

SELF-REGULATING GROWTH MODEL IN HOMOIOOTHERMS (SGM)

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The aim of this contribution was to demonstrate mathematical expression of the growth model which forms the growth curve from objectively measurable values describing the organism, its nutrition, and thermal conditions of the environment where the growth occurs. As presented, the self-regulating growth model (SGM) creates automatically the growth curve of body mass from the input data defined in SI units. In contradiction to currently used formulae of growth curves derived from the logistic curve or polynomials of the nonlinear regression analysis, SGM does not contain the coefficients which should be previously derived from the experimental data of the particular type of the experiment. SGM creates automatically the growth curve values from the following input data: the initial body mass (G_0), the average body mass of the defined adult organism (GLi), specific gross energy content of the body mass increase (SGEG) and a common coefficient (n) which indicates the relation of the rate of the metabolizable energy intake in the feed (MEIF) to the value of the standard metabolic rate (SMR). The physiological limits for the coefficient (n) are between 0 and 5 for most of the homoiotherm species. From the above-mentioned set of input data the SGM calculates the growth curve by integration of the body mass increase. The SGM was verified on growth curves of the rat, broilers, pigs, and cattle.

Growth curve, modelling, rat, broilers, pig, cattle

The sigmoid form of the growth curve called today a logistic curve, originally derived for the growth of a population, was applied by Robertson and Donaldson to the growth of the individual organism (Robertson 1908; Donaldson and Robertson 1915). The logistic curve can be found as a basis in many other growth models represented in various special forms as the growth models of Gompertz, created according to Parks as early as 1825, (Parks 1982), of Bertalanffy (1957), of Saturation Kinetics and of Richards (Richards 1959). All these growth models are widely used in experiments to the formation of growth curves of different animal species.

A comparison of three general growth models (Logistics, Gompertz's and Saturation Kinetics) on data from the broiler feed restriction study was published by Rogers et al. (1987). The Richards flexible model of growth has recently been used by many authors. For the evaluation of the postnatal growth in chickens (Knížetová et al. 1991a), in ducks (Knížetová et al. 1991b), for comparison of two different feeding regimes on the heritability of growth curve parameters in Japanese quail (Gebhardt-Henrich and Marks 1993), in geese (Knížetová et al. 1994), and in turkeys (Hyánková et al. 1995). As follows from the nice summary of Hyánek and Hyánková (1995) about the

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Richards flexible growth curves. most coefficients of the derived growth curves have no direct relation to the biological or physiological processes involved in growth. It is the same problem as that of the coefficients of the polynomials employed in linear or nonlinear regression analysis employed for instance by Emmans (1981, 1987), Moughan et al. (1995), and others. As pointed out by Emmans (1995), this problem of coefficients limits the use of any particular regression model to its having only a local value for a short time intervals.

In an effort to avoid this handicap of coefficients, namely that they have no precisely defined relation to the biological and physiological processes, we present in this paper a new approach in the formulation of the growth curve model based on the evaluation of the energy balance between the intake of metabolisable energy in the feed and the thermostatic heat production needed for the maintenance of body core temperature. We tried to formulate a growth model working with measurable data on the organism, its feeding, and thermal conditions of the environment.

Methods and Results

Each homoiotherm maintains, by means of thermoregulatory mechanisms, its body core temperature constant within a defined range ($T_i \pm dT_i$). To accomplish this basic physiological function, a homoiotherm must produce thermostatic heat (THP) in an amount equal to the cooling power of the environment (CPE). The metabolizable energy (ME) needed for THP must be compensated for by an equal amount of ME taken in the feed (MEIF) in a daily feeding dose (DFD), and only that part of the DFD which must not be used as the source of THP forms the potential production reserve (PPR) of metabolizable energy which can be used for the synthesis of proteins (PR), lipids (LP) and carbohydrates (CH) in the body mass increase (dG/dt) with a specific amount of gross energy (SGEG). The growth potential of the organism decreases with time in proportion to the increasing body mass ($G(t)$) and is theoretically exhausted when the organism reaches the average body mass of the adult organism as defined by its genetics. This coefficient is denoted as quotient of the growth limit (QGL). All the data are defined in SI units. The development of the body mass $G(t)$ in the defined time interval from ($t = 0$) to (t) is then, in the self-regulating growth model (SGM) according Novák (1994a, 1994b, 1995), defined by two basic equations in kg per individual per day (kg/id/dy)

$$\frac{dG}{dt} = \frac{PPR \cdot QGL}{SGEG} \quad [\text{kg/id/dy}] \quad (1)$$

$$G = G_0 + \int_0^t dG \cdot dt \quad [\text{kg/id}] \quad (2)$$

The value of SGEG depends on the content of proteins, lipids and carbohydrates according to the definition

$$SGEG = 22.180 (GPR) + 17.158 (GCH) + 38.920 (GLP) \quad \text{MJ/kg} \quad (3)$$

GPR - mass fraction of the protein content, GCH - mass fraction of the carbohydrate content, GLP - mass fraction of the lipid content.

In order that it might be possible to use SGM for modelling the growth of various species

and different body mass of the organisms, the components of the value $PPR = MEIF - THP$ are defined by the Kleiber's allometric formula for expression of the standard metabolic rate $SMR = f(G^{3/4})$ and Meeh's formula for the body surface $S = f(G^{2/3})$. (Meeh 1879), relatively as an n-multiple of the SMR value (n.SMR), (Novák 1994a). The daily body mass increase then may be expressed as

$$\frac{dG}{dt} = \left[\frac{0.19348 n - 0.28650}{SGEG} \right] \cdot \left[G^{3/4} - \frac{G^{7/4}}{GLi} \right] \quad \left[\text{kg/id/dy} \right] \quad (4)$$

The integration of the expression (4) according to expression (2) gives the values $G(t)$ of the growth curve for the organism defined by the input values: G_0 and GLi (kg), and $SGEG$ (MJ/kg) for the level of $MEIF$ (MJ/id/dy) relatively expressed by the nondimensional coefficient (n). All the values are calculated for the temperature of optimal production (T_{op} ; OC) (Novák 1994a). The general view on the family of the SGM growth curves $G(t)$ calculated for the input values $G_0 = 0.040$ kg, $GLi = 3.6$ kg, $SGEG = 5.386$ MJ/kg, $n = 2, 3, 4, 5$, in the time interval 0 to 90 days, is demonstrated in Fig. 1; the corresponding values of the SGM calculated body mass increases dG/dt are in Fig. 2.

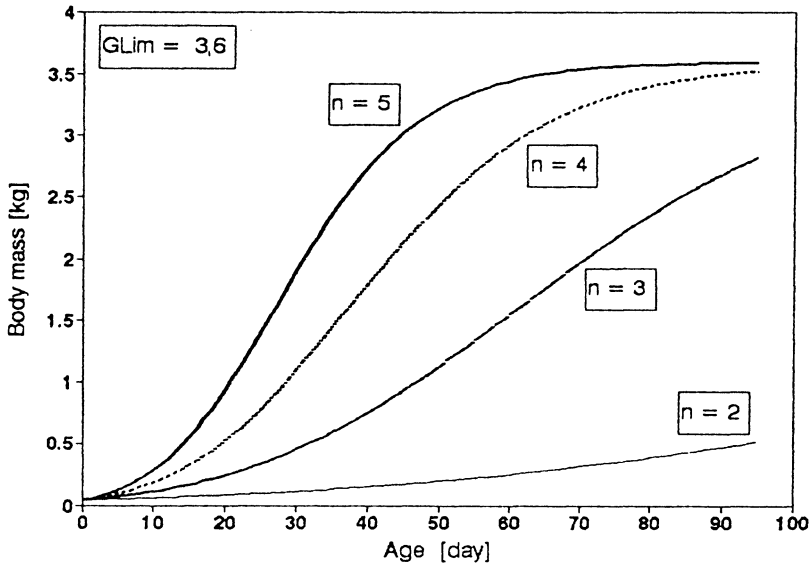


Fig. 1. SGM growth curves for different values of the n-coefficient. Abscissa: age in days. Ordinate: body mass in kg.

The priority of the presented model in comparison to all the other growth models is in that SGM may be applied to a homiotherm of any known size, defined by the GLi , for the anticipated $SGEG$ and the defined G_0 . By the variation of the coefficient (n) it is possible to approximate the growth curves of different species of animals. The approximation of the SGM curves to experimental values of the body mass growth of various animal species, formed by the search of the appropriate values of G_0 , GLi , $SGEG$ and (n) is, for illustration, presented in Figs. 3 to 5. In Fig. 3, there are two sets of data of the body mass growth in rats published by Robertson (1915), and data of rats of the Wistar strain reared in the Institute

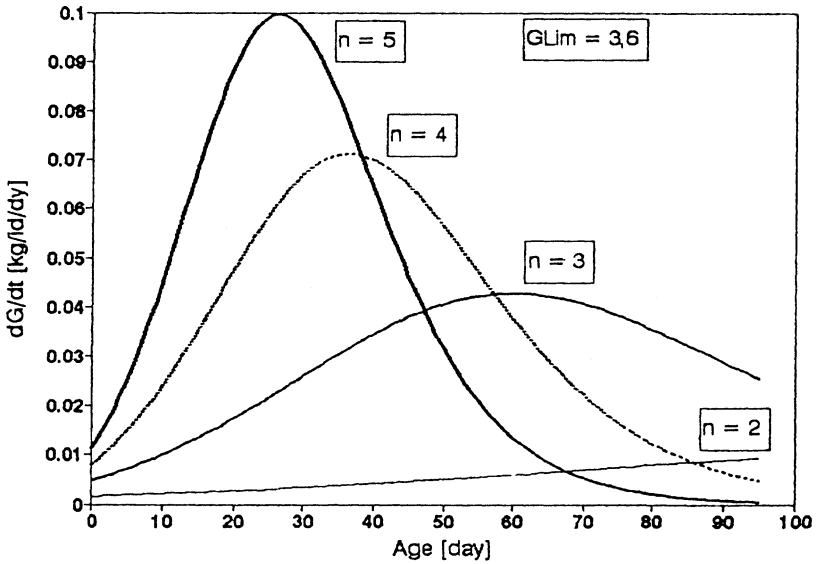


Fig. 2. SGM rates of body mass increase for different values of the n -coefficient. Abscissa: age in days. Ordinate: body mass in kg per individual per day.

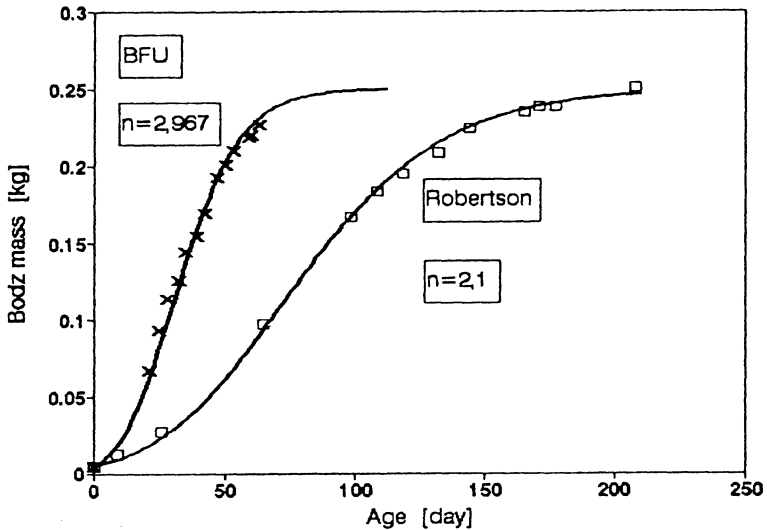


Fig. 3. Approximation of experimental average body mass by SGM growth curves in Wistar strain rats from two different breeds. Abscissa: age in days. Ordinate: body mass in kg.

of Biophysics, Brno (BFU) (Pípalová 1994, personal communication). Fig. 4 contains data of the body mass growth of pigs according to Kubíček and Zeman (1978). The approximation of the body mass growth of Holstein cows (Spector 1959) by the SGM growth curve is also presented in Fig. 4. The calculation of the SGM growth curve for the experimental values of the ROSS 208 broilers ($n = 35$) reared in regulated TOP

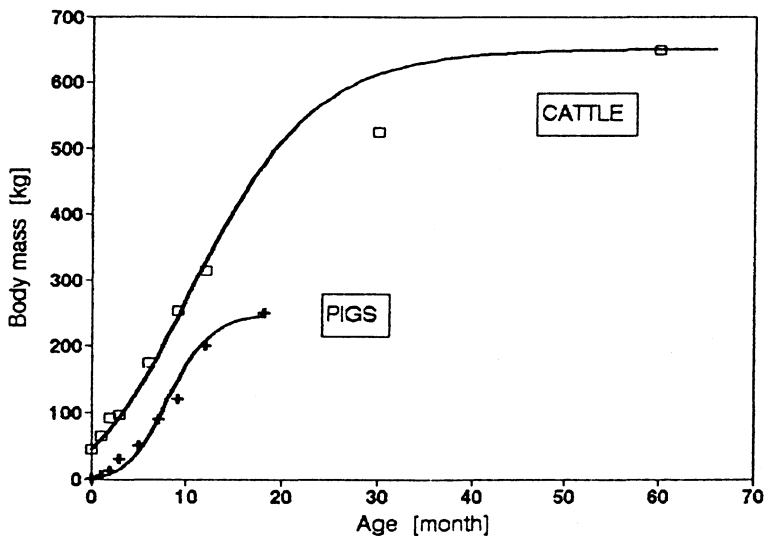


Fig. 4. Approximation of experimental average body mass of pigs and Holstein cows by SGM growth curves. Abscissa: age in months. Ordinate: body mass in kg.

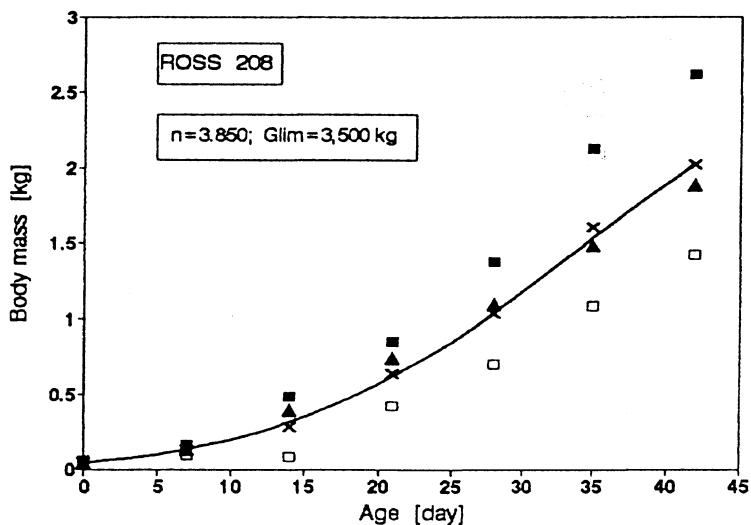


Fig. 5. The experimental and the breeder's tabular average body mass in ROSS 208 broilers approximated by SGM growth curve. Details are given in the text. Abscissa: age in days. Ordinate: body mass in kg.

(Holešová et al. 1995) is presented in the Fig. 5. The Heavy line denotes the calculated SGM values, the X markers denote experimental averages. Filled squares and Empty squares denotes the the interval for the 99 % probability of appearance of the experimental average value. Filled triangle indicate the Xaverov breeder tabular values. The input values for calculation of the SGM growth curves presented in Figs 1, 2, 3, 4 and 5 are summarized in Table 1.

Table I
The input values for calculation of SGM growth curves presented in Figs 1 to 5.

Fig. No.	G0 kg	GLi kg	SGEG MJ/kg	(n) -	Note
1	0.040	3,600	5,386	2, 3, 4, 5	
2	0.040	3,600	5,386	2, 3, 4, 5	
3	0.0045	0,250	5,386	2,100	Robertson
	0.0045	0,250	5,386	2,967	Pípalová
4	1,000	250,900	8,000	4,000	Kubiček
	45,000	650,000	6,500	2,500	Spector
5	0.041	3,500	4,872	3,850	Holešovská

Discussion

As demonstrated, the variation of the quotient (n) varies substantially the form of the body mass growth curve (Fig. 1) from the almost linear form at $n = 2$ to the classical form of a logistic curve at $n = 5$. The shape of the growth rate curves (Fig.2) is in the form of a bell. The value of the quotient (n) influences namely the height of the curve and the time of its peak position. It is important to stress that the quotient (n) represents a real value whose metabolizable energy intake by feed in MJ per individual per day (MEIF) can be easily estimated. For each point of the growth curve this value can be structured in the daily amount of the feed consumed (DFD) in kg per individual per day, with a defined specific amount of metabolizable energy (SMEF) in MJ per kg of feed. The calculation of the SGM growth curve is adjusted for the temperature of optimal production TOP. Calculation of TOP requires data about the body core temperature, thermal insulation and other measurable values (Novák 1994a, 1994b, 1995); such data are usually not presented in the current publications. From this reason it is difficult to interpret observed deviation if an individual point from the curve which covers perfectly all other measured values as shown in Fig. 4 (body mass at 30 months of age). The estimation of the TOP and the influence of its deviations from the optimal value on the growth will be the subject of a separate communication.

The adjustment of the SGM growth curves to the experimental values in Figs. 3, 4, 5, by means of the input values presented in Tab. I demonstrate a great flexibility, the SGM being reached by changes in four directly measurable values defined in SI units and having a clear relation to the biological and physiological processes of growth. The more accurately these values are known, the better is the correlation of the SGM calculated values to the experimental values as shown in Fig. 5.

From the theoretical point of view the presented SGM is similar, to the Bertalanffy's model (Bertalanffy 1957), in its conception of the growth as a dynamic equilibrium of two antagonistic processes: anabolism and katabolism. The SGM model however, is principally different in its structure of coefficients. The Bertalanffy's model needs to derive its coefficients from the experimental data, as do also the other known growth models, and these coefficients are valid only for a particular time interval and the particular experimental conditions employed. The coefficients of the SGM are derived from the well known allometric functions (Meeh 1879; Kleiber 1961) in combination with the known biophysical, biological and physiological rules governing the energy balance in homoiotherms with respect to the basic biophysical rule according to which "the body mass increase containing a defined amount of specific gross energy may be accomplished only with the amount of metabolizable energy taken in with the feed, which was not used to cover the thermostatic heat production or the external work done".

If we take into account the wide variety of species to which experimental values of body mass development and the growth curves calculated by the SGM were approximated, then it is possible to conclude the aim has been reached. SGM represents a new type of the growth model, which is able to calculate the growth curve for homoiotherms of different body size and biological species. The calculation is done from the input data, they have a direct relation to the biology and physiology of growth and are directly measurable.

Samoregulující model růstu homiotermního organismu (SMRO)

Cílem práce je předvést matematický model růstu, který tvoří růstové křivky z objektivně měřitelných hodnot, popisujících organismus, jeho výživu a tepelné podmínky prostředí, v němž růst probíhá. Samoregulující model růstu (SMRO) automaticky vytváří růstovou křivku hmotnosti těla z dat definovaných v jednotkách SI. Na rozdíl od běžně užívaných vzorců růstových křivek derivovaných z logistické křivky, polynomiální analýzy nelineární regrese. SMRO neobsahuje koeficienty, které by bylo potřebné předem derivovat z experimentálních údajů. SMRO automaticky tvoří hodnoty růstové křivky i následujících dat: iniciální živá hmotnost (G_0), průměrná hmotnost definovaného dospělého organismu (GLi), specifická brutto energie vzestupu živé hmotnosti (SGEG) a obecný koeficient (n), indikující vztah mezi rychlostí konzumu metabolizovatelné energie v krmivu (MEIF) k hodnotě standardní metabolické rychlosti (BMR). Fyziologické hranice pro koeficient (n) jsou mezi 0 a 5 pro většinu homiotermních druhů.

Ze shora uvedených dat počítá SMRO růstovou křivku integrací denních přírůstků živé hmotnosti. SMRO byl ověřen na růstových křivkách potkanů, broilerů, prasat a skotu.

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List of abbreviations used

BFU	Institute of Biophysics
CPE	Cooling Power of the Environment
dG/dt	Body mass increase in the time differential (dt)
DFD	Daily Feeding Dose
dy	Day
G ₀	Initial body mass
GLi	Genetic Limit of average body mass
GCH	Body mass fraction of Saccharides
GLP	Body mass fraction of Lipids
GPR	Body mass fraction of Proteins
G(t)	Body mass in the age of t-units
id	Individual
ME	Metabolizable Energy
MEIF	Metabolizable Energy Intake in the Feed
n	coefficient indicating the multiple of SMR
PPR	Potential Production Reserve
S	Surface area of the body
SGEG	Specific Gross Energy content in the body mass increase
SGM	Selfregulating Growth Model
SMEF	Specific Metabolizable Energy content in the Feed
SMR	Standard Metabolic Rate
THP	Thermostatic Heating Power
T _i	Body core Temperature
T _{Op}	Environmental Temperature of Optimal Production