

Ileal and total digestibility of amino acids in feeds used in mink and polar fox nutrition

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ABSTRACT

The results of research on the apparent ileal and total digestibility of nitrogen and amino acids in mink and polar foxes are presented. The research reveals lower values of apparent nitrogen and amino acid digestibility coefficients in the small intestine than in the whole alimentary tract of these animals fed on diets containing different sources of animal protein. Fresh fish proteins showed higher ileal and total digestibility of nitrogen and amino acids than fish meal proteins. The increase or sole content of fish meals in the diets caused more rapid digesta passage, a rise in the amount of voided faeces and lower apparent ileal and total digestibility of nitrogen and amino acids. After diets containing whole fish and beef, the amino acids with the highest digestibility were methionine and lysine. After the diets containing fish meal, meat meal, meat-and-bone meal, and poultry by-product meal, arginine was the amino acid that was the quickest to be absorbed from the small intestine in mink and polar foxes. The amino acids of the lowest availability in the small intestine, as well as in the whole alimentary tract of these species appeared to be threonine and cystine. The lowest apparent digestibility of these amino acids probably resulted from their high content in endogenous nitrogen released in the digestive tract of mink and polar foxes.

KEY WORDS: mink, polar fox, feeds, amino acids, digestibility

INTRODUCTION

Mink (*Mustela vison*) and polar foxes (*Alopex lagopus*) are carnivorous animals, whose small capacity alimentary canal is adapted mainly to digesting feed of animal origin. Mink is an animal characterized by a simple and short digestive tract (only 4 to 5 times its body length), without a caecum and very short passage times for digesta (only 2.5-4 h) (Kainer, 1954; Sławński et al., 1962; Hansen, 1978;

Bleavins and Aulerich, 1981; Szymeczko and Skrede, 1990). The length of the alimentary canal of polar foxes is slightly shorter than in mink (about 3-4:1) (Sławiński et al., 1962; Szymeczko et al., 1992; Szymeczko and Burlikowska, 1996). In comparison with the digestive tract of mink, foxes like dogs, have a better-developed large intestine (Akajewski, 1979). A more complex structure of the large intestine in foxes results in slower digesta passage which, depending on the diet, lasts from about 7 to 11 h (Sławiński et al., 1962; Faulkner and Anderson, 1991; Szymeczko et al., 1992). The comparatively simple, small capacity alimentary canal of those animals and rapid rate of digesta passage (particularly in mink) may probably be offset by the higher, in comparison with other species, efficiency of proteolytic enzymes (Krogdahl, 1983). On the other hand, such a structure of the digestive tract indicates that in order to meet both mink's and polar foxes' maintenance and reproduction requirements, full growth and development of winter fur, it is necessary to provide a high energy diet and protein with highly digestible and available amino acids, mainly sulphur amino acids (Glem-Hansen, 1980; Glem-Hansen and Hansen, 1981; NRC, 1982; Ahlstrøm, 1992; Hansen, 1992; Børsting and Clausen, 1996; Clausen et al., 1998; Damgaard and Clausen, 1999; Hejlson and Clausen, 2000).

The method still used today to estimate the degree of apparent amino acid digestibility of different kinds of feeds used in mink and fox nutrition was introduced by Kuiken and Lyman (1948). It is a faecal analysis method that compares the amounts of amino acids consumed and voided in the faeces (Faulkner et al., 1992; White et al., 1996; Skrede et al., 1998; Ahlstrøm et al., 2000; Ljøkjel and Skrede, 2000; Ljøkjel et al., 2000).

Żebrowska (1973, 1975) and Żebrowska et al. (1978) proved the indisputable influence of bacterial flora of the large intestine in pigs on amino acid catabolism released from different kinds of casein protein. The released nitrogen was utilized by animals to a minimal extent and almost fully excreted in urine in the form of urea nitrogen. The authors of these findings also observed that a poorer quality of protein (heat-treated casein) was accompanied by higher microbial activity in a particular segment of the digestive tract. The research by Buraczewska et al. (1975) and Makkink et al. (1997) conducted on the same animal species show a considerable correlation between the type of protein tested and the amount of endogenous nitrogen secretion. The protein of feeds of lower biological value increased endogenous nitrogen losses. Żebrowska et al. (1973, 1975) claim that apparent amino acid digestibility determined with the faecal analysis method informs only about the final result of protein digestion. It does not consider changes triggered by released endogenous nitrogen and the microbial population in the caecum and colon. This is the reason why the faecal method is often questioned (Sauer et al., 1980) possibly providing misleading information about the nutritive value of the protein sources tested (Żebrowska, 1973). Therefore, the availability of individual amino acids

determined with the use of this method should be considered with great care (Żebrowska, 1975).

Numerous experiments conducted on pigs (Żebrowska et al., 1982; Jørgensen et al., 1984; Just et al., 1985; Walker et al., 1986; Knabe et al., 1989; Makkin et al., 1997) fed on diets with different sources of protein of animal origin revealed lower values for apparent digestibility of nitrogen and amino acids in the small intestine than in the whole digestive tract. In the case of protein sources of low apparent amino acid digestibility in the small intestine, the differences between ileal digestibility and total digestibility were greater. Most authors of such research claimed, on the basis of obtained data, that the ileal method is more precise than the common faecal analysis method in the estimation of amino acid availability. The results of the presented research as well as some failures in breeding mink and polar foxes led to undertaking the first works on ileal availability of amino acids from the sources of protein used in feeding these species of carnivorous fur animals.

APPARENT ILEAL AND TOTAL DIGESTIBILITY OF NITROGEN AND AMINO ACIDS IN MINK

The findings presented in this study will show part of the results of research on the influence of different kinds of fish protein on the apparent digestibility of nitrogen and amino acids in the distal segment of the small intestine and in the whole alimentary tract of mink sacrificed 3 h after the last feeding. After laparotomy, the digestive tract was removed, its length measured and divided into different parts with three equally long segments of small intestine. Digesta from sectioned parts of the digestive tract was collected into the plastic cups by careful washing with cool distilled water and immediately frozen at -18°C . Samples of digesta were freeze-dried and ground and, in the case of faeces, sifted to remove hair. (Szymeczko and Skrede, 1990). The experimental diets were: a diet with whole fish protein (WF), a diet in which half of the whole fish protein was replaced with fish meal (WFFM), and a diet with fish meal as the only source of protein (FM). Chromic oxide was used as a digestibility marker. The ileal and total tract digestibilities of nitrogen and amino acids are presented in Table 1. The highest apparent digestibility of nitrogen, 82.1%, and amino acids, 74.7%, in the small intestine was after the WF diet. Increasing the proportion of fish meal in the WFFM and FM diets lowered the apparent ileal digestibility of nitrogen and amino acids. It also caused a change in the order of absorption of individual amino acids from the mink's small intestine. The amino acids with the highest rate of absorption were Met after the WF and WFFM diets, and Arg after the FM diet. The lowest amino acids absorbed were Cys, Gly, Thr and His after the WF diet, and Cys, Asp, His and Thr after the remaining diets. It needs to be stressed that the higher fish meal share increased the

TABLE 1

Ileal (I) and total (T) apparent digestibility (%) of nitrogen and amino acids in mink

Item	Diet ¹					
	WF		WFFM		FM	
	I	T	I	T	I	T
Nitrogen	82.1	93.7	77.0	89.7	74.6	83.6
Arg	79.0	96.5	79.5	94.9	79.2	92.2
Phe	79.4	96.8	74.4	94.3	74.7	90.5
His	71.7	95.2	64.4	91.4	64.3	85.8
Iso	82.9	96.6	75.2	94.5	75.3	90.8
Leu	79.8	97.0	74.8	94.5	76.1	91.4
Lys	82.0	97.6	77.3	95.4	76.6	91.8
Met	85.2	97.5	80.5	94.8	78.6	91.5
Thr	71.3	92.0	65.7	87.8	67.1	83.5
Val	76.9	96.1	71.5	93.4	73.1	89.7
Ala	75.5	95.7	75.0	93.3	76.0	90.5
Asp	76.8	95.2	60.8	87.8	53.4	77.9
Cys	45.9	86.2	38.6	77.5	31.3	60.1
Glu	79.7	96.3	76.0	93.7	73.8	89.5
Gly	64.1	93.2	61.5	89.9	66.9	84.5
Pro	69.5	93.7	66.8	90.2	71.3	86.3
Ser	70.3	93.6	66.5	90.2	65.4	85.0
Tyr	79.2	96.7	73.3	93.8	71.8	89.1
TAA ²	74.7	95.0	69.5	91.6	69.1	86.5

¹ WF – whole fish diet

WFFM – whole fish and fish meal diet

FM – fish meal diet

² TAA – total amino acids

rate of absorption of Arg and lowered the availability of Cys and Asp from the mink's small intestine. Jørgensen et al. (1984) proved a similar order of amino acid absorption in the small intestine of pigs fed on a diet with fish meal as the sole source of protein. The availability of Arg and Met was the highest and of Cys the lowest.

The apparent digestibility of nitrogen and amino acids in the whole alimentary tract was higher than the digestibility determined in the small intestine after any of the diets. The highest total digestibility of nitrogen, 93.7%, and amino acids, 95%, followed the WF diet. The increasing shares of fish meal increased the concentration of dry matter and ash and might have been one of the reasons for more rapid digesta passage and lower coefficients of apparent nitrogen and amino acid digestibility which, after the WFFM diet, were 89.7 and 91.6%, and after the FM diet,

83.6 and 86.5%, respectively. Skrede (1978) and Sławoń (1987) report that the increase of ash content in the feeds for mink lowered their apparent protein digestibility. The digestibility of individual amino acids determined in the faeces was higher and less variable than the digestibility determined in the content of a distal segment of the mink's small intestine. After feeding with, for example, the WF diet, the apparent digestibility of Met, Iso, Lys, Gly and Cys was, respectively, 85.2, 82.9, 82.0, 64.1, and 45.9%, and the total digestibility 97.5, 96.6, 97.6, 93.2 and 86.2%. It is very difficult to explain precisely the causes of mink's higher apparent nitrogen and amino acid digestibility in the whole alimentary tract than in the small intestine. These animals have a short, simple digestive tract devoid of a caecum, and exhibit rapid digesta passage. In an experiment conducted on mink, Skrede, (1979) also demonstrated very limited microbiological activity in the large intestine, which did not have a crucial influence on the amino acid composition and real nitrogen and amino acid digestibilities determined in the faeces of these animals.

APPARENT ILEAL AND TOTAL DIGESTIBILITY OF NITROGEN AND AMINO ACIDS IN ILEAL CANNULATED POLAR FOXES

The aims of the research carried out on polar foxes (Szymeczko et al., 1992) fitted with simple cannulas in the terminal segment of the small intestine were also to determine the influence of different types of fish protein on digesta passage as well as apparent nitrogen and amino acid digestibility in the ileum and in the whole alimentary tract of these animals. The experimental diets were: a diet with a sole content of eviscerated cod (EC) and a diet in which 50% of the protein was substituted with fish meal protein (ECFM). Diets were balanced to meet or slightly exceed nutrient requirements of polar foxes at maintenance. Each diet was fed to the animals for 12 days in one meal per day at 08.00. Faeces were collected during the last four days and digesta on the last two days of each feeding experiment. Ileal digesta was collected three times daily by attaching a rubber bag to the cannula barrel, and kept at -18°C. After freeze drying samples of the experimental diets, digesta and faeces were analyzed for dry matter, nitrogen, amino acids and chromium oxide, using standard methods. The apparent nitrogen and amino acid digestibility in foxes (Table 2) fed with diet EC was 87.9 and 78.6% and was significantly higher than the digestibility of nitrogen, 68.9% ($P < 0.005$), and amino acids, 67.3%, determined after the ECFM diet. The essential amino acids with the highest absorption rate from the small intestine after the EC diet were Met, Lys, Arg and Leu, and after the ECFM diet, Lys, Met, Leu and Arg. The amino acid slowest in absorption after both diets was Thr. The nonessential amino acids absorbed fastest were Ala, Glu and Tyr after the EC diet, and Tyr, Glu and Ala after

TABLE 2

Ileal (I) and total (T) apparent digestibility (%) of nitrogen and amino acids in cannulated polar foxes

Item	Diet ¹			
	EC		ECFM	
	I	T	I	T
Nitrogen	87.9	94.5	68.7*	89.4*
Arg	84.9	90.1	72.0	86.4
Phe	70.5	90.6	69.5	84.8
His	82.3	89.7	70.6	86.3
Iso	83.3	92.0	69.0	86.3
Leu	84.1	91.4	72.6	87.0
Lys	85.7	91.2	74.9	87.4
Met	88.4	93.5	74.7	88.2
Thr	75.7	87.8	65.3	83.7
Val	80.2	89.1	68.1	84.6
Ala	82.9	89.2	68.1	83.4
Asp	73.3	88.1	64.1	82.0
Cys	56.2	71.9	51.1	65.4
Glu	82.3	91.2	68.7	86.6
Gly	76.8	85.9	58.9	79.4
Pro	73.0	84.9	62.2	80.5
Ser	76.5	87.6	64.1	82.2
Tyr	80.4	88.5	69.3	85.8
TAA ²	78.6	88.4	67.3	83.5

¹ EC – eviscerated cod fish diet

ECFM – eviscerated cod fish and fish meal diet

² TAA – total amino acids

* P<0.01

the ECFM diet; the slowest after both diets was Cys. Similarly to mink, (Szymeczko and Skrede, 1990) it can also be noticed in foxes that substituting half of fresh fish protein with fish meal protein increased the rate of absorption of Arg in comparison with Met and Lys. Szymeczko and Burlikowska (1996) pointed out the high digestibility of nitrogen 93.7% and amino acids 90.6% in the distal segment of the small intestine of polar foxes fed on the diet with the 50% content of high quality fish and beef meat proteins. Among the essential amino acids, Met was the quickest to be absorbed, 93.7%, and Arg the slowest, 85.1%.

The apparent nitrogen and amino acid digestibility determined in the whole alimentary tract was higher than the digestibility determined in the small intestine after the EC and ECFM diets. After feeding on the EC diet, the average digesta passage time was 9.28 h and dry matter digestibility of 70.1%. The differences

between the ileal and total nitrogen and amino acid digestibilities were, respectively 6.6 and 9.8 percentage points. The increase of fish meal content in the ECFM diet considerably ($P < 0.05$) shortened the digesta passage to 7.37 h and considerably increased ($P < 0.01$) the amount of faeces and lowered ($P < 0.01$) dry matter digestibility, 62.5%. It also caused differences greater by 20.8 and 16.3 percentage points between the ileal and total digestibility of nitrogen and amino acids. Results obtained in the research carried out on polar foxes (Szymeczko and Podkówa, 1994) fed on a fresh fish protein diet and high quality fish meal, showed slightly higher values of apparent total nitrogen and amino acid digestibility.

APPARENT ILEAL DIGESTIBILITY OF NITROGEN AND AMINO ACIDS IN ILEAL RECTAL ANASTOMOSED POLAR FOXES

The aim of this part of the work is to present the results of the research on the apparent nitrogen and amino acid digestibility in foxes surgically prepared with end-to-end ileorectal anastomosis fed on diets containing different kinds of meat meal (Szymeczko, unpublished data). After surgery, the polar foxes were returned immediately to the metabolic cages located in a temperature-controlled room and fasted 24 h. The postoperative medication included analgesics and antibiotics. To prevent any deficiency caused by the isolation of the ceacum and colon, the foxes were supplemented with a special vitamin and mineral mixture. After a recovery period of 3 weeks, the animals were fed four experimental diets in succession: the fish meal diet (FM); meat meal diet (MM); meat-and-bone meal diet (MBM) and poultry by-product meal diet (PBPM). All diets contained 0.3% chromic oxide. Each diet was given to foxes for 8 days in one meal daily, at 08.00 a.m. Water was supplied *ad libitum*. Digesta samples were collected during the last four days of each feeding period. Digesta samples taken during the collection period were pooled and kept at -25°C . The samples of experimental diet and digesta were freeze-dried, ground and analyzed for dry matter, nitrogen, chromium oxide content and amino acid composition. After feeding on the FM diet the findings showed the significantly highest ($P < 0.05$) apparent digestibility of nitrogen, 79.4%, and amino acids, 79.2%, in comparison with the remaining sources of protein (Table 3). For the remaining tested meals, much lower values of apparent nitrogen and amino acid digestibility coefficients were obtained. With the exception of considerably higher ($P < 0.05$) amino acid digestibility after the PBPM diet, in comparison with the MM and MBM diets, the remaining differences appeared to be statistically insignificant. The rate of absorption (apparent digestibility) of individual amino acids depended on the kind of meat meal tested. Of the essential and nonessential amino acids, Arg had the highest ileal digestibility across diets, whereas Cys, Asp and Thr had the lowest ileal digestibility values.

TABLE 3

Ileal apparent digestibility (%) of nitrogen and amino acids in ileal rectal anastomosed polar foxes

Item	Diet ¹			
	FM	MM	MBM	PBPM
Nitrogen	79.4 ^a	59.3 ^b	56.3 ^b	55.7 ^b
Arg	88.2 ^a	73.6 ^b	68.2 ^c	76.7 ^d
Phe	83.7 ^a	64.0 ^b	60.1 ^c	66.4 ^b
His	76.9 ^a	53.2 ^b	55.2 ^b	59.0 ^b
Iso	82.0 ^a	57.2 ^b	54.4 ^b	64.9 ^c
Leu	83.8 ^a	60.5 ^{bc}	57.7 ^b	64.0 ^c
Lys	84.9 ^a	58.6 ^b	63.2 ^c	62.8 ^c
Met	84.1 ^a	61.8 ^b	62.3 ^b	66.4 ^c
Thr	78.2 ^a	50.4 ^b	50.3 ^b	59.8 ^c
Trp	81.3 ^a	53.0 ^b	60.2 ^c	71.0 ^d
Val	80.9 ^a	57.6 ^b	53.1 ^c	62.7 ^d
Ala	81.5 ^a	62.7 ^b	62.9 ^b	64.8 ^b
Asp	65.4 ^a	27.4 ^b	36.6 ^c	47.1 ^d
Cys	56.4 ^a	15.5 ^b	6.1 ^c	47.3 ^d
Glu	82.2 ^a	57.1 ^{bc}	56.2 ^b	61.0 ^c
Gly	74.9 ^a	60.2 ^b	58.3 ^b	66.2 ^c
Pro	78.9 ^a	64.7 ^b	59.2 ^c	64.6 ^b
Ser	77.5 ^a	51.7 ^b	46.2 ^c	63.6 ^d
Tyr	84.6 ^a	63.2 ^b	61.3 ^b	65.7 ^b
TAA ²	79.2 ^a	55.2 ^b	54.0 ^b	63.0 ^c

¹ FM – fish meal diet

MM – meat meal diet

MBM – meat-and-bone meal diet

PBPM – poultry by-product meal diet

² TAA – total amino acids^{a,b,c,d} – means within rows with no common superscript differ significantly ($P < 0.05$)

The results of the presented research showed lower values of the coefficients of apparent nitrogen and amino acid digestibility in the small intestine than in the whole alimentary tract of mink and polar foxes fed on diets containing different sources of animal protein. The protein of fresh fish had much higher ileal and total digestibility of nitrogen and amino acids than fish meal protein. The increase or sole content of fish meal in the diets increased the rate of digesta passage and the amount of voided faeces. It also lowered the apparent digestibility of nitrogen and amino acids and changed the order (apparent digestibility) of their absorption. The amino acids with the highest ileal availability after the diets containing fresh fish meat or fish and beef were Met and Lys. After the diets containing fish meal or other animal meals Arg was most quickly absorbed from the small intestine. One

of the probable reasons for the change in the order of absorption of these amino acids might be the greater ability of Met and Lys to react with oxidizing lipids in the process of meal production (Ljøkjel et al., 2000). The amino acids of the lowest availability in the small intestine and the whole alimentary passage in mink and polar foxes were Thr and Cys. The lower apparent digestibility of these amino acids was probably the result of their high concentration in endogenous nitrogen (Skrede, 1979; Szymeczko and Skrede, 1991; Szymeczko, unpublished data). The lowest digestibility of Cys might also have resulted from the high concentration of disulphide bridges resistant to digestion and absorption created during production of animal meal (Opstvedt et al., 1984; Ljøkjel et al., 2000). Research conducted on dogs (Muir et al., 1996; Zuo et al., 1996; Murray et al., 1997; Johnson et al., 1998) fed on the diets containing different animal meals also showed that Thr and Cys were the amino acids most slowly absorbed in the whole of the small intestine of these animals.

CONCLUSIONS

The presented results clearly show lower values of the apparent digestibility of nitrogen and amino acids in the small intestine than in the whole digestive tract of mink and polar foxes fed on diets with raw and dry protein sources. After the diets containing fresh meat (fish or fish and beef) methionine and lysine were the amino acids with the highest digestibility. After the different meat meal diets, arginine had the highest ileal digestibility. Cysteine and threonine had the lowest ileal and total digestibility values of all of the tested sources of protein.

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STRESZCZENIE

Jelitowa i całkowita strawność aminokwasów pasz stosowanych w żywieniu norek i lisów polarnych

Przedstawiono wyniki badań nad pozorną strawnością jelitową i całkowitą azotu i aminokwasów u norek i lisów polarnych. Stwierdzono, że wartości współczynników pozornej strawności azotu i aminokwasów w jelicie cienkim były niższe niż w całym przewodzie pokarmowym zwierząt, karmionych dietami z udziałem różnych źródeł białka pochodzenia zwierzęcego. Strawność jelitowa i ogólna azotu i aminokwasów białka świeżych ryb była większa niż białka mączek rybnych. Duży lub wyłączny udział mączek rybnych w dietach powodował przyspieszenie pasażu treści pokarmowej, zwiększenie ilości wydalanego kału i obniżenie pozornej strawności jelitowej i całkowitej azotu i aminokwasów. Przy żywieniu dietami z udziałem całej ryby i mięsa wołowego aminokwasami najlepiej trawionymi były metionina i lizyna, natomiast przy podawaniu diet z mączką rybną, mączką mięsną, mączką mięsno-kostną i mączką drobiową z jelita cienkiego norek i lisów polarnych najszybciej wchłaniana była arginina. Aminokwasami o najniższej dostępności w jelicie cienkim i w całym przewodzie pokarmowym tych gatunków zwierząt mięsożernych okazały się treonina i cystyna. Najniższa pozorna strawność tych aminokwasów była prawdopodobnie wynikiem dużego ich udziału w azocie endogennym, wydzielanym w przewodzie pokarmowym norek i lisów polarnych.