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The effect of inbreeding on the growth ability of meat sheep breeds in the Czech Republic

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Abstract: The aim of this study was to present the trend of inbreeding and to estimate the effect of inbreeding on the growth ability of lambs in the three most common sire breeds in the Czech Republic: Suffolk (SF; n = 49 345), Charollais (CH; n = 14 189) and Texel (T; n = 10 481). The growth ability of lambs was evaluated between 2000 and 2019 based on the weight at 100 days of age. The average inbreeding coefficient for Suffolk, Charollais and Texel was 0.013, 0.012 and 0.011, respectively. The average number of known generations was 5.260 for Suffolk, 3.355 for Charollais and 3.709 for Texel. To evaluate growth ability, lambs were divided into four groups according to the inbreeding coefficient (F = 0.00, 0.00 < F ≤ 0.062 5, 0.062 5 < F ≤ 0.125, F > 0.125). The results of this study show the negative effect of inbreeding on the growth ability of lambs was significant (P < 0.05). The regression coefficients of the weight for Suffolk, Charollais and Texel lambs for a change of 1% in inbreeding were estimated to be –0.028, –0.053 and –0.048, respectively.

Keywords: Charollais; pedigree analysis; Suffolk; Texel; weight of lambs

Genetic diversity in livestock populations serves as the basis for sustainable breed improvement strategies. Hence, consideration of the genetic diversity and population structure among and within breeds is essential for facing future challenges, such as production needs, food security, and climate change, as well as for the conservation and utilization of the breeds (Berihulay et al. 2019; Makanjuola et al. 2020).

The increase in inbreeding is a growing problem in livestock (Baes et al. 2019). It has a detrimental effect on different traits (Mirzaee Ilaly et al. 2019). This effect results in losses in production and reproductive traits (Reis Filho et al. 2015; Vostry et al. 2018; Hofmannova et al. 2019) and can affect the economic income of breeders (Leroy 2014).

The most significant consequence of inbreeding is a decrease in the average phenotypic value of the traits associated with reproductive capacity or physiological efficiency. The degree of inbreeding can be expressed using the inbreeding coefficient (Falconer and Mackay 2009). This coefficient is one of the basic parameters in population genetics and is traditionally calculated from pedigrees (Wang 2016).

Although harmful levels of inbreeding may be small in some flocks, in small isolated flocks in-

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breeding may have a significant detrimental effect (Drobik and Martyniuk 2016). Caution needs to be taken in the use of the designed mating system to maintain the level of inbreeding under control (Patiabadi et al. 1999). Maintain substantial genetic diversity to remain amenable to future market and breeding scheme changes (Makanjuola et al. 2020).

The aim of this study was to present the trend of inbreeding and to estimate the effect of inbreeding on the growth ability of lambs in the three most common sire breeds in the Czech Republic: Suffolk, Charollais and Texel.

MATERIAL AND METHODS

Data and pedigree information were obtained from the Association of Sheep and Goat Breeders in the Czech Republic from 2000 to 2019. The growth rate of lambs was evaluated by the live weight adjusted at 100 days of age, calculated from birth weight and weight measured between 70 and 130 days of age. Data included records of 74 015 lambs born from 20 402 dams and 1 956 sires. The lambs of the three most numerous sire breeds in the Czech Republic were selected for evaluation: Suffolk (SF; n = 49 345), Charollais (CH; n = 14 189) and Texel (T; n = 10 481). The information about the structure of the analysed population is shown in Table 1.

A pedigree has been created for each breed. The CFC 1.0 programme was used to calculate pedigree structure and regular inbreeding coefficients for individuals in the pedigree. CFC is a software package for pedigree analysis and monitoring genetic diversity (Sargolzaei et al. 2006).

For assessing the effect of individual inbreeding coefficient on the growth ability of lambs, individuals were divided into four classes. The first class included noninbred lambs (F = 0.00). The second class included lambs from distant inbreeding ($0.00 < F \leq 0.062\,5$), the third class included lambs from mild inbreeding ($0.062\,5 < F \leq 0.125$) and the fourth class included lambs from close inbreeding ($F > 0.125$).

The SAS General Linear Model (GLM) procedure (Base SAS/STAT® v9.4 software; SAS Institute, Inc., Cary, NC, USA) was used to identify fixed effects having a significant effect on weight (P < 0.05). These effects were: the effect of flock-year-season of lambing, the effect of sex (in two classes: male and female), the effect of lambs reared (in three classes: single, twin and triplet), the linear regression on age at the time of measurements in days (from 70 to 130 days), the effect of dam age at lambing (in 10 classes: from less than a year to 9 years), the effect of inbreeding class (in four classes). Average weights at 100 days of age in each inbreeding class were estimated for all three breeds evaluated to compare growth ability. Subsequently, a model with the inbreeding effect as a regression coefficient was tested. This model was used for further calculations.

For estimation of the regression coefficients of inbreeding for individual breeds, the following model equation was created:

$$Y_{ijklmnopqr} = \mu + AGE_i + FYS_j + AGED_k + SEX_l + LR_m + F_n + PE_o + DAG_p + MAG_q + e_{ijklmnopqr} \quad (1)$$

where:

$Y_{ijklmnopqr}$ – dependent variable (weight at 100 days of age);

μ – general value of dependent variable;

AGE_i – linear regression on age at the time of measurements in days;

FYS_j – random effect of flock-year-season of lambing;

$AGED_k$ – fixed effect of dam age at lambing (in 10 classes: less than a year to 9 years);

SEX_l – fixed effect of sex (in two classes: male and female);

LR_m – fixed effect of lambs reared (in three classes: single, twin and triplet);

F_n – the inbreeding coefficient of animal;

Table 1. The structure of analysed population

	Lambs (n)	Ewes (n)	Rams (n)	Flocks (n)	Lambs per flocks		Rams per flocks		Dams per flocks	
					mean	SD	mean	SD	mean	SD
Suffolk	49 345	13 069	1 212	192	257.20	636.93	7.40	10.62	70.86	136.96
Charollais	14 189	4 247	453	82	173.35	342.75	6.33	8.65	53.24	103.54
Texel	10 481	3 086	291	47	223.21	497.25	6.68	10.47	65.79	146.27

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PE_o – random effect of permanent environment of the dam;
DAG_p – random direct additive genetic effect;
MAG_q – random maternal additive genetic effect;
$e_{ijklmnopqr}$ – random residual error.

It included random effects in addition to statistically significant fixed effects and an individual inbreeding coefficient was added as a regression effect instead of the inbreeding coefficient class.

Genetic analysis for estimation of the (co)variance components was performed using REMLF90 software (Misztal et al. 2014) and using the restricted maximum likelihood method. Regression coefficients were estimated for each breed separately as well as the (co)variance components. Then the (co)variance components were used to estimate the breeding values by the Best Linear Unreal Prediction method using the BLUPf90 software (Misztal et al. 2014) and to determine the genetic trends.

RESULTS

The structure of the analysed pedigrees is given in Table 2. 62.34% of Suffolk individuals, 28.98% of Charollais individuals and 31.73% of Texel individuals were inbred. Both parents were known in the majority of individuals. The average inbreeding coefficient for Suffolk, Charollais and Texel was 0.013, 0.012 and 0.011, respectively. The highest average inbreeding coefficient for inbreds was in Charollais (F = 0.043). The maximum inbreeding coefficient for Suffolk was F_{max} = 0.4. The average number of generations was 5.260 for Suffolk, 3.355 for Charollais and 3.709 for Texel. The maximum number of generations for Suffolk, Charollais and Texel was 9.378, 8.750 and 7.980, respectively.

Table 2. The structure of analysed pedigrees

	Suffolk	Charollais	Texel
Number of individuals	63 818	20 353	14 502
Number of inbreds	39 784	5 898	4 602
Number of individuals with both known parents	60 807	18 282	13 198
Number of individuals with no progeny	42 544	12 937	8 893
Average inbreeding coefficient	0.013	0.012	0.011
Average inbreeding coefficient in the inbred	0.022	0.043	0.034
Maximum of inbreeding coefficient	0.400	0.381	0.375
Average number of generations	5.260	3.355	3.709
Maximum number of generations	9.378	8.750	7.980

The average trend of the inbreeding coefficient for the years 2000–2018 for the evaluated breeds is shown in Figure 1. The greatest increase in the inbreeding coefficient was recorded in Charollais. This coefficient increased from F = 0.005 to F = 0.017. The highest value was recorded in 2016 (F = 0.029). In Suffolk the value of the inbreeding coefficient rises slightly. Although this value was initially higher than that of Charollais, this value increased only to F = 0.016 over the years. The highest value was recorded in 2002 (F = 0.019). In Texel, this coefficient was the highest (F = 0.021) at the beginning of the observed period compared to the other

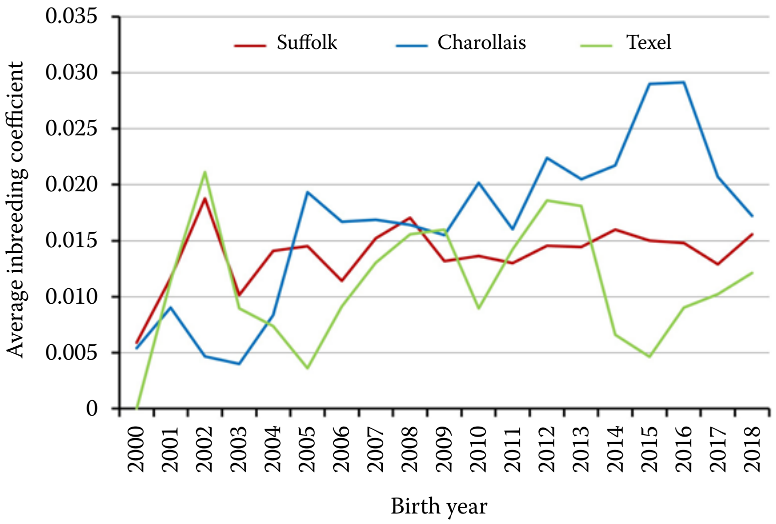

Figure 1. Inbreeding trend over the years

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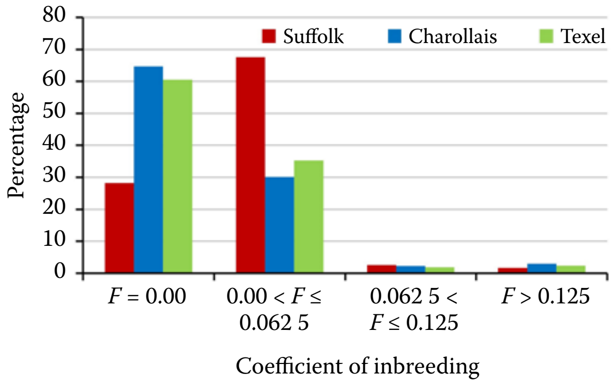

Figure 2. Distribution of inbreeding coefficient

Table 4. Estimates of co(variance) components and coefficient of heritability of the weight at 100 days of age

	σ^2_a	σ^2_m	σ^2_p	σ^2_f	σ^2_r	cov_{am}	r_{am}
Suffolk	1.57	1.27	1.70	14.68	16.08	–0.55	–0.39
Charollais	4.26	1.52	1.45	8.04	12.67	–1.28	–0.50
Texel	3.97	2.51	1.76	9.57	12.78	–2.04	–0.65

σ^2_a = direct aditive genetic effects; σ^2_m = maternal aditive genetic effects; σ^2_p = maternal permanent environmental; σ^2_f = effect of flock-year-season; σ^2_r = residual variance; cov_{am} = covariance between direct and maternal additive genetic effects; r_{am} = correlation between direct and maternal additive effects

breeds. Subsequently, this value fluctuated strongly. In the last evaluated year, this value was $F = 0.012$.

Figure 2 shows the frequency of lambs by breed in each inbreeding coefficient class. In most cases, with increasing inbreeding coefficients in individual classes, the numbers of lambs decreased. The Suffolk breed had most inbred lambs with inbreeding coefficient of $F < 0.062\,5$. Another exception is the Texel and Charollais lambs of the fourth class with inbreeding coefficient of $F < 0.125$ when there was a small increase compared to the previous class.

Inbred lambs with inbreeding coefficient of $F < 0.062\,5$ accounted for the largest proportion in the population, i.e. 55.79%. Another large proportion was represented by non-inbred lambs ($F = 0.00$) that accounted for 39.79% in the population. The rest of the population (4.41%) consisted of lambs with inbreeding coefficient of $F < 0.062\,5$.

The effect of inbreeding on lamb growth in individual breeds can be seen in Table 3. In the Suffolk breed, weight decreased in individual classes with increasing inbreeding coefficient except the last fourth class ($F < 0.125$) when this value was higher than in the second ($0.00 < F \leq 0.062\,5$) and third class ($0.062\,5 < F \leq 0.125$). There was a significant difference ($P < 0.05$) between the first ($F = 0.00$) and the second class ($0.00 < F \leq 0.062\,5$), first and third ($0.062\,5 < F \leq 0.125$), first and fourth and second and third class.

In Charollais, the highest weight was reached by lambs in the second class, first and third class, respectively. The lowest weight occurred in the fourth class, the class with the highest inbreeding coefficient. There was a significant difference between the first and fourth, second and fourth and third and fourth class.

The weight of Texel lambs was highest in non-inbred lambs. With the increasing coefficient of inbreeding in individual classes, the weight of lambs decreased. The lowest weight was observed in the fourth class. There was a significant difference between all classes except the second and third class.

Estimates of direct genetic effects for Suffolk, Charollais and Texel were 1.57, 4.26 and 3.97, respectively. Estimates of maternal genetic effects for Suffolk, Charollais and Texel were 1.27, 1.52 and 2.51, respectively. The permanent maternal enviromenatal effects, effects of flock-year-season and residual variances ranged from 1.45 to 1.76, 8.04–14.68 and 12.67–16.08, respectively. Genetic covariances between direct and maternal genetic effects ranged between –0.55 and –2.04. The genetic correlation between direct and maternal effects was negative for all breeds (Table 4).

Table 3. Average weight at 100 days of age by breed and inbreeding class (GLM)

Inbreeding class	Suffolk		Charollais		Texel	
	n	mean ± SE	n	mean ± SE	n	mean ± SE
$F = 0.00$	13 915	30.444 ± 0.07^{a}	9 182	29.184 ± 0.105^{a}	6 341	29.362 ± 0.144^{a}
$0.00 < F \leq 0.062\,5$	33 343	30.224 ± 0.062^{b}	4 272	29.256 ± 0.13^{a}	3 695	29.058 ± 0.158^{b}
$0.062\,5 < F \leq 0.125$	1 275	29.892 ± 0.147^{c}	324	29.112 ± 0.293^{a}	194	28.623 ± 0.384^{b}
$F > 0.125$	812	29.906 ± 0.177^{bc}	411	27.771 ± 0.258^{b}	251	27.554 ± 0.34^{c}

[a–c]Figures marked by different lettersdiffer at the level of significance ($P < 0.05$)

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Table 5. Regression coefficients of weight at 100 days of age (in kilograms) on inbreeding of lambs for a change of 1% in inbreeding

Breed	Regression coeficient
Suffolk	–0.028
Charollais	–0.053
Texel	–0.048

Table 5 shows the regression coefficients for the weight of lambs at 100 days of age (in kilograms) with a 1% change in inbreeding. In Suffolk lambs the weight was reduced by 0.028 kg when the inbreeding coefficient was increased by 1%. Charollais and Texel lambs were reduced in weight by 0.053 kg and 0.048 kg, respectively.

The genetic trend of the average breeding values (Figure 3), which allows us to compare the genetic levels of animals, shows a slight increase in the genetic value of Suffolk and Texel. For Charolais, the increase in this value is higher.

DISCUSSION

The average inbreeding coefficient ranged from 0.011 to 0.013. The lower average inbreeding coefficient (F = 0.000 043) was reported by Eteqadi et al. (2014). In contrast, the higher average inbreeding coefficient was determined in the Bharat Merino sheep population (2.32%) (Gowane et al. 2013) or in the genetically closed population of the Elsenburg Dormer sheep population (16%) (Van Wyk et al. 2009). The average inbreeding coefficient for Texel, Shropshire and Oxford Down breeds in the Danish sheep population was approximately between 6% and 10% (Norberg and Sorensen 2007). The average number of generations in this study ranged from 3.355 to 5.26, which is higher than e.g. in Pedrosa et al. (2010) and the Gholizadeh and Ghafouri-Kesbi (2016) studies, which averaged 2.26 and 2.49, respectively.

In both Charollais and Suffolk, the inbreeding coefficient has a generally increasing trend over the years under review, which occurs in the Lori sheep population evaluated in 2001–2010 (Yeganehpur et al. 2016). The increasing tendency for the inbreeding coefficient also occurred in the Segurena sheep population between 1983 and 2001 (Barros et al. 2017) and the Guilan sheep population in Iran between 1993 and 2011 (Eteqadi et al. 2014). Norberg and Sorensen (2007) evaluated the inbreeding trend in the Danish population of Texel, Shropshire, and Oxford Down between 1983 and 2008.

A total of 60.2% of inbred individuals were in the evaluated population. Breeders usually monitor the kinship of individuals two generations back, therefore inbreeding may arise earlier. Similar results were shown by Selvaggi et al. (2010) when in Leccese sheep up to 61.02% of ewes were inbred. The lower proportion of inbred individuals was described by Gholizadeh and Ghafouri-Kesbi (2016) in Baluchi sheep (45.4%). In contrast, in Santa Ines sheep, only 21.72% of individuals were inbred (Pedrosa et al. 2010). Charollais and Texel lambs showed the highest frequency in the class with inbreeding coefficient of F = 0.00. Similar results were reported by Dorostkar et al. (2012) in Iranian Moghani sheep.

The average weight at 100 days of age in non-inbred Suffolk lambs was 30.444 ± 0.07 kg. The lower weight in their study was reported by Maxa et al. (2007). The weight at the same age for that breed was 27.91 kg. On the contrary, higher weight (36.51 ± 5.8 kg) was published by Janos et al. (2018). Charollais non-inbred lambs weighed 29.184 ± 0.105 kg. In a study by Malkova et al. (2020), lambs of this

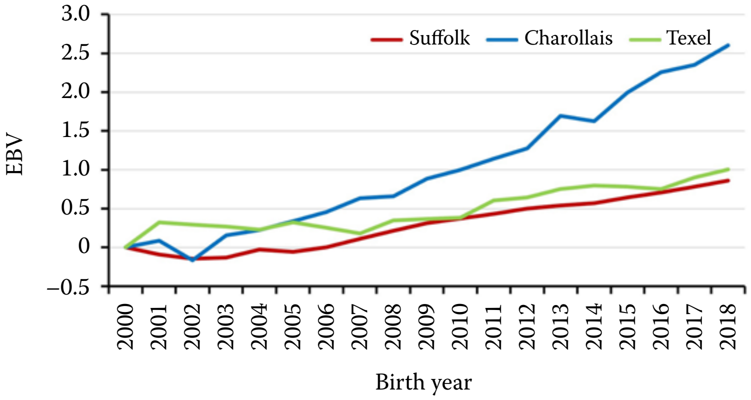

Figure 3. The genetic trend of mean breeding values (EBV) by year of birth for weight at 100 days of age

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breed weighed 31.12 ± 0.411 kg. In Texel, the weight at 100 days of age was 29.362 ± 0.144 kg. Similar weight was reported by Stolc et al. (2011) in their study. Texel lambs weighed an average of 28.388 kg over the five years evaluated. Lower weight (26.95 ± 1.21 kg) was published by Petr et al. (2009).

In Suffolk, the weight of non-inbred lambs was significantly higher compared to inbred lambs, as was the case with Texel lambs. In the studied Charollais, the weight was significantly lower in lambs with inbreeding coefficient of $F > 0.125$ compared to other lambs. The effect of inbreeding on growth was also evidenced by the results of Pedrosa et al. (2010) when non-inbred individuals weighed 0.62 kg more than inbred individuals at 60 days. Lower growth in inbred individuals compared to non-inbred ones was also achieved in individuals at three months of age (Mandal et al. 2002). In addition to the effect of inbreeding on lamb growth (Eteqadi et al. 2014), there is also a significant effect of inbreeding on birth weight (Selvaggi et al. 2010; Eteqadi et al. 2014; Gholizadeh and Ghafouri-Kesbi 2016). In contrast, Caro Petrovic et al. (2013) and Barros et al. (2017) did not show the effect of inbreeding on growth traits in their studies. In the case of Barros et al. (2017), this result could be influenced by a low number of inbred individuals in the studied population.

In this study, increasing the inbreeding coefficient of all breeds evaluated should reduce weight at 100 days of age. Weight loss due to inbreeding was also reported by Van Wyk et al. (2009), who concluded that an increase in inbreeding coefficient by 1% should reduce weaning weight (100 days of age) by 0.093 kg. For weight at three months of age, this regression coefficient was estimated to be –28.406 g (Eteqadi et al. 2014). The significant effect of inbreeding coefficient was on weaning weight (40 ± 3 days) when this weight decreased by 0.031 kg by increasing the inbreeding coefficient by 1% (Selvaggi et al. 2010). Gholizadeh and Ghafouri-Kesbi (2016) did not find out significant inbreeding depression on weaning weight (90 days of age). The same result was obtained by Yeganehpur et al. (2016).

The evaluation of the genetic level of animals born in individual years shows a larger increase in the genetic value of Charollais compared to other breeds. This may be due to more intensive selection, which may also increase the average inbreeding coefficient for this breed (Figure 2), together with the lower ratio of imported sires and higher percentage of sires that are used in the flock of their birth.

CONCLUSION

The results of this study show the significant negative effect of inbreeding on the growth ability of the lambs of sheep meat breeds. As the inbreeding coefficient increased, the weight of lambs at 100 days of age decreased. The analysis of the pedigree shows the inbreeding coefficient increases in the evaluated population. In particular, in the population there is a relatively high frequency of lambs with inbreeding coefficient of $0.00 < F \leq 0.062\,5$. Therefore, it would be advisable to use an appropriately designed mating system to constrain the rise of inbreeding in subsequent years.

Conflict of interest

The authors declare no conflict of interest.

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