting of nine 1 m^3 containers, three replicates for each treatment. Air was supplied constantly by a blower to maintain the O_2 concentration at 4-5 ppm. The temperature (23±1°C) was controlled by a thermostat, and the water flow was 20 ml/h for each container. Six fish were individually maintained in each container by dividing the container with nets into six equal areas of 40 x 40 x 80 cm (Degani et al., 1997b; Fig. 1). Water quality was measured routinely and maintained at pH 6.8-7 and ammonia 0-1 ppm, as described by Degani et al. (1985).

Diet formulation. Diets were formulated from ingredients commercially available in Israel. The three experimental diets consisted of 47.5% of rye, sorghum, or wheat bran (the test ingredients) plus 52.5% of a basal diet (Table 1). Soybean meal was the main protein source, constituting 25% of the total ingredients. Five samples of each diet were analyzed for dry matter, crude protein, crude fat, ash content, and Cr_2O_3 (Henken et al., 1987). The carbohydrate levels in the test ingredients ranged 64.8-82.9%, while the protein and lipid levels were very low, ranging 11.4-18.3% and 1.1-4.5%, respectively (Table 2). Hence, carbohydrates were the main source of energy. The diets were prepared as reported in Degani et al. (1997b) and fed in pellet form.

Feeding trials and analysis. The six fish in each container were acclimated to the container for two weeks, during which they were fed a commercial carp diet (Zemach Central Feed Mill, Israel). After acclimation, they were fed the experimental diets for another two weeks prior to the start of feces collection. Feces were collected from the cloacae by cannula six hours after feeding from each of the 18 fish in each treatment. The feces of three fish were pooled to provide a reasonable amount for analysis. The experimental period was 45 days. Each sample was collected over about a 9-day period, so that there would be enough feces for chemical analysis. Fifteen samples of feces (five from each treatment) were collected.

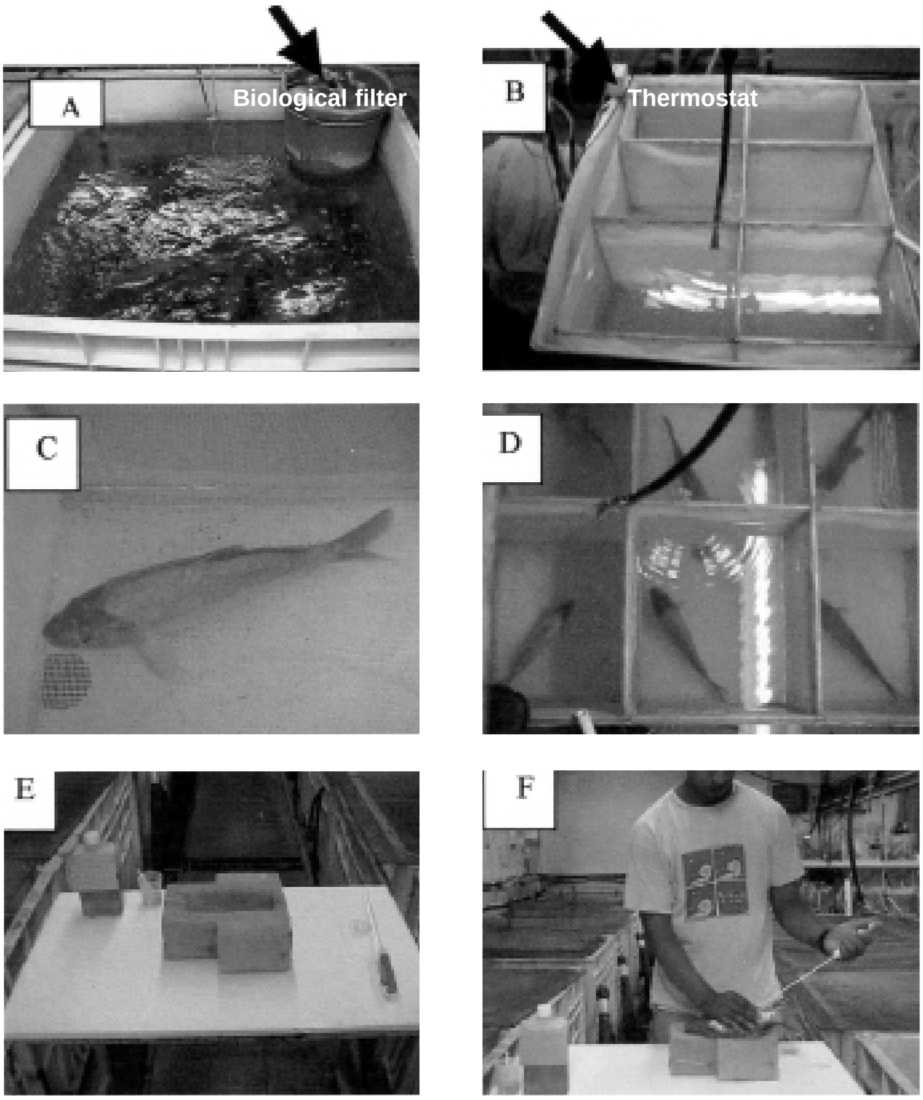

Fig. 1. Several views of a container divided into six equal areas of 40 x 40 x 80 cm, each, and the process of collecting feces from the cloaca by cannula.

Digestibility. Protein, carbohydrate, fat, and total energy digestibility were measured using the chromic oxide method described by Brisson (1956) and Maynard and Loosli (1962) and modified by Hanley (1987). Energy was measured using a bomb calorimeter (Parr, Model-1261).

Chemical analysis. Diets and feces were analyzed by the same method: dry matter was measured by drying the sample at 105°C for 10 h, ash by incineration at 600°C for 12 h, total nitrogen by the Kjeldahl technique (protein = N x 6.25), and total lipid content according to Folch et al. (1957) on the basis of net

Table 1. Composition of experimental diets (% dry matter).

Ingredient	*Rye diet*	*Sorghum diet*	*Wheat diet*	*Basal*
Rye meal	47.5	-	-	-
Sorghum meal	-	47.5	-	-
Wheat bran	-	-	47.5	-
Soybean meal	25.0	25.0	25.0	50.0
Wheat meal	17.5	17.5	17.5	35.0
Soybean oil	5.0	5.0	5.0	10.0
Egg yolk	2.5	2.5	2.5	3
Guar	1.5	1.5	1.5	1.0
Vitamin mix	0.5	0.5	0.5	0.5
Chromium oxide	0.5	0.5	0.5	0.5

Table 2. Proximate analysis of carbohydrate sources in experimental carp diets (% dry matter).

	Rye	*Sorghum*	*Wheat bran*
Crude protein	11.43	9.83	18.26
Crude lipid	1.13	3.60	4.50
Crude fiber	2.50	2.97	7.72
NFE (calculated carbohydrates)*	82.91	82.32	64.82
Ash	2.03	1.70	4.70
Total	**100**	**100**	**100**
Gross energy (kJ/g)	18.10	18.60	19.20

* Nitrogen free extracts, calculated as 100 - (crude protein + crude lipid + crude fiber)

body weight. Concentration of the chromic oxide (Cr_2O_3) indicator was measured using a spectrophotometer (Shimadzu UV-1601). Ammonia production was measured according to the method described by Rand et al. (1975) and energy content with a bomb calorimeter.

Calculations. Diet compositions were calculated as percents of the dry matter. Digestibility was calculated according to the equation: digestibility = 100 - [100(I_i/I_f x N_f/N_i)], where I = % indicator, N = % nutrient, i = ingesta, and f = feces. The digestibility of the experimental ingredient was calculated by the formula: digestibility = (c - bx)/y, where c = digestibility of the experimental diet; b = digestibility of the basal diet; x = proportion of basal diet (i.e., 52.5%); y = proportion of substitute (i.e., 47.5%). Results were calculated from the means of the 18 fish in the diet group. Differences between diets and digestibility of ingredients were analyzed by ANOVA, and significant differences between the means were analyzed by *t* test.

Results

Diet analyses are given in Table 3 and digestibility of the components in Table 4. The protein digestibility of rye (91.89%) was significantly higher ($p<0.05$) than that of sorghum (71.86%) and wheat bran (80.64%), producing 12.4 kJ/g digestible energy in rye, 6.7 kJ/g in sorghum and 9.3 kJ/g in wheat bran. While the lipid contents were very low, the lipid digestibility of rye meal was 79.84%, sorghum meal, 76.71% and wheat bran, 82.01%.

Discussion

To obtain optimal digestibility, nutritional components of fish diets must be studied and diets formulated specifically for each species (Bergot, 1979; Hanley, 1987; Appleford and Anderson, 1996, 1997; Degani et al., 1997a,b; Fagbenro, 1999). Determination of digestibility, together with chemical analysis, allows for more precise estimation of the nutritive value of a given protein and carbohydrate source (Plakas and Katamaya, 1981).

The chromic oxide method for determining digestibility (Austreng, 1978), used in the present study, has been extensively applied in other studies of fish feeds. Other methods have also been employed, including abdominal pressure (Nose, 1967) and metabolic chambers and suction (Schmitz et al., 1984). Each method must be adapted to the species in question, based on the composition and solubility of the feces in water. Carp feces dissolve quickly in water; hence, it is very difficult to extract them without some loss of components. For this reason, the abdominal cannula method of collection was used in the present study.

The use of different methods in different studies makes comparison of results difficult (Henken et al., 1987). Further, the digestibility of a given component may be affected by other diet components (Henken et al., 1987). Additional parameters may also affect the comparison of results, such as the amount fed in the trial (Henken et al., 1987), the age and size of the fish (Henken et al., 1987), and the temperature and quality of the water.

Degani et al. (1997b) indicated that, for carp, the digestibility of wheat meal protein is significantly higher than that of barley meal or corn meal. However, although the differences in their study were less than 10%, the compo-

Table 3. Proximate analysis of test diets (% of dry matter basis).

	Rye diet	*Sorghum diet*	*Wheat diet*	*Basal*
Protein	25.83	22.71	23.79	33.36
Lipid	8.15	7.70	6.80	12.16
Crude fiber	5.14	2.60	2.50	3.22
NFE (calculated carbohydrates)*	54.36	60.87	61.54	44.38
Ash	5.70	4.90	5.4	5.48
Chromium oxide	0.82	1.22	0 .82	1.40
Total	**100**	**100**	**100**	**100**
Energy (kJ/g)	19.9	20.0	23.4	20.3

* Nitrogen free extracts, calculated as 100 - (crude protein + crude lipid + crude fiber)

Table 4. Digestibility of carbohydrate sources (%), n = 18.

	Rye (mean±SD)	*Sorghum (mean±SD)*	*Wheat bran (mean±SD)*
Protein	91.89±1.74	71.86±3.87	80.64 ±2.87
Lipid	79.84±1.71	76.71±1.73	82.01±1.34
NFE (calculated carbohydrates)*	55.35	22.10	34.33
Digestible energy (kJ/g)	12.40±1.05	6.70±1.21	9.30±0.85

* Nitrogen free extracts, calculated as 100 - (crude protein + crude lipid + crude fiber)

sition and proportions of protein and carbohydrate sources varied among test diets. The present study demonstrates that the digestibility of protein in rye and wheat bran is 80-90%, very similar to that in wheat meal and corn as reported by Degani (1997b). Fagbenro (1999) obtained apparent digestibility coefficients (ADC) for crude protein in carp that were a little lower than in the present study, i.e., 79.1% for wheat middlings, 78.2% for maize grain, 76.6% for rice bran, 71.4% for sorghum grain, and 70.9% for millet grain, with no significant differences. The minor variations among studies might be explained by varying conditions in which the fish were maintained or differences in diet compositions. Degani et al. (1986) found a similar effect in eels (*Anguilla anguilla*) where wheat meal led to faster growth than other carbohydrate sources.

Digestibility of carbohydrates in test diets ranges 22.10-55.35% for various fish. Chow et al. (1980) showed that carp can utilize up to 48% of its dietary starch while Cowey and Sargent (1979) found that rainbow trout take advantage of significantly less dietary carbohydrates, up to only 25%. The carbohydrate content of soybean is 64.46%, oats 25.52%, and corn 61.62% (Degani et al., 1997b). In the present study, the NFE content (representing the carbohydrates) was slightly higher (rye 82.9%, sorghum 82.3%, and wheat bran 64.8%).

The percentage of lipids in the carbohydrate sources of the present study was low, due to the difficulty of producing feed pellets with a high lipid content. The established optimal lipid content for carnivorous fish is 10-20% (Cowey and Sargent, 1979). The digestibility of lipids in the present study was relatively high in rye (79.84%) and wheat bran (82.01%), and low in sorghum (76.71%).

In conclusion, carp show a preference for animal protein feed sources, such as fishmeal (Degani et al., 1997a). However since, for economic reasons, a certain percentage of carbohydrates must be included in feed formulas, we propose that sorghum, rye, and wheat bran are all high-quality candidates for this purpose.

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