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Comparative nutrient digestibility of arctic foxes (*Alopex lagopus*) on Svalbard and farm-raised blue foxes (*Alopex lagopus*)

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Abstract

Arctic foxes from Svalbard ($n=4$) and farmed blue foxes ($n=4$) was used in a digestibility experiment with a high-carbohydrate feed to add more information to the nutritional physiology of the arctic fox, and to compare its digestive capacity with that of the farmed blue fox. The arctic fox has a diet containing mainly protein and fat from mammals and birds, while farmed blue foxes have been exposed to an omnivorous dietary regime for more than 80 generations. The experiment showed in general no difference in digestive capacity for protein and fat between the foxes ($P>0.05$), but for carbohydrates, including starch and glucose, the blue fox revealed higher digestibility values. The superior digestive capacity for carbohydrates in blue fox might be a result of a long-term selection of animals digesting dietary carbohydrates more efficiently, or that an early age exposition to dietary carbohydrates has given permanent improvement of the carbohydrate digestion in the gut.

Keywords: *Alopex lagopus*; Amino acids; Carbohydrates; Fat; Fox; Digestibility; Protein; Starch

1. Introduction

The arctic fox (*Alopex lagopus*) lives in a circumpolar tundra zone of North America, Eurasia, Greenland, Iceland, Svalbard, and alpine Scandinavia (Hersteinsson, 1989). They exist in two colour types; white and blue. The white dominates in nature and accounts for approximately 97% of the population (Hersteinsson, 1989). The blue fox (*Alopex lagopus*) is the most numerous in farm condition and has its origin in trapped arctic foxes from Greenland, Alaska, Iceland and Svalbard approximately 80 years ago (Nes et al., 1987).

The food availability for the arctic fox on Svalbard varies with season. Seabirds and eggs are main food sources in summer, and terrestrial birds and carcasses of Svalbard reindeer and seal are dominating during winter (Frafjord, 1993; Prestrud, 1992). Thus, the arctic fox has a diet consisting mainly of protein and fat of animal origin and nothing or very little from vegetable sources. The farmed blue fox, on the other hand, is given a diet with considerable amount of carbohydrates coming from grain or other vegetable sources. According to feeding recommendations, carbohydrates may account for as much as 35% of metabolisable energy (ME) in the diet of farmed blue foxes (NRC, 1982; Enggaard Hansen et al., 1991).

The objectives of the present work were to compare digestibility of a vegetable based diet in

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wild arctic foxes captured at Svalbard and farm-raised blue foxes.

2. Material and methods

2.1. Animals

The experiment with wild arctic foxes was carried out at the Norwegian Polar Institute's Research Station in Ny-Ålesund (78°55′N, 11°56′E), Svalbard, Norway, 11–17 June, 1997. Four adult male foxes were randomly chosen out of eight males comprising the experimental animal stock at the Research station. They had been trapped in the near-by area of Ny-Ålesund and kept captured for 1–2 years for other scientific purposes (Fuglei and Øritsland, 1999, 2001; Fuglei et al., 2000; Fuglei, 2000). The age of the animals were at least 12 months (probably 14 months old) and average body weight at the start of the experiment was 3.80 kg (S.D. 0.55). The foxes were housed in individual, adjacent outdoor cages (2.5 m long×2.0 m wide×2 m high) made of plastic-coated steel wire. Each cage was furnished with a wooden sleeping box (0.5 m long×0.5 m wide×1.0 m high). Prior to the experiment, they were given free access to a commercial extruded fox feed produced by Felleskjøpet, Norway. The ME distribution among the main nutrients in this feed was 33% from protein, 43% from fat and 24% from carbohydrates. Thus, the arctic foxes had been well adapted to dietary carbohydrates after capture.

The experiment with farmed blue fox was carried out at the experimental fur farm at Department of Animal Science, Agricultural University of Norway, Ås, Norway, 27 June–3 July, 1997. The experimental animals were four 13–14 months old males randomly chosen out of ten males of the same age. The average body weight was 6.0 kg (S.D. 0.70). Before and after the experiment the animals were kept in individual semi-outdoor cages (1.5 m long×1.2 m wide×1.0 m high) made of plastic-coated steel wire. The cages were equipped with a wooden shelf. Ad libitum feeding was adopted and water was supplied with a semi-automatic system. Prior to the experiment the blue foxes were given feed produced at a local supplier of moist fur animal feed. Energy distribution (ME) among main nutrients was approximately 30% from protein, 50% from fat and 20% from carbohydrates.

Table 1
Chemical content (%) and amino acid content (g/16 g N) of the experimental diet

Chemical content (%)	
Dry matter	92.5
Protein ($N\times6.25$)	21.2
Fat	6.4
Carbohydrates (by difference)	58.8
Starch	39.3
Starch + glucose	45.9
Ash	6.1
Amino acid (g/16 g N)	
Cysteine	1.26
Methionine	1.91
Aspartic acid	7.95
Threonine	3.78
Serine	4.44
Glutamic acid	12.78
Proline	5.93
Glycine	7.11
Alanine	5.98
Valine	5.14
Isoleucine	3.98
Leucine	7.46
Tyrosine	3.13
Phenylalanine	4.25
Histidine	2.55
Lysine	5.82
Arginine	5.92
Hydroxyproline	2.05
Tryptophan	1.10
Total amino acids	92.54

The experiments were carried out with permission from the National Animal Research Authority and experimental procedures followed Norwegian protocols of ethical standards for the use of live animals.

2.2. Experimental procedure

The experimental diet was commercial dog feed from the same batch with a relatively high carbohydrate content, and low protein and fat level (Table 1). Feed ingredients in descending weight order were: rice, cornmeal, chicken meat meal, chicken meat, corn germs, beet pulp, chicken broth, potato protein, mineral mixture, flaxseed meal, lecithin and vitamin mixture. The approximate ME level per kg dry matter (DM) was estimated to 14.5 MJ. Protein constituted 23%, fat 17% and carbohydrates 60% of ME using these factors: 18.8 kJ/g digestible protein, 39.8 kJ/g digestible fat and 17.6 kJ/g digestible carbohydrates (Enggaard Hansen et al., 1991).

Feed allowances (100 g mixed with 200 g water daily) covered the maintenance energy requirement (NRC, 1982; Enggaard Hansen et al., 1991) by 115–120% for the arctic foxes and by 100–105% for the blue foxes. Since the body weight differences between arctic foxes and blue foxes mainly were made of body fat, the same feed allowances were used.

During the experiment all foxes were kept in cages ($1\times1\times1$ m^3) equipped for controlled feeding and quantitative collection of faeces and for separation of urine. The cages used in Ny-Ålesund were kept out door and put together only for the present experiment, while the cages at Ås were placed in side as a permanent part of the metabolism laboratory. Average daily temperature was 12–15 °C in both places. Day length was 24 h in Ny-Ålesund and 19 h in Ås. For the farmed blue foxes the adaptation period lasted for 3 days. For the arctic foxes, the adaptation lasted for 7 days before they were moved to the experimental cages to ensure a satisfactory feed intake. Thus, the adaptation period all together lasted for 10 days for the arctic foxes. The period of faecal collection lasted for 4 days for both types of foxes. The same person conducted the experiments in both locations.

The apparent digestibility of the experimental feed (%) was calculated as:

$$((a-b)/a)\times100$$

where *a*, amount consumed and *b*, amount excreted in faeces.

2.3. Chemical analyses

Samples of the experimental diet and faeces (freeze-dried) were analysed for DM, crude protein ($N\times6.25$), amino acids, crude fat, starch, glucose and ash. Carbohydrates content was calculated by subtracting protein ($N\times6.25$), fat and ash from DM content.

All chemical analyses except for amino acid analyses were carried out at AnalyCen, Lidköping, Sweden, using standard methods. DM was obtained by heating at 105 °C for 5 h. The method of Dumas was applied for determining crude protein ($N\times6.25$). Amino acid analyses were performed at the Department of Animal Science, Agricultural University of Norway using a ninhydrine method approved by the European Communities. Crude fat was assayed by acid hydrolysis followed by extraction with diethyl ether. Starch and glucose were assayed enzymatically. Ash was obtained by heating at 550 °C for 10 h.

2.4. Statistical analyses

The ANOVA procedure in the Statistical Analysis Systems Institute (SAS, 1985) was applied for statistical analyses of the digestibility values. Type of fox was the only fixed variable in the model. Variation was expressed as pooled standard error of the mean (pooled S.E.M.).

3. Results and discussion

3.1. Feed intake and faecal output

Both experiments were carried out without any problems and the feed was accepted with practically 100% intakes for the eight animals. The average body weights were reduced with 0.08 kg (S.D. 0.02) and 0.18 kg (S.D. 0.04) during the experiment in arctic foxes and blue foxes, respectively. This was not expected since reference studies have shown that the present dietary energy supply should cover maintenance energy requirement (NRC, 1982). But since energy for physical activity is included in the maintenance energy requirement, differences in physical activity of the animals between experiments may have influenced the results. However, there are no reasons to believe that minor underestimation of energy requirement had any impact on digestibility values.

Faeces consistency was satisfactory and there were no signs of diarrhoea in any animals. Faecal production on wet and DM basis did not differ significantly between the groups (Table 2), but the blue fox showed the lowest average values. Differences in faecal output on wet weight basis were mainly accounted for by carbohydrates and water (Table 2), while the difference in faecal output of protein and fat was insignificant.

Faecal starch and glucose were highest in arctic foxes and accounted for the significantly higher faecal carbohydrate output compared with that of blue foxes. Exact composition of dietary and faecal carbohydrates was not known as only starch and glucose were analysed for. Yet, the rest of the carbohydrate fraction besides starch and glucose would probably be non-starch polysaccharides (Table 2). Surprisingly, the percentage of water in faeces was somewhat lower for the arctic foxes

Table 2
Average feed intake (g) and faecal production (g) during the 4-day faecal collection period and average chemical content of faeces (g)

	Arctic fox $n=4$	Blue fox $n=4$	Pooled S.E.M.	P-value
Feed intake	1190.8	1189.6	0.8	0.96
Dry matter intake	367.2	366.8	0.4	0.97
Faeces	339.7	306.9	25.0	0.39
Faecal water	233.1	219.5	18.1	0.35
Faecal dry matter	106.6	87.4	6.3	0.07
Faecal protein ($N\times6.25$)	26.0	24.8	1.8	0.09
Faecal fat	2.8	2.6	0.1	0.11
Faecal carbohydrates (by difference)	61.8	45.3	4.3	0.01
Faecal starch	9.2	4.2	1.6	0.09
Faecal starch + glucose	16.2	6.1	2.8	0.05
Faecal ash	16.0	14.7	0.8	0.30

than in blue foxes, even though there was higher faecal DM output in the arctic foxes. This result could be owing to the high level of faecal starch and glucose in arctic foxes. Starch and glucose, which made up for a major difference in faecal output of carbohydrates between the foxes, have less ability than non-starch polysaccharides to bind water.

3.2. Digestibility

DM digestibility was significantly higher in blue foxes than in arctic foxes. The higher digestibility value was due to higher average digestibility of all nutrients, but mainly carbohydrates, which was significantly higher (see below).

The average protein digestibility values differed 4.7% between arctic foxes and blue foxes, but due to the fact that one of the arctic foxes showed almost the same protein digestibility value as the four blue foxes, a significant difference was not found ($P<0.08$). The protein digestibility values were generally low for all foxes in the present study (Table 3). Fish- or slaughterhouse by-products commonly used in fur animal feed have protein digestibility values approximately 80–88% in blue foxes (Rouvinen et al., 1991; Skrede and Ahlstrøm, 1995). Skrede and Ahlstrøm (1995) showed that apparent protein digestibility decreased from 88 to 84% in blue foxes when the carbohydrate level increased from 7.7 to 40% of dietary DM. Vegetable protein is often less digestible than animal protein (Ahlstrøm and Skrede, 1997), thus the high vegetable protein level in the experimental diet may also explain the low digestibility of protein.

The high non-starch polysaccharide content of the experimental diet in the present study, may have affected protein digestibility negatively. It has been demonstrated that protein digestibility in dogs is reduced by fibre (Burrows et al., 1982). The fibre sources of the present study would mainly be beet fibre and a minor part originating from corn meal, flax seed and rice. Beet fibre contains approximately 79.9% non-starch polysaccharides (Bach Knudsen, 1997).

Generally, the apparent amino acid digestibility revealed somewhat higher values than for protein (Table 4). Most of the amino acid digestibilities did not differ significantly between arctic fox and blue fox, but aspartic acid, proline, glycine and hydroxyproline revealed significantly higher digestibilities in blue foxes (Table 4). Except for aspartic acid, these amino acids are dominating in connective tissue and in bone. Farmed blue foxes are receiving a ground wet feed containing small fractions of bone originating from slaughterhouse by-products, fish by-products or meat-and-bone meal. The dominating remains at arctic fox dens from reindeer are bones, and from birds mainly feathers, wings and whole carcasses (Prestrud, 1992). Therefore, arctic foxes have not the possibility to eat finely ground bone material in the same amount as farmed blue foxes. There is, however, no similarity in the absorption mechanism for the four mentioned amino acids except for proline and hydroxyproline and we therefore believe that the significant differences occurring

Table 3
Average apparent digestibility values (%) and energy data

	Arctic fox $n=4$	Blue fox $n=4$	Pooled S.E.M.	*P*-value
Dry matter	71.0	79.3	1.7	0.01
Protein ($N\times6.25$)	69.1	73.9	1.6	0.08
Fat	89.1	91.0	0.6	0.07
Carbohydrates (by difference)	73.5	83.4	1.9	0.01
Starch	94.1	97.7	1.0	0.04
Starch + glucose	91.1	97.2	1.5	0.03
Ash	34.0	47.1	3.7	0.05
Energy content, ME, MJ/kg feed	12.6	13.9		
Energy distribution, % of ME				
From protein	21.8	21.2		
From fat	18.0	16.7		
From carbohydrates	60.2	62.1		

Factors used to calculate ME: 18.8 kJ/g digestible protein, 39.8 kJ/g digestible fat and 17.6 kJ/g carbohydrates (Enggaard Hansen et al., 1992).

are casual, and a result of the general difference in protein digestibility values between the two groups of foxes.

Digestibility values of fat for blue foxes and arctic foxes were high and did not differ significantly (Table 3). The values are in agreement with digestibility of beef tallow in blue foxes (Rouvinen et al., 1988). The low dietary fat:carbohydrate ratio level may have reduced the fat digestibility values somewhat as observed with mink (Ahlstrøm and Skrede, 1995). However, the lecithin, which was added to the experimental diet could have improved fat digestibility. Lecithin itself is a fat source and could also serve as an emulsifier of other dietary fat and thereby increase fat absorption (Polin, 1980).

Carbohydrate, starch and starch + glucose digestibility was significantly lower in arctic fox than in blue fox (Table 3). The enzymatic digestion of starch takes place in the small intestine by alpha-amylase. Murray et al. (1999) demonstrated with ileally cannulated dogs that starch is almost totally digested in the small intestine and an insignificant amount in the large intestine. Thus, this indicates that the difference in starch and glucose digestibility between arctic fox and blue fox is depending on the production or the efficiency of alpha-amylase. Furthermore, the split up of starch to glucose units followed by absorption of glucose are time consuming and it could be that the passage rate in arctic foxes is higher than in blue foxes. However, passage rate was not registered in the present experiments.

A considerable part of the difference in carbohydrate digestibility might be related to different fermentation capacity for non-starch polysaccharides in the large intestine (colon and caecum). One could speculate if this difference was due to the fact that blue foxes could have been selected for improved digestive capacity in the large intestine by being exposed to dietary non-starch polysaccharides through 80 generations. Improved digestive capacity could be owing to altered physical structure of the large intestine or changes in

Table 4
Average apparent amino acid digestibility values (%)

	Arctic fox $n=4$	Blue fox $n=4$	Pooled S.E.M.	*P*-value
Cysteine	54.5	60.1	2.4	0.15
Methionine	75.7	79.6	1.3	0.08
Aspartic acid	66.9	74.4	1.9	0.03
Threonine	70.0	74.5	1.6	0.10
Serine	72.9	77.8	1.5	0.06
Glutamic acid	77.8	81.2	1.1	0.07
Proline	78.8	83.4	1.1	0.02
Glycine	76.1	81.8	1.3	0.02
Alanine	77.0	80.0	1.2	0.13
Valine	74.4	77.7	1.3	0.11
Isoleucine	74.8	76.8	1.0	0.19
Leucine	76.5	79.5	1.1	0.11
Tyrosine	71.6	74.0	1.3	0.23
Phenylalanine	77.7	81.3	2.0	0.26
Histidine	78.4	82.2	1.5	0.13
Lysine	76.2	79.0	1.5	0.24
Arginine	83.8	85.6	0.9	0.19
Hydroxyproline	78.0	86.7	1.8	0.01
Tryptophan	73.9	76.9	1.3	0.16

the microflora in the large intestine. It has been reported in dogs that dietary fibre affects intestinal transit time (Burrows et al., 1982) and that various fibre sources also influence fermentation characteristics of the large intestine (Muir et al., 1996). One could also speculate if the low glucose digestibility in arctic foxes was caused by less colonic bacteria in faeces, and thereby less glucose fermented.

The present experiment show, that arctic foxes have an ability to digest carbohydrates, even though digestive capacity for carbohydrates in blue foxes was higher.

Digestibility of ash was also highest in the farmed blue fox. This was not surprising as the digestibility of all the other nutrients was highest in the farmed blue fox. Digestion of ash is complicated because some of the ash fraction found in the digestive tract originates from body excretions, especially calcium (McDonald et al., 1995). Digestibility values for ash are therefore difficult to interpret, but low DM digestibility, as for the arctic fox in the present study, may imply that minerals are more susceptible to binding to digesta and thereby poor absorption.

Due to higher digestibility values, dietary content of ME was approximately 10% higher for farmed blue foxes than for arctic foxes (Table 3). The ME distribution, however, appeared to be similar, with only a slight difference in ME contribution from carbohydrates.

In conclusion, arctic foxes from Svalbard and farm blue foxes show similar digestive capacity for main nutrients in a vegetable-based diet, except for lower carbohydrate digestibility in arctic foxes.

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