GENETICS OF FURS AND SPECIAL FIBRES

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INTRODUCTION

Within the given, very wide and complex topic I will concentrate in my paper mainly on fur animals. Of special fibres only some information about rabbit fur and wool of angora rabbits is included.

In fur production the definition and measuring of traits, important for good economic result, is more difficult than in other lines of animal production. Objective measures can be applied for size but most fur traits can so far only be judged visually. The inaccuracy of sensory evaluation is reflected also in genetic parameters, where the variation of results from different studies is large. In this paper I will try to give a review of genetic parameters found in literature and shortly discuss the future challenges for research.

FUR AND FIBRE TRAITS

Four main characteristics are the basis for classifying fur skins for sale: size, quality, colour intensity and colour clarity. these traits are thus also included in most breeding programmes. In production of angora fibre the main traits are the volume of wool and the wool quality.

Size. In the final product, the dried pelt, the size is normally the length of the pelt as standard size drying boards are used. In selection of breeding animals the size has to be measured/judged on live animals. This can be done in different ways : 1. by judging the size visually ; 2. by measuring the body length or 3. by using body weight. For practical reasons the body weight is most commonly used in mink, chinchillas and nutria. In fox production the visual judging of the size is common except in Norway where a simple tool for measuring the body length has been developed and is gaining use on the farms. In addition to differences in heritability, a vital question is, which of these measures has the best correlation with pelt size and the most favourable relation to other pelt traits, especially fur quality.

Colour intensity. Visual evaluation is the most common method to judge the colour intensity. The range of the scale is set within colour types and varies also between judges. In many cases only a three level scale is used. New research by Rasmussen and Berg (2000) has shown that it is possible to develop colorimetric methods to be used both on live animals and on pelts.

Colour clarity. The clarity defines the shade of the colour ranging from bluish to reddish. The variation is largest in brown types of mink, brown types of nutria and *Castor rex* rabbits. In visual grading of animals and pelts an interaction between colour intensity and clarity has been discovered. Colorimetric methods, which give information of red (a*) and yellow (b*) chromaticity co-ordinates and chroma (C*), seem to be extremely suitable for measuring the shade of the colour (Rasmussen and Berg, 2000).

Quantity of wool. The fleece weight is recorded at each shearing. It is important to define which shearing gives the best estimate for the total genetic production capacity.

Fur/wool quality. Most complicated is the definition of fur and wool quality. The trait is a sum of several sub traits, which in the sensory evaluation of quality on live animals or pelts most often are weighted together to one single trait "overall fur quality". Important sub traits for fur are e.g. hair density, hair length, length relation between guard hair and wool hair (often called nap), elasticity of hair etc. The main parameters of angora wool quality are length of hair, cleanness, and fibre diameter (Rochambeau and Thebault, 1990). Homogeneity is the ratio of best quality wool from the total and the structure is the ratio between the length of down fibres and that of bristles. Additionally, some genetic fur defects like metallic and white spotting on mink, woolly back and tangled hair in blue fox, hair parting in silver fox and felting of hair in angora rabbits, affect the quality classification.

GENETIC PARAMETERS

Mink *(Mustela vison)*.

Heritability of traits. An excellent review of estimates of heritability is given by Berg (1993c), who has summarised information of altogether 37 different investigations. The following tables 1 and 2 are based on his report and comprise data of different colour types. The information sources include, among others, the reports of Jónsson (1971) ; Olausson (1976) ; Reiten (1977b, 1977c) ; Maciejowski *et al.* (1980) ; Pingel (1986) ; Kenttämies (1988) ; Kenttämies and Vilva (1988) ; Lohi (1988) ; Lohi and Hansen (1989) ; Berg and Lohi (1991) ; Hansen *et al.* (1992) ; Berg (1993a, 1993b).

Table 1. Summary of heritability estimates for size on mink. Number of estimates (N), mean and standard deviation (std), 25 % quartile, median and 75 % quartile
According to Berg (1993c)

Trait	N	Mean	Std	Q25 %	Median	Q75 %
Body size (points)	14	0.17	0.12	0.10	0.14	0.22
Body weight	84	0.33	0.20	0.17	0.29	0.44
Body length	13	0.53	0.16	0.43	0.52	0.62
Skin length	16	0.28	0.15	0.14	0.33	0.40

Visual scoring of body size includes inaccuracy as the fatness of the animal tends to affect the size evaluation. E.g. in mink estimates of heritability (table 1) based on visual scoring are fairly low, h^2 around 0.20 (raging from 0.0 to 0.42, Kenttämies and Vilva, 1988 ; Berg, 1993c). Higher estimates are achieved by using body weight especially if the weight is recorded at the correct developmental stage. Lagerkvist (1992) has reported $h^2 = 0.54$ for male kit body weight in September. Hansen and Berg (1997) achieved the highest direct heritability for body weight (h^2 = 0.53 - 0.54) from August to September. In their material the direct heritability of body length was 0.44 - 0.46 in September and December, respectively. Of the four measures for size the body length has shown the highest heritability.

Table 2. Summary of heritability estimates for fur traits on mink. Number of estimates (N), mean and standard deviation (std), 25 % quartile, median and 75 % quartile
According to Berg (1993c)

Trait	N	Mean	Std	Q25 %	Median	Q75 %
Quality live animals	17	0.32	0.26	0.12	0.27	0.38
Quality skin	13	0.23	0.12	0.10	0.19	0.37
Density guard hair [A]	8	0.21	0.11	0.17	0.22	0.27
Density wool hair [A]	8	0.29	0.09	0.23	0.29	0.36
Elasticity [A]	6	0.23	0.13	0.14	0.22	0.29
Colour live animals	53	0.44	0.24	0.27	0.44	0.59
Colour intensity skin	8	0.28	0.20	0.10	0.31	0.46
Colour clarity live animals	16	0.22	0.09	0.16	0.22	0.29
Colour clarity skin	3	0.09	0.12	0.00	0.04	0.22
Guard hair length	21	0.44	0.23	0.27	0.40	0.62
Wool hair length	17	0.44	0.17	0.28	0.44	0.61
Guard hair/wool relation	8	0.12	0.08	0.09	0.10	0.16
Metallic defect	15	0.40	0.16	0.32	0.36	0.43
White spots	20	0.45	0.14	0.38	0.42	0.56

[A] results on both live animals and skins

The figures in table 2 derive from many selection trials and animals and skins have been graded by experienced judges. Similar heritabilities have, however, been achieved on field data. Hansen and Berg (1998) reported heritability estimates for quality on live animals ranging from 0.16 to 0.34 in a material from 10 private farms. They also found an effect of common litter environment on fur quality (c_s^2 = 0.04 - 0.10) still in November.

Genetic correlations. In present fur animal breeding selection is based on live animal data but the price of the product depends on the auction classification of pelts. Necessary for improving pelt traits is therefore a good correlation between live animal grading and pelt traits. Breeding fur animals also involves simultaneous selection for several traits. The information about genetic correlations is therefore highly important, but fewer reports on correlations than on heritability are found. There is a strong positive genetic correlation between body weight and skin length. Negative phenotypic correlation between body weight and live animal fur quality is reported by Børsting and Therkildsen (1992) and by Hansen *et al.* (1992). In Hansen *et al.* the correlation was -0.24 for body weight in July-August but increased to -0.40 for body weight in September and later.
Table 3 summarises the information about genetic correlations between traits and between grading results on live animals and skins found in literature. The results confirm that also the genetic correlation between size and quality is negative. The correlations between quality and sub traits of quality are positive but present large variation. Large variation is also characteristic for correlation between grading of live animals and skins.

Table 3. Genetic correlations between different traits on mink

Traits	Genetic correlation	Source
Body weight Sept. - Skin length	0.63	Lagerkvist (1993)
Body weight (Aug-Nov) - Skin length	0.33 - 0.91	Berg (1993a)
Body weight Sept. - Wool density	- 0.24	Lagerkvist (1993)
Skin length - Skin quality (points)	-0.06 - -0.94	Berg (1993b)
Overall quality - Guard hair density	0.93	Lagerkvist (1993)
Overall quality - Wool density	0.70	Lagerkvist (1993)
Fur quality - Wool length	0.11 - 0.57	Berg (1993b)
Guard hair length - Wool length	0.70 - 0.86	Berg (1993b)
Gradings		
Overall quality animal - skin	0.57	Lagerkvist (1993)
Guard hair quality animal - skin	0.25	Lohi (1988)
Wool density animal - skin	0.15	Lagerkvist (1993)
Overall quality animal - skin	0.06	Lohi (1988)
Overall quality skin points - auction	0.50 - 0.96	Berg (1993b)

Arctic fox *(Alopex lagopus)* and silver fox *(Vulpes vulpes)*

Genetic parameters. Most studies on genetic parameters of fox are from recent years. Many Polish and Russian reports are, however, published in the native language with only an abstract in English. The available results are collected into table 4.

Table 4. Heritability estimates for some fur traits on arctic fox (Polish and Russian results)

Trait	White and shadow	Blue fox	Source
Body size (points)	0.16 - 0.67	0.29	Socha (1998) ; Wierzbicki (2000)
Colour clarity	0.26 - 0.66	0.49	Socha (1998) ; Wierzbicki (2000)
Fur density	0.04 - 0.51	0.31	Socha (1998) ; Wierzbicki (2000)
Hair length	0.04 - 0.75	0.53	Socha (1998) ; Wierzbicki (2000)
Points total	0.30 - 0.72	0.37	Socha (1998) ; Wierzbicki (2000)
Skin size		0.46 - 0.58	Wierzbicki *et al.* (1998)
Skin quality		0.42 - 0.65	Wierzbicki *et al.* (1998)
Hair follicle density		0.27 - 0.74	Diveeva *et al.* (1981, 1982)

Number of hair follicles is an objective measure of hair density. Diveeva *et al.* (1981 ; 1982) reported heritability for primary follicle density at birth to be 0.48 - 0.74 (variation between years). The corresponding heritability at pelting was 0.27 - 0.73. The genetic correlation of the density of guard hair follicles with body weight was -0.51 at birth and 0.24 at the end of the growth period. The correlation between body weight and total skin area was 0.68.

Filistowicz *et al.* (1999) collected data from 2072 silver foxes from the same farm in years 1988 - 1994. After probit transformation of the skewed data the heritability estimates for body size, colour clarity, hair density and hair length were 0.08, 0.21, 0.28, 0.35, respectively. Socha *et al.* (2000) have reported heritabilities in silver fox of 0.60, 0.24 and 0.28 for body size,

colour clarity and fur quality, respectively. The genetic correlations of size with fur quality and colour clarity were 0.14 and -0.13, respectively. The correlation between quality and clarity was -0.34.
In the Nordic genetic research heritability of behaviour traits has been in focus. Information on fur traits has been included in the recorded data and allowed simultaneous estimation of genetic parameters for some fur characteristics. The results from Finnish and Norwegian experiments are summarised in table 5.

Table 5. Genetic parameters for some fur traits on blue fox and silver fox (Nordic results)

Trait	Blue fox 0 ± s.e.	Silver fox 0 ± s.e.	Source
Heritability			
Pelt size (auction)	0.30 ± 0.02	0.26 ± 0.02	Nikula *et al.* (2000)
Colour clarity (auc.)	0.22 ± 0.02	0.16 ± 0.02	Nikula *et al.* (2000)
Fur quality (auction)	0.09 ± 0.01	0.11 ± 0.02	Nikula *et al.* (2000)
Body size (cm)	0.39 ± 0.04	0.16 ± 0.04	Nordrum *et al.* (1999)
Quality (live animal)	0.24 ± 0.04	0.11 ± 0.02	Nordrum *et al.* (1999)
Genetic correlations			
Temperament - size	0.13 ± 0.05	0.60 ± 0.10	Nikula *et al.* (2000)
Temperam. -clarity	-0.01 ± 0.04	-0.24 ± 0.13	Nikula *et al.* (2000)
Temperam. - quality	0.13 ± 0.04	-0.39 ± 0.17	Nikula *et al.* (2000)
Temperament - size	-0.36 ± 0.15	0.09 ± 0.09	Nordrum *et al.* (1999)
Temperam. - quality	-0.15 ± 0.16	-0.21 ± 0.18	Nordrum *et al.* (1999)

Except for the pelt size and body size in blue fox, the heritability estimates are low. There is a great variation in genetic correlations of fur traits with temperament from different materials.
The preliminary results on fur defects "woolly back" and "tangled hair" on blue fox have given heritability estimates around 0.25 - 0.30 (unpublished). The fur defects "parting of hair" and "curly hair" on silver fox have shown inheritance similar to qualitative traits and it is obvious that in both cases a recessive autosomal gene is responsible for the occurrence of the defect.

Other fur animals
Very little information on genetic parameters on chinchilla *(Chinchilla laniger)* and nutria *(Myocastor coypu)* can be found in the literature. Cappelletti and Rozen (1995) have a report on chinchilla and Mezzadra *et al.* (1992) one on genetic and phenotypic parameters in nutria.
Castor rex is a strain of rabbit developed especially for fur production. A new line, *Orylag*® has been derived from rex population in INRA, France. Genetic parameters for this special breed reported by Thébault *et al*. (2000) are presented in table 6.

Table 6. Heritabilities and genetic correlations between fur production traits in *Orylag*® Castor. According to Thebault *et al.* (2000)

	LBW 8	BR	HL	CO	FP	ABE	FCI	FCH
Live body weight 8 w (LBW8)	**0.40**	0.09	0.15	-0.11	0.10	0.20	-0.02	0.32
Bristlyness (BR)		**0.29**	0.38	0.37	0.39	-0.21	-0.36	0.33
Hair length (HL)			**0.19**	0.33	-0.16	-0.36	-0.07	0.14
Compactness (density) (CO)				**0.20**	-0.09	-0.21	0.14	-0.09
Fur priming (FP)					**0.09**	-0.02	-0.67	0.69
Agouti band extension (ABE)						**0.16**	0.35	0.09
Fur colour intensity (FCI)							**0.28**	-0.58
Fur colour homogeneity (FCH)								**0.09**

Pelts of broiler rabbits. The pelts of broiler rabbits can also be used by the fur industry even though they do not have the same excellent quality as the rex breed. According to Khalil *et al.* (1998) some important traits on these pelts are hair length, hair diameter and hair medullation. Heritability of hair length in the studied breeds, New Zealand White and Californian, was medium: (0.36 - 0.39) in New Zealand White and high (0.67 - 0.77) in Californian. Corresponding figures for down hair diameter were 0.25-0.40 and 0.30-0.33. Heritabilities for guard hair diameter and percentage medullation were low with large standard errors.

Angora wool from rabbit. Allain *et al.* (1999) found direct heritability for fleece weight, sheared at 8 and 21 weeks and thereafter at 14 weeks intervals, from 0.31 to 0.42. Maternal heritability was also significant at all ages but decreased from 0.44 at the first shearing to 0.10 along the age. The second shearing is suggested as the best predictor for total fleece production. In the report of Magofke *et al.* (1994) heritability for fleece weight increased from 0.19 to 0.33 from 1st to 4th shearing, but decreased at 5th sharing to 0.26. Genetic correlation of single shearing with total fleece production increased from 0.16 at 1st to 0.71 at 5th shearing. Body weight at 132 days had high correlation with fleece weight at 2nd and 3rd shearing (0.89 and 0.63, respectively). In the study of Caro *et al.* (1984) the highest heritability for wool yield was at second shearing (0.23 ± 0.12). Correlations of body weight with wool yield were 0.63 ± 0.21, 0.97 ± 0.70 and 0.70 ± 0.37 at 1st, 2nd and 3rd shearing, respectively.

RELIABILITY OF SENSORY EVALUATIONS

An important condition for achieving effective estimates for breeding values is the accuracy of the recorded data. This is not a problem with objective measuring techniques, which normally exhibit good repeatability (Lohi *et al.*, 1996). Sensory evaluation can unfortunately never achieve the same accuracy and is often bound to use a very limited scale of scores. Factors affecting the reliability are e.g. the experience of the grader and the conditions, especially the lighting, as reported by Reiten (1977a), Kenttämies (1992b) ; Kenttämies and Käyhkö (1992) and Kenttämies and Smeds (1992a ; 1992b). It is also important that the grading of animals has a good correlation with the evaluation of pelts (Lagerkvist and Lundeheim, 1990 ; Kenttämies, 1992a).

FUTURE CHALLENGES

Great improvements have been made to the breeding programmes in the recent years. The breeding value estimation is in most programmes now based on animal model and thus allows the use of all available information and also corrections for systematic effects. Furthermore, in recent studies about heritability the direct and maternal part have increasingly been separated. This is important especially in regard to body size, where the maternal effect in early weight development is strong (Hansen and Berg, 1997). The increasing demand for including new traits to breeding programmes emphasises the need for knowledge about genetic correlations between traits. We must also bear in mind that including more traits always decreases the response on the others.

The overall goal in all production is profitability. Therefore it is important to consider the economic value of the traits when deciding the weighting of traits in selection. The Nordic Breeding Committee for Fur Animals provides annual reports on the price differences between grading categories within traits. Presently these price reports are the best basis for comparing the economic value of different traits. In future it would be important to get more information about the effects of marketing situation on the value of different traits and the long term trends in price development and the interactions between traits.

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