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Nutrient digestibility of angling baits for carp, *Cyprinus carpio,* with implications for groundbait formulation and eutrophication control

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Abstract To evaluate the suitability of angling groundbaits as a fish feed and the potential for nutrient loss, the macronutrient digestibility of four groundbaits was investigated in carp, *Cyprinus carpio* L., using a sieving method of faeces collection and chromic oxide. Apparent digestibility coefficients (ADCs) of protein and lipids were $> 80\%$ for all angling baits. ADCs of nitrogen-free extracts and phosphorus (P) differed significantly between the test diets, probably because of divergent feed compositions and ingredient treatments. The generally high digestibility estimates indicated that fish feeding on angling groundbait will benefit from this food source. The differences in nutrient digestibility suggested that type of groundbait and ingredient used will have a major effect on potential eutrophication and fish production caused by groundbaiting. The principle of groundbaits to protect the environment should be to minimise the P-content of the groundaits and maximising P-digestibility and P-retention efficiency.

KEYWORDS: boilie, coarse fishing, cultural eutrophication, groundbaiting, phosphorus retention, recreational fisheries.

Introduction

Groundbaiting is commonly practised in freshwater recreational (i.e. non-salmonid) angling to attract fish [e.g. bream, *Abramis brama* (L.), carp, *Cyprinus carpio* L., or tench, *Tinca tinca* (L.)] to the angling site (Wolos, Theodorowicz & Grabowska 1992; Arlinghaus & Mehner 2003). In Germany, the mean amount of bait used per angler was estimated at 7.3 kg yr^{-1} (Arlinghaus 2004a). Given about 3.3 million active anglers in Germany (Arlinghaus 2004a), the total amount of bait used in 2002 was about 24 000 t. When large quantities of anglers' baits are introduced to a fishery, these items may become important in the diet of the fish (Specziár, Tölg & Bíró 1997). The energy and nutrients provided by groundbait can lead to considerable additional production of fish (Schreckenbach & Brämick 2003; Niesar, Arlinghaus, Rennert & Mehner 2004). This additional fish production in turn has a direct effect on yield and angling carrying capacity of the fishery (i.e. yield and carrying capacity increases if groundbait is used in large amounts). At the same time, nutrient inputs by egested, excreted or uneaten groundbait may substantially contribute to anthropogenic euthrophication (Arlinghaus & Mehner 2003; Niesar *et al.* 2004), and/or result in local deoxygenation and reduction of benthic invertebrates (Cryer & Edwards 1987). Accordingly, angling clubs in Germany and the UK are beginning to ban the practice of groundbaiting in some fisheries (Niesar 2003). However, these fisheries management measures are not established objectively because of a lack of thorough scientific studies (Niesar *et al.* 2004).

Against this background, nutrient digestibility is an important aspect of evaluating the suitability of feedstuffs. Highly digestible angling groundbait is desirable for three reasons: (1) high digestibility allows the feeding fish to benefit (i.e. grow) from the artificial

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food, which will also benefit anglers that often target bigger-sized fish (Arlinghaus 2004a,b); (2) high absorption efficiencies are the prerequisite to minimize loss of nutrients by undigested feed; (3) low percentages of egested nutrients minimise the potential impact of undigested feed resulting in bacterial breakdown and associated loss of oxygen in the water column and the sediments. Although previous research has determined growth parameters, such as specific growth rates and feed conversion ratios in carp fed with angling baits (Niesar *et al.* 2004), no studies on the macronutrient digestibility of groundbaits have been conducted. The digestibility of nutrients in angling baits may be different from the digestibility of nutrients in commercially sold (and intensively studied) fish feeds because of potentially divergent feed ingredients used. Therefore, the aim of this study was to determine the macronutrient digestibility of selected, commonly-used, angling groundbaits for carp and compare the estimates with the values published for commercially available carp feeds. It was hypothesised that the digestibility of nutrients should differ between different types of angling baits resulting from divergent bait formulations and nutrient compositions (Niesar *et al.* 2004).

Materials and methods

To determine the digestibility of angling groundbait for fish, a controlled digestibility experiment was carried out. Two angler surveys helped to assess the main types of groundbait used in coarse fishing in Germany (Arlinghaus & Mehner 2003; Arlinghaus 2004a). Random samples of the main bait types were made up. These bait samples were then fed to juvenile carp and apparent digestibility coefficients (ADCs) of the macronutrients and the energy were determined by the indirect method using chromic oxide as an inert marker substance and the automatic faeces sieving method (see Choubert, de la Noüe & Luquet 1982; Arlinghaus, Wirth & Rennert 2003 for details on experimental set up).

Fish and culture conditions

Experiments were carried out using 1+ carp (see Niesar *et al.* 2004 for details on experimental fish origin). This age of carp was chosen because of the space constraints of the experimental tanks which did not allow the use of bigger-sized carp targeted by anglers. However, the effect of age or size of carp on digestibility was considered negligible once fish have reached juvenile stages (e.g. Watanabe, Takeuchi, Satoh & Kiron 1996). On 14 November 2001, when the fish reached a mean wet body mass of 115.1 ± 16.2 (SD) g, a random sample was stocked into experimental tanks and acclimatised to the test diets for 11 days. Fish were held in two semi-recirculating systems. Each system was constructed and operated following Choubert *et al.* (1982) and Arlinghaus *et al.* (2003), and consisted of three cylindro-conical tanks (60 L each) of dark synthetic material strengthened by fibreglass. Seventeen fish were held per tank at a stocking density ranging from 32.5 to 32.8 kg m^{-3}. The ranges of water quality parameters in the tanks were ($n = 8$ measurements per tank): water temperature 21.8–22.7 °C, dissolved oxygen 5.4–6.5 mg L^{-1}, conductivity 719–739 $\mu S\ cm^{-1}$, pH 7.8–8.0, ammonium < 0.04 mg L^{-1}, nitrate < 50 mg L^{-1}. Water quality was homogenous in all experimental tanks with the exception of the nitrite concentrations. The latter were generally < 1 mg L^{-1}. However, in two trials (self-made boilies and commercial fish pellet) nitrite values increased temporally up to 15 mg L^{-1}, which may have impacted negatively on the experimental fish. This was the result of the high protein level in these diets (Table 1). Photo period was natural.

Diet formulation and preparation

Four randomly selected angling bait test diets were formulated (Table 1): commercial ready-made boilies; commercial ordinary groundbait; self-made boilies; and particles (i.e. a mixture of cereals, beans and nuts). The latter two were made up according to recipes published in the angling media. The feed samples were milled and mixed thoroughly. Chromic oxide (Cr_2O_3) was added [0.5% of wet weight according to National Research Council (NRC) 1993] as a non-digestible marker to allow calculation of digestibility. Because of varying water contents of the feedstuffs, the final chromic oxide concentration based on dry matter somehow varied among the test diets (Table 1). However, the inclusion level was high enough to guarantee a reliable chemical analysis. Pellets were created by passing a water/feed mixture through a mincer with 1.0-mm diameter holes. The wet pellets were air-dried for 3 days and stored in a refrigerator at 4 °C to minimise loss of nutrients. At the beginning of the faeces collection period, samples of feed were freeze-dried for analysis (Table 1). Four treatment groups were fed exclusively on the basis of the angling bait diets. In addition, a control group was fed with a commercial fish feed (carp pellet, Table 1) that was milled and pelleted according to the same procedure as in the groundbait test diets.

Table 1. Chemical composition of test diets and filtered faeces as well as apparent digestibility coefficients for selected macronutrients in random samples of angling groundbait compared with a control diet (fish pellet)

	Composition (mean, % of dry matter, $n = 1$) of diets					Composition (mean ± SD, % of dry matter, $n = 3$) of faeces					Apparent digestibility coefficients (mean ± SD, % of dry matter, $n = 3$) of the macronutrients in the diet				
Nutrients	Ready-made boilies*	Self-made boilies†	Particles‡	Ground-bait§	Fish pellet¶	Ready-made boilies	Self-made boilies	Particles	Ground-bait	Fish pellet	Ready-made boilies	Self-made boilies	Particles	Ground-bait	Fish pellet
Crude protein	19.2	43.6	15.9	13.7	51.3	13.3 ± 0.5	23.9 ± 0.5	10.2 ± 1.8	11.0 ± 1.2	27.1 ± 0.6	85.1 ± 1.6^{a}	84.7 ± 0.8^{a}	81.2 ± 4.0^{a}	84.5 ± 1.0^{a}	84.1 ± 0.4^{a}
Crude lipid	6.8	11.4	9.1	6.9	13.3	5.0 ± 0.9	6.9 ± 0.2	4.6 ± 0.2	6.0 ± 0.9	6.2 ± 0.6	84.2 ± 3.5^{a}	83.2 ± 0.7^{a}	84.7 ± 0.6^{a}	83.3 ± 1.2^{a}	85.9 ± 1.3^{a}
Crude ash	3.9	8.0	3.3	5.1	13.4	12.9 ± 0.6	16.9 ± 0.6	9.2 ± 0.2	12.3 ± 0.7	33.2 ± 0.6	–	–	–	–	–
NFE	70.1	37.1	71.8	74.4	21.1	68.8 ± 1.1	52.3 ± 0.9	76.0 ± 1.8	70.7 ± 2.7	33.5 ± 0.6	78.9 ± 1.3^{a}	60.6 ± 2.6^{b}	69.1 ± 0.3^{c}	81.6 ± 2.4^{a}	52.2 ± 1.4^{d}
Energy (kJ g^{-1})	19.6	21.4	20.0	19.1	21.3	17.3 ± 0.3	17.7 ± 0.1	17.7 ± 0.2	17.5 ± 0.2	14.9 ± 0.1	81.1 ± 1.5^{ab}	77.0 ± 1.3^{cd}	74.3 ± 1.0^{d}	82.3 ± 1.5^{a}	79.0 ± 0.5^{bc}
Total P	0.42	0.92	0.44	0.30	1.8	1.1 ± 0.1	2.4 ± 0.2	1.1 ± 0.1	1.0 ± 0.1	5.2 ± 0.1	44.8 ± 1.3^{a}	26.5 ± 2.6^{b}	25.1 ± 4.6^{b}	37.4 ± 2.6^{a}	14.2 ± 2.7^{c}
Cr_2O_3	0.65	0.69	0.53	0.50	0.37	3.0 ± 0.2	2.4 ± 0.1	1.8 ± 0.1	2.4 ± 0.3	1.2 ± 0.02	–	–	–	–	–
Organic matter	96.1	92.0	96.7	94.9	86.6	87.1 ± 0.6	83.1 ± 0.6	90.8 ± 0.2	87.7 ± 0.7	66.8 ± 0.6	80.5 ± 1.4^{a}	74.8 ± 1.5^{bc}	72.6 ± 0.9^{c}	82.1 ± 1.8^{a}	76.5 ± 0.5^{b}

Different superscripts indicate significantly different mean digestibility at $P < 0.05$. Digestibility was not calculated for ash and chromic oxide (–).
NFE, nitrogen free extracts (carbohydrate and crude fibre).
*Companies included in the random bait sample: Nutrabaits, Top Secret, Mosella, Eurobaits, Pelzer Baits, Enforcer, Mistral, Nash Bait (see Niesar *et al.* 2004 for addresses of companies).
†Ingredients supplier for the random sample was M + M Baits (see Niesar *et al.* 2004 for address) using the following boilie ingredients: acid casein, birdfood, blood plasma, calf milk powder, egg albumin, low temperature fish meal, lactalbumin, maize meal, semolina, rice meal, soy bean meal fullfat, soy bean protein and spices.
‡Types of particles included in the random sample: barley, hemp, maize, maple peas, peanuts and a commercial dove feed composed of various cereals, nuts and beans (Mariman ZRW OPTI-Max 27 M, n.v. Molens Mariman, Molenweg 200, 2830 Willebroek, Belgium).
§Companies and ingredients included in the random sample: Grebenstein, Marcel van den Eynde, Mosella, Sensas, Tubertini, Top Secret (see Niesar *et al.* 2004 for addresses) and breadcrumbs.
¶Commercial juvenile carp pellet by Kraft Futterwerk Beeskow GmbH, Hafenstraße 11, 15848 Beeskow. Feed: FM 48/14.

Feeding and faeces collection

An automatic continuous collector for fish faeces was attached to each tank (see Choubert *et al.* 1982; Arlinghaus *et al.* 2003 for details). Faeces were collected for 7 days per experiment by which time the faeces amount was considered sufficient for analysis. During the experimental period (25 November 2001 to 22 December 2001), fish were fed 2% wet body weight in the late afternoon. The daily ration was divided into small portions and the feeding was carried out by hand. Generally, most pellets were eaten on the first instance, but uneaten pellets were reapplied. Therefore, although the water stability of the test feeds was presumably lower compared with the more compact angling baits used *in situ*, quick intake by experimental fish ensured limited leakage of nutrients. Feeding lasted between 1.5 and 3 h each day and ended between 19:00 and 20:00 hours. One hour after feeding was finished, the residue of feed in the collection pans was cleared and the pans were set up for collection of faeces. First faeces usually appeared 2 h after feeding stopped. The following day the filtered faeces were collected between 7:00 and 8:00 hr and stored at a temperature of −20 °C. At the end of the digestibility trial the frozen faeces were freeze dried, ground and stored in a refrigerator (4 °C).

Each experiment was conducted in triplicate. Only six tanks were available for five experiments corresponding to the four types of angling bait and the control diet (fish feed). Assuming three replicates for five digestibility trials, 15 tanks would have been needed. Thus, the same fish were used for all trials. This procedure overcame potential group variability in digestibility by carp. The first two experiments were conducted (each in three tanks) followed by a further two, and then the last experiment. The order of the test diets was chosen at random. After the first two experiments were terminated (7 days duration), fish were fed for 5 days with a mixture of the new test diet and a commercial fish feed. This was done to acclimatise the fish to the new diet and allow the fish to overcome potential nutritional deficiencies resulting from the experimental period. One day before each experiment started only the test diet was fed to assure that gut contents were not biased by diet components other than the test diet.

Analytical procedures and calculations

Samples of feed ($n = 1$) and faeces ($n = 3$ per group) were chemically analysed in triplicate (Table 1) using the analytical procedures described in Arlinghaus *et al.* (2003). Gross energy was calculated according to values published in Steffens (1989). ADCs of crude protein, crude fat, nitrogen-free extracts (NFE), organic matter, gross energy and total phosphorus (P) were estimated indirectly as follows:

$$\mathrm{ADC}(\%) = 100 - 100 \times \frac{\%\mathrm{Cr_2O_3 feed}}{\%\mathrm{Cr_2O_3 faeces}} \times \frac{\%\mathrm{nutrient\ faeces}}{\%\mathrm{nutrient\ feed}}$$

The ADCs of ash and dry matter were not determined, because fish may excrete minerals uptaken by way of their gills out of the water into the gut, biasing the estimates for absorption of ash and dry matter. Group differences of mean ADCs between test diets were analysed by one-way-analysis of variance (ANOVA) and the conservative Tukey *post hoc* tests at a type-one-error probability of $P < 0.05$. Dunnet-T3 *post hoc* tests were used in case of heteroscedasticity of variances. ANOVA was used because of its standard use in fish nutrition research using similar experimental set-ups. Moreover, ANOVA is fairly resistant against deviations from the normal distribution of the data.

Results

All the test diets were highly digestible by juvenile carp (Table 1). Mean ADCs of crude protein and crude lipid were >80%, and not significantly different between the groundbaits and between the baits and the control diet. There was no correlation between the protein and lipid content of the test diets and the ADCs of protein or lipid respectively (linear correlation, $P > 0.05$). Greater differences in ADCs were found with respect to NFE, which can be regarded as a surrogate for carbohydrate digestibility. The highest mean ADC of NFE was found in the NFE-rich diets ordinary groundbait (81.6%) and ready-made boilies (78.9%, Table 1). Significantly lower ADCs of NFE were determined for particles (69.1%), self-made boilies (60.6%) and the control diet (commercial fish pellet, 52.2%) ($P < 0.05$).

As a result of the different ADCs-values of NFE, the mean ADCs of organic matter and energy, which summarise the ADCs of the single macronutrients and allow evaluation of the digestibility of the whole diet, were significantly higher (80.5–82.3%) in the ordinary groundbait and ready-made boilies test diets compared with self-made boilies and particles (72.6–77.0%, $P < 0.05$, Table 1). The mean ADC of organic matter in the commercial fish feed (76.5%) was also significantly lower compared with ready-made boilies and ordinary groundbait ($P < 0.05$), but was significantly higher than in the particle diet (72.6%; $P < 0.05$). Similarly, concerning ADCs of energy, the energy in the commercial fish feed was better absorbed than the energy in the particle diet, but lower digestible compared with the energy in the ordinary groundbait. No differences were found comparing the ADCs of energy in commercial fish feed and ready-made boilies.

The apparent digestibility of P was higher for ready-made boilies and ordinary groundbait compared with the other three test feeds (Table 1). The total P-digestibility was lowest in the commercial fish feed diet, and intermediate in the particles and self-made boilies. At the same time the fish pellet and the self-made boilies had the highest total P-concentrations (Table 1).

Discussion

The method by which digestibility is calculated is the decisive factor that determines accuracy in digestibility measurements (e.g. Vens-Cappell 1985). Because of the filtering procedure, leakage of nutrients was the major source of error for the ADCs in the present study leading to a potential overestimation of digestibility. Therefore, only literature results obtained by faeces collection methods that used faeces egested into the water are comparable with the ADCs of this study.

Generally, the ability of carp to digest dry groundbaits used in coarse angling is substantial. Normally fish are able to digest and use dietary proteins, particularly fish proteins and dietary lipids, particularly fish oils, efficiently (NRC 1993). Proteins and lipids in angling groundbaits are no exception and high ADCs > 80% were found similar to other studies on dry carp feeds used for aquaculture (cf. Kirchgessner, Kürzinger & Schwarz 1986; Kim, Breque & Kaushik 1998). Similarly, the mean ADC-values for NFE in the present investigation (52–82%) are in the upper range reported by Kirchgessner *et al.* (1986) for 23 different feed mixtures in carp (17–90%, mean 56%). Correspondingly, the mean ADCs of organic matter and energy ranging between 72 and 82% in the present investigation were in agreement with literature data on carp feeds (e.g. 50–90% according to Kirchgessner *et al.* 1986).

Irrespective, digestibility does not necessarily equate with utilisation of the absorbed nutrient and energy. Niesar *et al.* (2004) used the same angling test diets in a growth experiment, i.e. utilisation of the angling baits in terms of body growth increment was assessed. By comparing the digestibility values reported in this paper with the growth rates in Niesar *et al.* (2004), the potential disconnection between digestibility and utilisation becomes visible, i.e. high digestibility does not necessarily yield high growth. For example, although the ADCs of organic matter and energy were of comparable magnitude in ordinary groundbait and ready-made boilies (Table 1), the specific growth rates of carp fed exclusively with these angling groundbaits differed significantly from each other (cf. Niesar *et al.* 2004 for values). Highest growth rates and lowest feed conversion rations were achieved with the commercial fish pellet and self-made boilies (Niesar *et al.* 2004), although their ADCs of organic matter and energy were significantly lower compared with the digestibility values of ready-made boilies and ordinary groundbait (Table 1). Therefore, high digestibility of nutrients is a necessary but not the sufficient prerequisite for high growth rates. Ideally, digestibility and growth trials have to be combined to allow for an objective evaluation of the nutritional quality of angling groundbaits.

Despite the overall high digestibility values found, noteworthy differences between the mean ADCs of NFE and P in several test diets were determined, supporting the initial hypothesis. Feed composition and treatment of ingredients are probably responsible for these differences. Unfortunately, commercial suppliers rarely indicated the ingredients used for preparation of angling baits. This stops identification of factors responsible for the detected differences. Two explanations are nevertheless likely. As regards carbohydrate digestibility, the comparatively lower ADCs of NFE in the commercial fish feed and the particle test diet were probably the result of the heat treatment to which most angling baits or bait ingredients are subjected. Every boilie once mixed with eggs and manufactured to small balls is boiled by anglers or commercial suppliers to harden its texture. Furthermore, ingredients commonly used in ordinary groundbait are often baked (e.g. biscuit meal) or roosted (e.g. hemp seed meal). Carbohydrates (and consequently NFE) are more digestible by fish, including carp, if they are thermically treated or extruded (Steffens 1989). By contrast, the commercial fish feed was a pellet and not an extruded feed, and the particles used were uncooked. This may explain the higher ADCs of both the two boilie diets and the ordinary groundbait feed compared with the particles and the fish feed. The differences in ADCs of P between the test diets are probably related to the predominant chemical form of P in the groundbait (cf. Shcherbina, Gamygin & Sal'kova 1997). Carp and other cyprinids lack an acid-secreting stomach essential for digesting various chemical forms of P, particularly tricalcium phosphate, which is the main P source in fish meal (Ogino, Takeuschi, Takeda & Watanabe 1979; Satoh, Viyakarn, Takeuschi & Watanabe 1997). The fish meal inclusion was high in the self-made boilie and the fish pellet test diets, but low or absent in ready-made boilies, ordinary groundbait and in particles. This may explain the comparatively lower ADCs of P for self-made boilies and commercial fish feed compared with ready-made boilies and ordinary groundbait. The ADC of P was also relatively low in the particle test diet. This is probably because the particles were made of various seeds, beans and cereals. Phosphorus in seeds is primarily the calcium–magnesium salt of phytic acid known as phytin (Lall 1991). Phytin-P is unavailable to animals with simple or no stomachs, such as carp, because they lack the enzyme phytase in the gastrointestinal tract (Lall 1991). Phytic acid also forms insoluble salts with free calcium in the digestive tract (NRC 1993). Hence, the digestibility of P in most plant products is low (Ogino *et al.* 1979; Lall 1991; NRC 1993; Shcherbina *et al.* 1997).

The high, but variable, digestibility estimates found in this study allow four main conclusions. First, digestibility of angling groundbaits is comparable to the digestibility values reported for commercial carp feeds. Thus, the ingredients used for formulating angling baits and carp feeds seem to be similar in nutritional quality. Digestibility of angling groundbait seems high enough to facilitate high retention of nutrients compared with a situation of low digestibility characterised by high egestion and feed loss rates, which can lead to local deoxygenation in sediments. Secondly, fish feeding on angling groundbait may significantly benefit from the artificial food source as nutrients and energy can be absorbed, which complements their natural food. Thus, angling carrying capacity is higher in fisheries receiving high inputs of groundbaits. Thirdly, nutrient inputs resulting from angling groundbaits might be reduced if anglers introduce groundbaits in moderate amounts and only after locating feeding fish to allow the attracted fish to consume most or all of the groundbait introduced to a water body. Anglers, particularly if they are only interested in the attraction of fish, should be educated that overfeeding of fish or heavy groundbaiting at fishless sites might lead to substantial nutrient inputs which may be detrimental to water quality (Arlinghaus & Mehner 2003; Niesar *et al.* 2004). An alternative would also be to reduce catch-and-release fishing to remove nutrients by way of fish harvest (Arlinghaus & Mehner 2003; Niesar *et al.* 2004). However, feed loss may always be high if groundbait particles are $< 250\ \mu m$ or become pulverised or small-sized after being crushed by the pharyngeal teeth (Sibbing 1984). Groundbaits should be as coarse grained and waterproof as possible. Lastly, the differences in nutrient digestibility between different groundbaits suggests that type of groundbait and ingredients used for bait formulation will have a major effect on the potential eutrophication caused by groundbaiting and the potential growth of coarse fish feeding on groundbait. From an ecological and nutrient loading point of view, the aim of 'ecological groundbaits' should be to minimise the P-input by maximising P-digestibility and P-retention efficiency and minimising the P-level of the groundbaits (cf. Niesar *et al.* 2004). This can best be achieved by avoiding P-rich ingredients in composed baits and uncooked particles characterised by low overall nutrient digestibility values. However, reducing fish meal and other animal meals in composed baits, which typically contain the highest P-concentration, may reduce its attractiveness for fish (and the angler), because free amino acids, betaine (trimethylglycine), nucleotides and nucleosides contained in fish meal and other animal products act as feeding stimulants for some coarse fish (Kasumyan & Døving 2003). Further studies should therefore investigate how the addition of specific feeding stimulants to ecological groundbaits may result in baits that are highly digestible and attractive on the one hand, but low in fish meal and P on the other hand.

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