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GROWTH MODELLING OF DIFFERENT SHEEP TYPES USING COMPUTED TOMOGRAPHY (CT)

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1 INTRODUCTION

One of the most important goals of the sheep breeding research as in any other production is to satisfy the consumer's demand which is recently the healthy nourishment. Therefore to avoid the increased fatness livestock should be fattened till an ideal slaughter weight. This is the end of the intensive stage of lean growth. During that time the live weight gain slows down and the tissue proportion of the carcass changes. The growth curves of the tissues as well as the live weight generally have a sigmoid shape (Taylor, 1980). Mathematical functions are able to describe the growth well. One of the basic condition of growth modelling, the accuracy, is provided by the slaughter trials, but it is time- and energy-consuming, because of the need of successive slaughter series. In contrary, the individual-performance (growth capacity and maturing) of the candidates may be estimated, which provides new prospects for meat research. In sheep, there is little information in the literature on the modelling of growth curve variables, especially about results based on *in vivo* examinations.
Therefore the computation was derived from Computer Tomography (CT) images of two, extreme meat-types (Dutch Texel and American Suffolk) and the most common Hungarian genotype of sheep, the Hungarian Merino. Based on the results of further research in this field the possibilities of the utilisation of the growth curves in selection to alter the growth curve shape should be investigated.

The aims of the investigations discussed in the dissertation were the following:

a) establish a scanning procedure for growth modelling in sheep (images were made on the same anatomical point),

b) comparative examination of body composition changes in different growth types during growth from early stage to maturity,

c) analysis of the growth of tissues and cuts by monophasic allometric equation,

d) analysis of the growth of tissues and cuts by growth functions.

2 MATERIALS AND METHODS

American Suffolk (n=10), Dutch Texel (n=10) and Hungarian Merino (n=10) rams reared under identical conditions were scanned 6 times during their growth period. Scanning weights for the study were: 5 to 7 kg, 15 to 17 kg, 25 to 27 kg, 35 to 36 kg and 43 to 45 kg live weight and around the age of 18-21 months providing the asymptotic point. These types differ extremely in their growth intensity and duration.

CT scans were performed by Siemens Somatom Plus 40 and Siemens Somatom Expert 4 spiral CT equipments at the Health Sciences Centre of the University of Kaposvár. The CT scans were made from the atlantooccipitalis joint to the tarso-metatarsalis joint with a 10 mm slice thickness. The slice distance was calculated by dividing the distance of the joints of shoulder and femur into 30 scans adapting the methodology in rabbits, established by Romvári (1996). Therefore the numbered identical scans of an individual were positioned on the same anatomical point in every scanning weight during the growth.

Area and tissue distribution was recorded by CTCP and MIP programmes based on the Hounsfield Units (1980). The volume data derived from Cavalieri method (which is named in honour of Bonaventura Cavalieri, 1598-1647) were corrected for weight by values of Fullerton (1981).

Data analysed in the investigation were the following: live weight from weighing and whole body, carcass, fat, lean, long loin, short loin and leg based on CT scans.

For the analysis of differential growth describing a whole-to-part relationship the original Huxley's (1932) monophasic form of allometric function was used. For the regression analysis the data were plotted in logarithmically on the axes. The mathematical form is

$$y = a * x^{b} \quad \rightarrow \quad \log y = \log a + b * \log x,$$

where *y* is the weight of tissue or cuts, *x* is the body weight or main part and *b* is the allometric growth coefficient. Isometric growth (*y* grows as the same rate as *x*) is assumed if $b=1$. If $b>1$, *y* grows faster than *x*, and the opposite is true if $b<1$.

For modelling growth dynamics of different sheep types three non-linear functions were applied. The Gompertz (1825) and logistic (Robertson, 1908) modified by Bünger and Schönefelder (1984) to use parameters, which are immediately biologically interpretable:

Gompertz $\mathbf{A * \exp[-\exp(B e (C-t)/A)]},$

logistic $\mathbf{A/[1+\exp(4B(C-t)/A)]},$

where *A* is the theoretical final body weight (g), *B* is the maximum weight gain (g/day) and *C* is the age at the maximum weight gain (day).

asymmetric S-curve $\mathbf{A/[1+B\exp(-C\gamma t)]1/\gamma},$

where *A* is the theoretical final body weight (g) and γ gives a flexibility for the shape of the function, however, the $\gamma = 0.01$ value was used for the analysis. By the first and second derivation of asymmetric S-curve (Kralik et al, 1999) the inflection point (t_I) were obtained. By two functions involved *B* and *C* values the maximum point of intensive growth (t_B) and minimum point of degressive growth (t_C) were calculated.

The growth curves fitted the data by different input methods:

- Input1: each individual lamb data set separately and averaging the parameters per growth type (6 points/individual/curve),
- Input2: weight data for every age points were averaged within growth types (6 points/type/curve),
- Input3: all individual weight data per growth type (60 points/ type/curve).

The analysis of genotype effect was conducted by SPSS 10.0 package (2001) using GLM (Generalized Linear Model) procedure and using live weight as a covariant (LSD-test; $P<0.05$). Allometric equations of growth of fat, lean and cuts were estimated by regression analysis (SPSS 10.0). The estimation of the parameters of growth functions and their accuracy of fit (R^2 and RSS) were undertaken using the NLIN procedure of the SAS 9.1 (2004). The allometric coefficients and the parameters of growth curves were tested using a pairwise t-test ($P<0.0025$).

3 RESULTS

3.1 Variation in body parts and in body composition

Independent of the correction to live weight the Hungarian Merino had significantly less carcass, lean and cuts (long and short loin, leg) than the meat-types ($P<0.05$). Beyond 15 kg live weight the fat content of Hungarian Merino was significantly higher than in meat-types, although it was less at the beginning of the experiment. However, these differences especially in fat content were inconsiderable even till 25 kg live weight, do not have the effect that sheep breeders change the genotype of their flocks.

3.2 Allometric growth

The relative growth rates of tissues and cuts in relation to live weight were expressed as allometric coefficients (*b*), providing a quick overview about the type of growth.

The growth of lean was isometric (*b* = 0.95 to 0.98) from 5 to 25 kg, then slowed down (*b* = 0.88 to 0.89) in all growth types (Hungarian Merino, American Suffolk and Dutch Texel). The average allometric coefficient for the whole period of the examination was 0.92 without significant type effect. The fat was definitely late maturing tissue, and the *b* value of these types were averagely 1.4 to 1.5 (from 5 to 25 kg *b* = 1.16 to 1.26, above 25 kg *b* = 1.52 to 1.75). The Hungarian Merino had significantly higher fat growth (b = 1.75).

The coefficients of the investigated carcass parts are ranked in a caudal-cranial gradient which is typical in ruminants: the growth of leg was slower than the live weight (*b* = 0.92 to 0.93), the growth coefficients of short and long loin were 1.04 to 1.07 and 1.06 to 1.2, respectively. The long loin has a significantly longer maturity in the American Suffolk than in the other two types, which is well-marked above 25 kg live weight. The tendency was the same for short loin, but the coefficients of the types for leg growth did not differ ($P<0.05$).

Relative growth rates of tissues and cuts expressed in relation to carcass were a bit higher than in relation to live weight. Since the thoracic and abdominal organs have an early maturing nature.

3.3 Dynamic (temporary) growth

To determine the ideal slaughter weight for the investigated types the (potential) growth of live weight, whole body, carcass, lean and fat tissues and cuts were examined by growth (non-linear) functions. All 3 models (modified Gompertz, logistic and asymmetric S-curves) used here fitted the data derived from CT scans well ($R^2>0.98$). The Gompertz model provided the best fit in every type (the lowest RSS values). The only exceptions were the late maturing fat tissue and long loin of American Suffolk lambs, which had better results using logistic function.

Different *data input*s were used for the models. The effect of *data inputs* – individual data (I1), averaged data per types (I2) and all data together (I3) – on parameters of growth curves was small. The I2 method provided the best fit because of the averaging.

The *A* parameter of the growth models were the asymptotic weights of the three types: 64 kg, 84 kg and 71 kg for Hungarian Merino, American Suffolk and Dutch Texel, respectively (*Figure 1*). Type effects were observed in the parameters of growth functions. The maximum daily weight gain (*B* parameter) was 310, 283 and 240 g/day for Dutch Texel, American Suffolk and Hungarian Merino, respectively. The age and live weight at maximum daily weight gain (*C* parameter) was the 76th day (26.3 kg), the 102nd day (23.6 kg) and the 110th day (30.7 kg) for Dutch Texel, Hungarian Merino and American Suffolk, respectively.

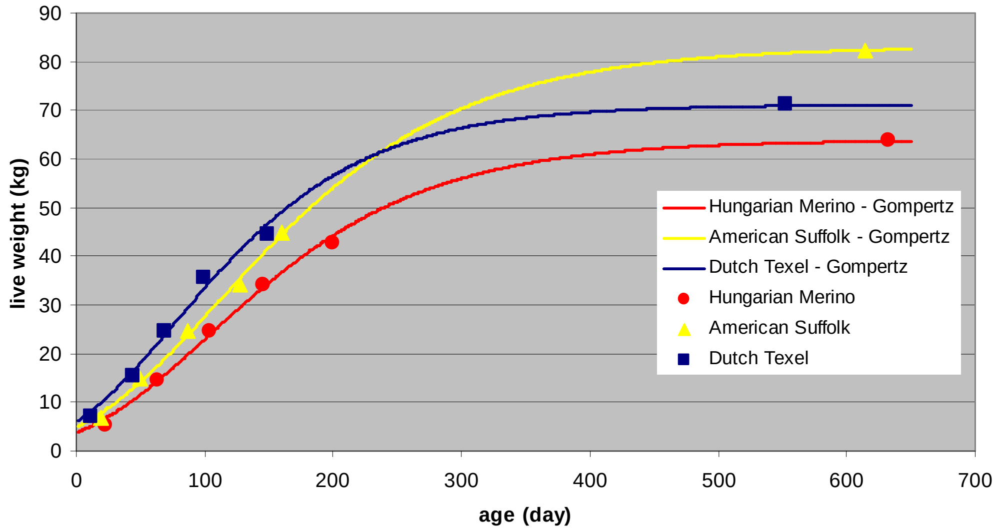

Figure 1 Modelling the live weight growth of examined growth types by Gompertz function (I2 method)

The age at maximum gain of carcass of types based on CT-scans was a few days later than of the whole body. It was confirmed by the allometric coefficient of the carcass (b = 0.98) as well.

The curve shapes of the relative growth of carcass were almost identical for the American Suffolk and the Hungarian Merino, albeit the asymptotic weight and the time required to gain the asymptote were different. The Dutch Texel had a totally different type of growth. The 2/3 of the asymptotic weight was reached at the 150th day by the Dutch Texel, for the other two types 190 to 198 days were required (*Figure 2*).

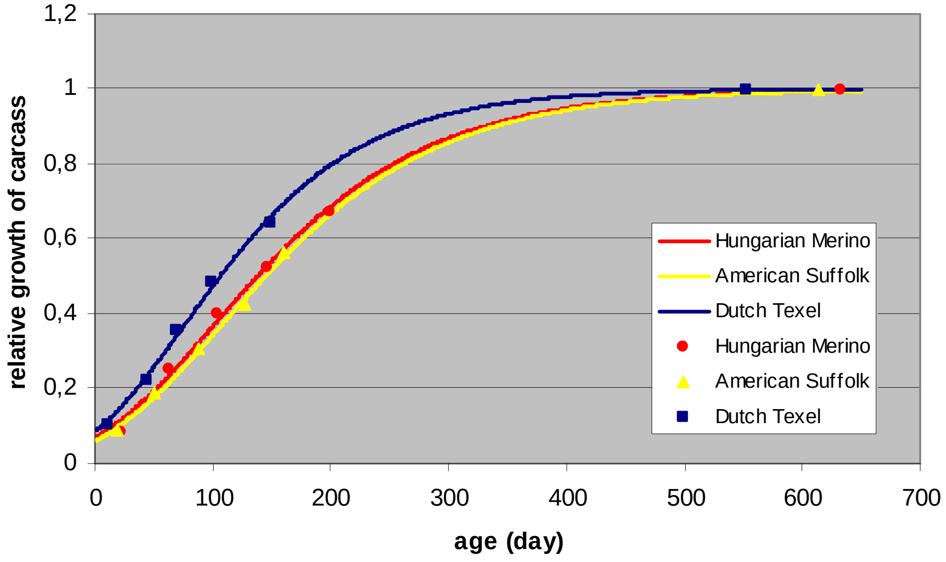

Figure 2 The relative growth of carcass by Gompertz function (I2 method)

The maximum daily gain of fat tissue was 20 to 21 grams in all three types, however, the inflexion points were influenced by the types: 107th day, 142nd day and 165th day in Dutch Texel, Hungarian Merino and American Suffolk, respectively. If the fat gain of American Suffolk was calculated by logistic function because of its better RSS value, the inflexion point increased to 188 days. At early stages, until around 200-250 days, the fat content of the early maturing Dutch Texel rams was higher, but further on was less than the other two types, because the fat gain of the Texel slowed down considerably.

The daily gain of lean is shown in *Figure 3*. The Dutch Texel lambs reached the maximum lean weight gain (113 g/day on 69th day) first and the American Suffolk (101 g/day on 97th day) last. The Hungarian Merino had only 72 g/day maximum lean weight gain, they set between the above mentioned meat-types (89th day). The parameters of growth function calculated for lean were significantly different.

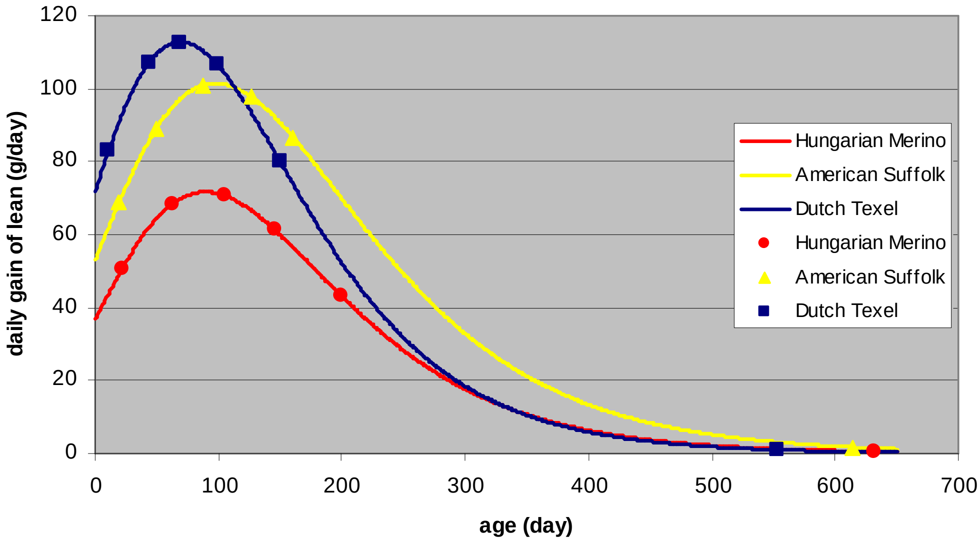

Figure 3 The daily gain of lean tissue of the examined types by Gompertz function

By the second derivation of the asymmetric S-curve the stage of intensive muscle growth (Δt_C-t_B) could be predicted. The optimal slaughtering weights, in sense of a maximal utilisation of muscle growth potential (t_C), were 47 kg (151st days) for Dutch Texel, 53 kg (196th days) for American Suffolk and 40 kg (178th days) for Hungarian Merino. For the highest lean content with the lowest fatness the Hungarian Merino lambs should be slaughtered between 20.5 kg (89th day) and 33 kg (142nd day). These intervals were the following for the Dutch Texel and the American Suffolk lambs: 24 kg (69th day) to 36 kg (107th day) and 27 kg (97th day) to 45 kg (163rd day), respectively. During this time the fat content of the Hungarian Merino carcasses increased from 8% to 12%. In meat-types it grew from 7% to 9%, which was considerably lower in heavier lambs as well.

The required times to reach the maximum gain of body parts (long and short loin, and leg) were significantly different in these types: first were Dutch Texel with short duration but large growth intensity (73 to 86 days) and last were American Suffolk (103 to 123 days). The maximum gain of leg was the highest in Dutch Texel (60g/nap), while the American Suffolk lambs were able to gain the most volume in long loin (19 g/day using logistic function). There were no significant differences between these two meat-types in growth intensity of short loin (12 to 13 g/day). The characteristics of the Hungarian Merino were considerably lower than the meat-types ($P<0,05$). The inflexion point of the loin growth was 24.5 to 26 kg in Hungarian Merino, 28 to 29 kg in Dutch Texel and 33 to 34 kg in American Suffolk. Therefore it is obvious, that the capacity of the American Suffolk in the gain of loin is unutilized when slaughtered at 25 kg. The inflexion point of leg growth influenced by type was around 22 to 29 kg, due to its relatively early maturity.

4 CONCLUSIONS AND PROPOSALS

The results of growth coefficients of fat, lean and cuts in relation to live weight or carcass were in agreement with the literature. Fat had faster development (b=1.4) in relation to the live weight, and lean was isometric ($b\approx1$) in all three growth types. The coefficients of the carcass parts were shown to be increased in a caudal-cranial gradient. Type effects were found in the coefficients of fat, long and short loin growth, but the coefficients of the types for lean and leg growth did not differ.

For the determination of the optimal slaughter weight or tissue composition the growth models should be used. One of the criteria to choose which growth function is the most appropriate is the biological interpretation. The goodness of fit of the logistic functions was considerably weaker than the two asymmetric functions, proved by the highest RSS values. However, the logistic model, due to its symmetric shape, had better fit on the growth of the fatness and the long loin of the American Suffolk, because these properties have a low gain at the early stage of life, which becomes accelerated with age. Furthermore, the use of the logistic model is limited, since it underestimates marginally the mature size of the traits.

The effect of data input on parameters of growth curves was small. However, the standard errors of I2 method (fitting of the growth curves to averaged points) were the highest, ergo the type effects were the lowest comparing with the other methods. The lowest standard errors were provided by the I3 method (fitting of the growth curves all individual weights data). The I2 had the lowest, the I3 had the highest RSS values.

The applied functions support the interpolation, but the extrapolation is limited. Therefore the weights of older animals are underestimated (inappropriate for the estimation of more-or-less linear growth of fat deposition in adults). The results around or pre-birth may be biased as well. For increasing the accuracy of estimation of these flexible models, the frequency of the measuring points should be increased or add more points from subsequent age.

More purebred individuals of the examined or further genotypes are suggested to be involved in selection orientated research. The growth and slaughter traits of the important but less extreme meat-types are supposed to be within of the examined three types. Therefore the growth functions may be corrected. Involving the results into selection criteria, the body constitution of any genotype may be modified, accordingly the lean growth may be improved.

Considering practical aspects, the F1 crossbred of the meat-types should be examined as well, because of the existence of the commercial populations. By these results the optimal slaughter age of the any interested genotypes may be determined.

From the CT scans, by following the applied methods, the growth modelling of further cuts (neck, shoulder, rib, flank) or their tissue composition is enabled.

Therefore the maximum utilisation of any cuts and the market specified products may be determined.

The growth rate parameters (asymptotes, daily gain) of the examined types were proved to be different by the applied techniques. Estimating the relative growth, however, the shapes of the curves were almost identical for the American Suffolk and the Hungarian Merino, verifying the conservatism of the growth characteristics (Taylor, 1965). Albeit, the growth curve of Dutch Texel considerably deviated due to the efficient breeding. Knowing the heritabilities of growth curve variables and the correlations between these variables (genetic flexibility) the shape of growth curves may be modified, and it can be used as a selection criteria. High genetic correlations ($r<-0.8$ or $r>0.9$) between the variables (asymptotic value, maximum daily gain, inflexion point) have been found (Lambe et al, 2006). The estimation of the genetic parameters of Hungarian population may improve the sheep breeding in Hungary.

5 NEW SCIENTIFIC RESULTS

1. The method for growth modelling used in other species was successfully adapted in sheep, providing comparable CT scans at subsequent times. Practically by dividing the distance of the joints of shoulder and femur into 30 scans, therefore the numbers of identical scans of an individual are positioned on the same anatomical point at every scanning time during the growth.

2. The growth of long and short loins calculated by CT scans were determined to be faster ($b>1$), leg were slower than live weight ($b<1$), independent of the growth types (Hungarian Merino, American Suffolk, Dutch Texel).

3. Among the used dynamic functions – asymmetric S-curves, modified Gompertz and logistic functions – the Gompertz model provided the best fit (based on the lowest RSS values) on the growth of the examined types, except the late maturing fat tissue and long loin of American Suffolk lambs, which had better results using logistic function.

4. The effect of data input – fitting of the growth curves to each individual weights data set separately (I1), to averaged points (I2) or to all individual weights data (I3) – on parameters of growth curves were small.

5. The differences among the growth pattern of the examined types (Hungarian Merino, American Suffolk, Dutch Texel) were lower, as it was expected, however, it was provable by the applied techniques (the use of CT-measurements and growth functions).

6. The method of the CT based estimation of optimal slaughter weight and age (at the highest leanness with the lowest fatness) were processed and proved in sheep species by growth modelling.

7. Based on this model experiment, in lambs slaughtered or exported at 22 kg live weight, as it is usual in Hungarian commercial market, fat content did not deviate significantly, albeit the genotypes considerably differ from each others in lean content and in slaughter ages.

1. PUBLICATIONS CONCERNING THE SUBJECT OF THE DISSERTATION

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