Effect of diet fat and feeding intensity on production performance and welfare in blue foxes (*Vulpes lagopus*)

Hannu T. Korhonen[1)], Juhani Sepponen[2)]
[1)] *Natural Resources Institute Finland (Luke), Teknologiakatu 7, 67100 Kokkola, Finland, hannu.t.korhonen@luke.fi*
[2)] *Natural Resources Institute Finland (Luke), Halolantie 31A, 71750 Maaninka, Finland juhani.sepponen@luke.fi*

Abstract

The aim was to find out effects of maximum and restricted feeding intensity with high and normal diet fat content on production performance and welfare in growing-furring blue foxes. Study groups were: (1) high fat, 60% of metabolizable energy (ME), maximum feeding; (2) high fat, 60% of ME; restricted feeding 20%. (3) normal fat, 50% of ME, maximum feeding; (4) normal fat, 50% of ME, restricted feeding 20%. Maximum fed animals grew better, and their final weights were significantly higher compared to restricted ones ($P<0.001$). Body condition score was affected by feeding intensity ($P<0.001$) but not by the amount of fat in the diet. Animals fed maximum feeding level had highest body condition score. The amount of diet fat did not influence on feed consumption. Breaking strength of ulna was not affected by the amount of diet fat or feeding intensity. Breaking strength of radius, on the other hand, was higher in animals fed restricted ($P<0.001$). Feeding intensity significantly affected on foot condition, i.e. foot bending was highest at maximum feeding groups ($P<0.05$). Ash content of bones was higher in maximum feeding groups compared to restricted ones ($P<0.001$). Ash content was higher in restricted than ad libitum animals ($P<0.05$). Liver weights were heaviest in animals of maximum feeding level ($P<0.001$). Condition of liver was best in restricted fed animals with lower amount of diet fat ($P<0.05$). According to live animal grading, fur mass, cover, purity and overall impression were poorer in restricted fed animals. Animals fed high fat diet were found to have better fur properties than restricted ones.

Key words: Energy metabolism, farmed fox, feeding regimen, animal welfare

Introduction

The Arctic fox (*Vulpes lagopus*) living in the wild has adapted to marked fluctuations in the abundance of food. It has also accustomed to eating large quantities whenever food is available (Frafjord 1993). Body weight of Arctic fox is varying seasonally, being lowest in early summer and highest in late autumn. The blue fox is a colour mutation of Arctic fox housed for its fur on farms. It has inherited the good appetite and energetic efficiency of its wild conspecific (Korhonen and Harri 1988a). Also farmed blue fox exhibits seasonal fluctuations in feed intake and accretion of body fat, being very high during autumn and early winter periods. In practice blue foxes on farms are then fed unrestrictedly. This has led extremely obese animals, pronounced foot welfare problems and declined reproductive performance (Korhonen et al. 2014, 2015, Mustonen et al. 2017, Mononen et al. 2018). Furthermore, blue foxes have been subject to efficient genetic selection for body size and growth efficiency (Kempe et al. 2010, 2018, Peura et al. 2013). This selection criterion has led to a dramatic increase in the actual body size (Kempe 2018). Although often economically beneficial for farmer, excessive body size and mass may compromise animal welfare (Korhonen et al. 2017).

The main ingredients in farm fox feed are products of the fish and slaughter-house industries. Typically their amount varies seasonally (Korhonen 2014). This means that also the amount and distribution of metabolizable energy (ME) varies. Crucial for intense fattening and furring process is the amount of fat from ME. During autumn period, its amount can be even 60% of the total ME in the diet (Koskinen et al. 2012). Essential for preventing excessive autumn fattening is, first, the control of fat percentage in the diet. Kopczewski et al. (2001) found that an increase in feed energy content from 4.83 to 7.02 MJ kg^{-1} caused a significant increase in body weight of Arctic foxes. However, an improvement in the quality of fur was also found. Opposite effects are also available. Gang et al. (2012) clarified effects of various fat levels (12%, 26%, 40%, 54% of ME) on production performance on growing-furring blue foxes. They found that diets with 12 and 26% fat content tended to increase skin size. The amount of fat content over 40%, on the other hand, had negative effects on skin size and fur quality. Older study by Rimeslåtten (1976) supports the concept that even 8–22% diet fat is high enough for proper quality of fur production in blue foxes. In those days, body weight of blue foxes was no more than 6–7 kg only.

Farmers typically fed blue foxes *ad libitum* during autumn. This is a crucial cause for very obese animals (Kempe 2018, Mononen et al. 2018). In previous studies, the amount of feed restriction has been either too low or otherwise not succeeded as planned (Koskinen et al. 2009, 2011). Therefore, further clarification on effects of both feeding intensity and high fat levels on growing-furring blue foxes are needed. The aim of the present study was to clarify effects of maximum and restricted feeding intensity (*ad libitum* vs 20% restricted) with high and normal diet fat (60 vs 50 % of ME) on production performance and animal welfare in juvenile blue foxes during growing-furring period.

Material and methods

The study was performed at Research Station, Kannus, in western Finland (63.54° N, 23.54° E) during the growing-furring period September 3 – November 30. The use of experimental animals was evaluated and approved by the Animal Care Committee of Finland. The general health of the animals was checked daily. Health evaluation was based on general appearance of animals, including consistence of faeces. Furthermore, health of eyes and feet were also followed. Evaluations were done visually by the same person each time. Dirtiness of cage floor was visually evaluated according to scale: 1=clean, 2= fairly clean, 3= dirty, 4=extremely dirty.

Experimental groups employed were: (1) Group 1 (Gr 1): high fat, 60% of metabolizable energy (ME), maximum feeding; (2) Group 2 (Gr 2): high fat, 60% of ME; restricted feeding 20%. (3) Group 3 (Gr 3): normal fat, 50% of ME, maximum feeding; Group 4 (Gr 4) normal fat, 50% of ME, restricted feeding 20%. Feeding restriction was made by restricting the amount of daily feed 20% of the daily maximum feed amount. The groups were formed on Sept 1. Each group comprised 25 males and 25 females. Experimental animals were juvenile blue foxes born in May 2010. Study groups were made genetically equal so that one kit from same litter was placed to each group. The animals were housed in male-female pairs. Housing cages were 105 cm long x 115 cm wide x 70 cm high. Each cage had a wire-mesh platform (105 cm long x 25 cm wide) and a wooden block for chewing (diameter 7 cm, length 35 cm). Daily routine treatments were conducted according to standard farming procedures.

Details of the raw materials, vitamins and chemical compositions of the experimental diets are shown in Tables 1 and 2. Diets were the same throughout the study. Freshly mixed fox feed was supplied twice a day. The feed was manufactured by the research station’s feed kitchen. Palatability of feed was checked before the study. The feed was dispensed by a commercial feeding machine. Leftovers were collected the next day. Watering was automatic *ad libitum*. Daily feed portions were adjusted according to the animals' appetite and seasonal standards.

Table 1. Composition of experimental diets (%)

Raw materials	60% of fat from ME	50% of fat from ME
Broiler	38.0%	36.0%
Baltic herring	14.0%	18.0%
Fox fat	7.1%	4.4 %
Barley	14.5%	21.0 %
Meatfeather meal	2.2%	1.7 %
Meatbone meal	3.5%	2.2 %
Fish meal	2.2%	1.0 %
Water	18.7%	15.7 %
Dietary supplement		
Vitapol formula 2 super, vitamin mixture	150g tn^{-1}	
Polifer super –iron solution	0.33l tn^{-1}	
E- vitamin, folic acid- selen	0.5l tn^{-1}	
DL-methionine	1.05kg tn^{-1}	

Table 2. Chemical compositions and calculated metabolizable energy (ME) in experimental diets

Fat level 60 %	In sample	In dry matter	% of ME
Dry matter	40.8 %		
Ash	3.8 %	9.3 %	
Crude protein	12.2 %	29.8 %	22.4 %
Crude fat	13.6 %	33.4 %	61.6 %
Crude carbohydrates	11.3 %	27.6 %	16.0 %
Metabolizable energy	8.1 MJ kg^{-1}	19.9 MJ kg^{-1}	
Metabolizable energy	1930 kcal kg^{-1}	4740 kcal kg^{-1}	
Fat level 50%	In sample	In dry matter	% of ME
Dry matter	40.8 %		
Ash	3.4 %	8.3 %	
Crude protein	11.3 %	27.7 %	23.0 %
Crude fat	10.8 %	26.5 %	53.1 %
Crude carbohydrates	15.3 %	37.6 %	24.0 %
Metabolizable energy	7.40 MJ kg^{-1}	18.175 MJ kg^{-1}	
Metabolizable energy	1772.5 kcal kg^{-1}	4340 kcal kg^{-1}	

Foreleg carpal joint angle as an indicator of leg bending was evaluated. Evaluation was based on subjective evaluation of forelegs (Kempe et al. 2010, Korhonen et al. 2014) by one evaluator on a scale of

1–5. In the worst case (score 1=very poor condition), the carpal joint was bended to a 90º angle compared to normal. In the best case (score 5=excellent condition) normal angled carpal joint. If one of the carpal joints was more bent than the other, the score was based on the worse leg. The thickness of subcutaneous fat was assessed by a subjective body condition score (BCS) method, which gives an estimate of the degree of fatness independent of the fox's body size (Kempe et al. 2010). BCS was evaluated for each animal on a scale of 1–5, where 1=very thin and 5=extremely fat.

Animals were pelted (Nov 30) according to normal farming practice. Skin grading was performed by Saga Furs Ltd, Vantaa. Fur characteristics evaluated were fur mass, cover of hair and quality. The scale ranged from 1 (poorest) to 10 (best). Fur defects were also evaluated. Skins were weighed with a Mettler SM 15 balance, accuracy ±10 g. Skin length was measured by using a tape measure, accuracy ±1 cm. Grading of live animals was made on November 20 according method of Koskinen et al. (2012a). The bones from left foreleg was removed, cleaned and stored at –20 ºC until assays. The breaking strength of radius and ulna was measured with a Lloyd Instrumental testing machine (1000R, bulb 5 kN, accuracy ±0.05, speed 50 mm min^{-1}), which gives the load (N) required to break the bone (Korhonen et al. 2001). Dry matter and ash contents of bones were measured at MTT laboratory in Jokioinen. Carcass autopsy was made after pelting. The degree of fatness in organs were evaluated according to scale 1–3, 1= normal, 2=moderate fat, 3=very fat. Condition of liver was estimated visually according to scale 1–4 (1=normal, 4= brittle, yellowish, lots of granules) (Koskinen et al. 2012a). Liver was weighed with a Mettler SM 15 balance.

Statistical analyses were made by using SAS 9.2 statistical procedures (SAS 2009). Continuous variables were evaluated by linear mixed model. Fixed effects were fat content of feed and the amount of feed intake. Sex of animal was third factor in most of analyses. The statistical model used was:

$$y_{ijkl} = \mu + \alpha_j + \beta_k + \gamma_l + (\alpha\beta)_{jk} + \varepsilon_{ijkl}$$

where μ was the general mean, α_j effect of fat content j (50, 60), β_k effect of feeding level k (maximum, restricted), γ_l = effect of sex l (male, female), $(\alpha\beta)_{jk}$ was interaction of fat content and feeding level and ε_{ijkl} on was the residual error. Pairwise comparisons were made by Tukey's test. Statistical significance level: <0.05. Classified data (size and quality classes of furs) was tested by chi-square test.

Results

At the beginning of study, body weights of groups varied between 7.13 and 7.70 kg (Table 3). Lightest animals were in Group 1 and heaviest in Group 4. Significant differences did not initially exist between the groups when compared the amount of fat in the diet. Animals in maximum feeding group grew significantly better that animals fed restricted (P<0.001). Final weights of maximum feeding groups (Group 1, 3) were significantly higher (P<0.001) compared to restricted groups (Group 2, 4).

The amount of diet fat and feeding intensity affected body condition score (BCS) in early November (Table 3). At pelting, body condition score was affected by feeding intensity (P<0.001) but not by the amount of fat in the diet. Animals fed maximum feeding had highest body condition score, i.e. they were very obese. The amount of feed consumed was highest in maximum feeding groups. The amount of diet fat did not influence on feed consumption (Table 3).

Table 3. Body weights (BW), body condition scores (BCS) and feed intake (FI) per group. P_1=between fat levels (60% vs 50 %). P_2=between feeding level (maximum vs restricted), P_3=interaction between fat level and feeding level. Means with same uppercase letters are not significant.

	Group 1	Group 2	Group 3	Group 4	P_1	P_2	P_3
BW, kg							
03.09.	7.13±0.72[a]	7.59±1.08[ab]	7.26±0.68[ab]	7.70±0.70[b]		<0.01	
11.10.	11.58±0.78[a]	10.84±0.73[b]	11.62±0.67[a]	10.70±0.57[b]		<0.0001	
29.-30.11.	17.02±1.70[a]	15.33±0.77[b]	16.96±1.05[a]	14.98±0.43[b]		<0.0001	
BCS							
03.11.	4.70±0.38[c]	3.76±0.44[a]	4.90±0.20[c]	4.28±0.41[b]	<.0001	<0.0001	<0.05
29.-30.11.	4.52±0.62[a]	4.10±0.43[b]	4.46±0.63[a]	3.96±0.63[b]		<0.0001	
FI, g day^{-1}	1956±54[a]	1597±7[b]	1958±53[a]	1597±11[b]		<0.0001	

On September 10th, condition of foreleg was similar in all groups (Table 4). Thereafter, feeding intensity significantly affected on foot condition, i.e. foot bending was highest at maximum feeding groups (P<0.05). Ash content of bones was higher in maximum feeding groups compared to restricted ones (Table 5). Breaking strength of ulna was not affected by the amount of diet fat or feeding intensity (Table 5). Breaking strength of radius, on the other hand, was higher in animals fed restricted portions (P<0.001).

Table 4. Foot bending score (1=heavily bended, 5=good, normal feet). Means with same uppercase letters are not significant.

	Group 1	Group 2	Group 3	Group 4	Fat P	Feeding P	Fat* Feeding P
10.9.2010	2.20±1.00	2.68±0.56	2.34±0.92	2.36±0.65			
05.10.2010	2.00±0.78	2.08±0.59	1.86±0.80	2.34±0.67		<0.05	
01.11.2010	1.20±0.52	1.40±0.52	1.22±0.36	1.46±0.58		<0.05	
25.11.2010	1.08±0.40[a]	1.46±0.63[b]	1.12±0.26[a]	1.2±0.46[ab]		<0.05	

Weight of liver was not affected by the amount of diet fat. However, liver weights were heaviest in animals of maximum feeding level (Table 5). Condition of liver was affected by both the amount of diet fat and feeding intensity. Condition was best in restricted fed animals with lower amount of diet fat. Quality of faeces was poorest in maximum feeding animals with higher amount of diet fat (Table 5). Condition of cage floor was best in Group 2, i.e. in restricted fed animals with higher amount of diet fat.

According to live animal grading, fur mass, cover, purity and overall impression were poorer in restricted fed animals (Table 6). Body size was also smaller in restricted fed animals. Feeding intensity did not influence on health of eyes (Table 6). According to raw skin evaluation, the amount of diet fat did not influence on studied fur parameters except the cover (Table 7). Cover was better in maximum feeding animals. Animals fed high fat diet were found to have better fur properties than restricted ones.

Table 5. Ash content of bones (%), weight of liver (g), condition of liver (1=normal, 4= brittle, yellowish, lots of granules), amount of inner body (IB) fat (1=slight fat, 3+=plenty of fat), dirtiness of cage floor (1= clean 2= fairly clean 3= dirty, 4= extremely dirty), and condition of faeces (1=solid, 2= loose, 3=diarrhea). Means with same uppercase letters are not significant.

	Group 1 n=10	Group 2 n=10	Group 3 n=10	Group 4 n=10	Fat P	Feeding P	Fat* Feeding P
Ash content, bones, %	31.6±0.86[ab]	33.2±0.85[b]	28.9±0.64[a]	32.8±0.58[b]	<0.05	<0.001	
Breaking strength, N							
Radius	399±56[ab]	444±77[ab]	388±96[a]	483±64[b]		<0.001	
Ulna	349±69	368±76	342±97	395±70			
	n=11	n=16	n=17	n=16			
Liver, g	636±60[a]	496±55[b]	599±104a	489±102[b]		<0.001	
Liver condition	3.64±0.51[a]	1.94±0.93[b]	2.06±1.25[b]	2.00±1.03[b]	<0.01	<0.01	<0.01
IB fat	2.86±0.48	2.64±0.40	2.77±0.46	2.44±0.40		<0.05	
Dirtiness	1.88±0.60[b]	1.40±0.50[a]	1.72±0.68[ab]	1.68±0.48[ab]		<0.05	
Faeces, condition	1.56±0.71[ab]	1.24±0.44[a]	1.80±0.71[b]	1.56±0.65[ab]	<0.05	<0.05	

Table 6. Grading of live animals. Group mean ± SD. Score: 5=best, 1=worse. Means with same uppercase letters are not significant.

	Group 1	Group 2	Group 3	Group 4	P-value	P-value	P-value
	60 % max.	60 % res.	50 % max.	50 % res.	Fat	Feeding	Fat* Feeding
Mass	3.55±0.87[a]	2.54±0.77[b]	3.98±0.88[a]	2.82±0.77[b]	<0.01	<0.0001	
Cover	3.14±0.98[a]	2.56±0.87[b]	3.20±0.84[a]	3.28±0.83[a]	<0.01	<0.05	<0.05
Purity	3.35±0.80[a]	2.96±0.74[b]	3.08±0.67[ab]	2.90±0.65[b]		<0.01	
Overall impr.	3.55±0.87[a]	2.38±0.67[b]	3.80±0.82[a]	2.66±0.77[b]	<0.05	<0.0001	
Body size	3.73±0.97[a]	2.58±0.96[b]	3.86±0.79[a]	2.74±0.99[b]		<0.0001	
Eyes health	4.31±0.47[ab]	4.44±0.50[a]	4.16±0.55[b]	4.10±0.46[b]	<0.001		

Table 7. Evaluation of raw skins. Group mean ± SD. Means with same uppercase letters are not significant. Piksel=colour point

	Group 1	Group 2	Group 3	Group 4	P-value	P-value	P-value	P-value
	60 % max.	60 % res.	50 % max.	50 % res.	Sex	Fat	Feeding	Fat* Feeding
Weight, g	925±122[a]	852±87[b]	957±118[a]	853±86[b]	<0.0001		<.0001	
Piksel	379±49[a]	364±51[ab]	382±43[a]	353±51[b]	<0.0001		<0.01	
Purity	5.26±0.44[ab]	5.30±0.52[ab]	5.14±0.37[a]	5.37±0.45[b]	<0.01		<0.05	
Size, mm	1333±63[b]	1308±55[ab]	1362±51[c]	1303±57[a]	<0.0001		<0.0001	<0.05
Mass	7.84±1.25[a]	6.63±1.41[b]	7.86±1.76[a]	6.90±1.33[b]	<0.05		<0.0001	
Impression	7.69±1.16[a]	6.46±1.35[b]	7.69±1.57[a]	6.70±1.45[b]			<0.0001	
Quality	7.76±1.47[a]	6.44±1.54[b]	7.90±1.66[a]	6.78±1.46[b]			<0.0001	
Cover	7.08±1.55[a]	6.21±1.37[b]	7.43±1.53[a]	6.78±1.33[ab]		<0.05	0.001	

Discussion

Body condition, nutritional state and energy intake may have an essential impact on productive success and animal welfare (Rouvinen 1991, Korhonen et al. 2017, Mononen et al. 2018). Farmed blue foxes are typically fed with high amount of feed and energy particularly during growing-furring period (Geng et al. 2012, Korhonen et al. 2014, Kempe 2018). Excessive feeding may be potential economic and animal welfare problem in this species. Therefore, different kind of feeding restrictions have been clarified recently. In a study by Rekilä et al. (2001), feeding restriction by 10% did not influence on final body weights in blue foxes. Higher restriction by 30%, however, declined final body weights significantly, i.e. about 1.5 kg ($P<0.05$). In a study of Koskinen et al. (2009, 2011), aim was to restrict feeding during autumn gradually 20–30%. The realized restriction in those studies in practice was below 20% because of occasional loss of appetite. Therefore, final body weights in restricted and *ad libitum* groups were not significantly different. In a study by Korhonen et al. (2017), feed restriction of 40% from *ad libitum* level was done during August-late September, after which blue foxes were fed *ad libitum* until pelting. Comparison between animals fed permanently *ad libitum* revealed that foxes fed 40% restriction had significantly lower final body weights than those fed all the time *ad libitum*. Correspondingly, body condition scores were higher in *ad libitum* animals.

In the present study, feeding regiments used succeeded as planned. Essential loss of appetite was not found. Furthermore, significant differences were found in final weights between restricted and maximum feeding groups. Body condition score was also highest in maximum feeding groups. These results well coincide with those of Korhonen et al. (2017).

Pronounced bending of forelegs is a common phenomenon in farm bred blue foxes today (Ahola et al. 2014, Kempe 2018). Although the exact cause is unknown, excessive nutrition and body mass, rapid growth and a hereditary component are suspected to be contributing factors (Korhonen et al. 2017, Mustonen et al. 2017). The body size of farm-raised blue foxes has dramatically increased during the last decades. Nowadays foxes can weigh more than 20 kg's whereas 15–20 years ago their average weight was less than 10 kg (Korhonen et al. 2014). It is assumed that strong selection of large body size is linked with developmental disorder of bones and joints (Smith 1991, Mustonen et al. 2017, Kempe 2018). This is a common problem, for example, in large size dog breeds, too (Bealey 1999, Brianza et al. 2006). It has led to a physiological adaption with increased levels of growth hormone (GH) and insulin-like growth factor 1(IGF-1). It may also be connected to poor mineralization of bones (Korhonen et al. 2006). In the present study, condition of feet was poorest in animals fed maximum feed portions. Parallel results were found in our previous studies (Korhonen et al. 2015, 2017) in which high body weight was related to moving difficulties and thus caused foreleg bending.

Restriction of feed significantly increased ash content of bones in the present study. Thus, bone mineralization seems to be more effective when the amount of feed is restricted. Partly this can be due to fact that metabolism of lighter animals is more efficient and faster than that of obese animals. Restricted fed animals with lower body weights can be expected to be more active. Pronounced activity and moving is known to strengthen bones (Korhonen et al. 2001). Mineralization of bones is very much to do with calcium (Ca) and phosphorus (P) amounts in the diet in foxes (Harris et al. 1951, Valaja et al. 2000, Korhonen et al. 2005). Low Ca:P ratio typically weakens mineralization and thus increases foreleg bending (Korhonen et al. 2015).

The results showed that the amount of inner body fat was greatest in animals with high feeding intensity. This can be a welfare problem related to disturbances in organ functions (Korhonen and Harri 1985, Kopczewski et al. 2001). For example, yellow-fat disease of liver is related to high fat content and high feeding intensity. In the present study, condition of liver was affected by feeding intensity and fat content of feed. Livers of maximum fed animals with high amount of fat in the diet were in poorest condition. Liver weights were also highest in animals fed maximum feeding level. Organ size is highly depended on body size and feeding level (Koong et al. 1982). Typically highly-fed animals with larger body weight have larger liver size than smaller animals.

High feeding intensity was seen also as a poorer consistence of faeces. High feeding typically declines digestibility of feed and thus may cause diarrhea or loose faeces (Korhonen and Harri 1988b, Koskinen et al. 2012a, b). High amount of fat in the diet declined quality of faeces in the present study. In practice, it is known phenomenon that faeces are loose during late autumn because of high diet fat content with high feeding intensity. This quite likely is a kind of common welfare problem nowadays on farms (Koskinen et al. 2012b).

It is a common concept among farmers that best quality furs can be produced when animals are fed on a high-fat diet *ad libitum* (Koskinen et al. 2012a). In other words, the bigger and obese the fox, the better fur properties and *vice versa*. In the present study, it was also clearly seen that feeding intensity essentially affected size and fur properties. Animals with maximum feeding level typically had bigger skins and better fur properties. Both live animal and raw skin evaluations also clearly showed that the amount of high fat diet had slight effect on fur properties. Furthermore, effect on size was non-significant. These results temp us to conclude that larger skins with good properties can be achieved with high feeding intensity with lower fat-content.

Conclusions

High feeding intensity increased growth, body condition score and feed consumption. Fur properties of live animals and raw skins were better in animals fed maximum feeding level. Foot welfare, bone and liver variables, the amount of subcutaneous fat, dirtiness of cage floor and condition of faeces were better in animals fed restricted amounts. The conclusion here is that animals are recommended to be fed with maximum feeding with 50% fat level in the diet.

Acknowledgements

This study was financially supported by the Finnish Fur Breeders' Association. The staff of Kannus Fur Research Station is acknowledged for their valuable help in carrying out this experiment.

References

Ahola, L., Huuki, H., Koistinen, T. & Mononen, J. 2014. Eläinten hyvinvointi kettutiloilla: tuloksia tilakäynneiltä. Itä-Suomen yliopisto, Biologian laitos ja Maa- ja elintarviketalouden tutkimuskeskus MTT, Kotieläintuotannon tutkimus. 107 p.

Beale, B.S. 1999. Osteochondrosis in dogs: surgical indications and consideration. Proceedings of North American Veterinary Conference 13: 471–472.

Brianza, S.Z.M., Delisem, M., Ferraris, M.M., D'Amelio, P. & Botti, P. 2006. Cross-sectional geometrical properties of distal radius and ulna in large, medium and toy breed dogs. Journal of Biomechanics 39: 302–311. https://doi.org/10.1016/j.jbiomech.2004.11.018

Frafjord, K. 1993. Food habits of arctic foxes (*Alopex lagopus*) on the western coast of Svalbard. Arctic 1: 49–54. https://doi.org/10.14430/arctic1321

Geng, Y.Y., Yang, F.H., Xing, X.M. & Gao, X.H. 2012. Effects of dietary fat levels on nutrient digestibility and production performance of growing-furring blue foxes (*Alopex lagopus*). Journal of Animal Physiology & Animal Nutrition 96: 610–617. https://doi.org/10.1111/j.1439-0396.2011.01186.x

Grondalen, J. & Lingaas, F. 1991. Arthrosis in the elbow joint of young rapidly growing dogs: a genetic investigation. Journal of Small Animal Practice 32: 420–464. https://doi.org/10.1111/j.1748-5827.1991.tb00989.x

Harris, L.E., Bassett, C.F. & Wilke, C.F. 1951. Effect of various levels of calcium, phosphorus and vitamin intake in bone growth. I. Foxes. Journal of Nutrition 43: 153–165. https://doi.org/10.1093/jn/43.1.153

Kempe, R., Koskinen, N., Mäntysaari, E. & Stranden, I. 2010. The genetics of body condition and leg weakness in the blue fox (*Alopex lagopus*). Acta Agriculturae Scandinavica 60: 141–150. https://doi.org/10.1080/09064702.2010.515241

Kempe, R. 2018. Selection for Welfare and Feed Efficiency in Finnish Blue Fox. Ph.D. Thesis. University of Helsinki, Faculty of Agriculture and Forestry. 59 p.

Koong, L.J., Nienaber, J.A., Pekas, J.C. & Yen, J.T. 1982. Effect of plane of nutrition on organ size and fasting heat production in pigs. Journal of Nutrition 112: 1638–1642. https://doi.org/10.1093/jn/112.8.1638

Kopczewski, A., Nozdryn-Plotnicki, Z., Ondrasovic, M., Bis-Wenzel, H., Saba, L., Zon, A., Slawon, J., Strzalkowski, L. & Ulewicz, W. 2001.The effect of feed with various high-energy levels on anatomical and histopathological changes in arctic foxes. Folia Veterinaria 45: 134–185.

Korhonen, H. & Harri, M. 1985. Organ scaling in the raccoon dog, *Nyctereutes procyonoides* Gray 1834, as monitored by influences of internal and external factors. Comparative Biochemistry & Physiology 82A: 907–914. https://doi.org/10.1016/0300-9629(85)90504-3

Korhonen, H. & Harri, M. 1988a. Regulation of energy balance in farmed canids. In: Murphy, B.D. & Hunter, D.B. (eds.). Biology, Pathology and Genetics of Fur Bearing Animals. Proceeding of the IV International Congress in Fur Animal Production, August 21-24, 1988. Ontario. p. 344–350.

Korhonen, H. & Harri, M. 1988b. Growth, body composition and fur quality of farmed minks and polecats on brewers' mash and basal diets. Animal Physiology & Animal Nutrition 59: 107–112. https://doi.org/10.1111/j.1439-0396.1988.tb00053.x

Korhonen, H., Jauhianen, L., Niemelä, P., Harri, M. & Sauna-aho, R. 2001. Physiological and behavioural responses in blue foxes (*Alopex lagopus*): comparisons between space quantity and floor material. Animal Science 72: 375–387.

Korhonen, H.T., Happo, M., Rekilä, T., Valaja, J. & Pölönen, I. 2005. Effects of diet calcium:phosporus ratio and metabolizable energy content on development of osteochondrosis, foot bending and performance in blue foxes. Animal Science 80: 325–331. https://doi.org/10.1079/ASC4062032

Korhonen, H.T., Eskeli, P., Lappi, T., Huuki, H. & Sepponen, J. 2014. Effects of feeding intensity and Ca:P ratio on foot welfare in blue foxes *(Vulpes lagopus*). Open Journal of Animal Sciences 4: 153–164. https://doi.org/10.4236/ojas.2014.44020

Korhonen, H.T. 2014. Effect of slaughter-house offal and fish levels on production performance in mink and blue fox. Open Journal of Animal Sciences 4: 237–243. https://doi.org/10.4236/ojas.2014.45030

Korhonen, H.T., Eskeli, P., Huuli, H. & Sepponen, J. 2015. Foreleg bending in blue foxes (*Vulpes lagopus*) as evaluated by radiography. Open Journal of Veterinary Medicine 5: 61–67. https://doi.org/10.4236/ojvm.2015.53008

Korhonen, H.T., Ojala, E., Moisander-Jylhä, A-M., Kempe, R., Sepponen, J., Koistinen, T. & Peura, J. 2017. Effects of plane of nutrition on foot condition and animal welfare in blue foxes. NJF Seminar 498, Radisson Blur Plaza Hotel, Oslo, Norway, 18- 20 October 2017. Proceedings. p. 55–56.

Koskinen, N., Sepponen, J., Rekilä, T. & Tauson, A-H. 2009. Energy metabolism of growing blue foxes. NJF Report 5: 37–41.

Koskinen, N., Sepponen, J. & Tauson, A-H. 2011. Feeding intensity and body condition of young blue fox vixens, effect on the breeding result. NJF seminar nr 450, Knivsta, Sweden, 1-2 November, 2011. 2 p.

Koskinen, N., Mikkola, T., Sepponen, J. & Eskeli, P. 2012a. Sinikettujen rehun rasva- ja energiapitoisuuden vaikutus taloudellisiin tuotanto-ominaisuuksiin ja terveyteen. MTT Agrifood Research Finland. Loppuraportti 18.12.2012. 21 p.

Koskinen, N., Joki-Tokola, E., Sepponen, J. & Eskeli, P. 2012b. Puujauholisäyksen vaikutus sinikettujen tuotantotuloksiin. MTT Report 11.10.2012. MTT Agrifood Research Finland. 11 p.

Mikkola, T. 2013. Tutkimustuloksia. Turkistalous 85: 14–15.

Mustonen, A.M., Lawler, D.F., Ahola, L., Koistinen, T., Jalkanen, L., Mononen, J., Lamidi, M-L. & Nieminen P. 2017. Skeletal Pathology of farm-raised obese juvenile blue foxes (*Vulpes lagopus*). Journal of Veterinary Anatomy 10: 51–74.

Mononen, J., Lindeberg, H., Korhonen, H.T. & Kempe, R. 2018. Large size of farmed foxes and its effects on animal welfare. Report for FurEurope. Natural Resources Institute Finland, Luke. 42 p.

Peura. J., Strandén, I. & Mäntysaari, E.A. 2013. Profitable blue fox production: Economic values for Finnish blue fox. Acta Agriculturae Scandinavica, Section A – Animal Science. https://doi.org/10.1080/09064702.2013.789547

Rekilä, T., Korhonen, H.T., Siirilä, P., Valaja, J., Pölönen, I. & Sauna-aho, R. 2001. Rajoitetun ruokinnan vaikutus siniketun nahanpituuteen, kasvuun ja terveyteen. Rehunvalmistajien luentopäivät, Kylpylä Hotelli Eden, Nokia 30.-31.1.2001. 8 p.

Rimeslåtten, H. 1976. Experiments in feeding different levels of protein, fat and carbohydrates to blue foxes. In: Proc. First International Scientific Congress in Fur Animal Production, Helsinki, Finland. 21 p.

Rouvinen, K. 1991. Dietary effects of omega 3 polysaturated fatty acids on body fat composition and health status of farm-raised blue and silver foxes. Acta Agriculturae Scandinavica 41: 401–414. https://doi.org/10.1080/00015129109439923

SAS 2009. SAS/STAT® 9.2 User's Guide. Cary, NC: SAS Institute Inc. 633 p.

Smith, C.W. 1991. Osteochondrosis in the dog – diagnosis, treatment, and prognoses. Canine Practice 16: 15–22.

Valaja, J., Pölönen, I., Jalava, T., Perttilä, S. & Niemelä, P. 2000. Effects of dietary mineral content on mineral metabolism and performance of growing blue foxes. Scientifur 24: 28–31.