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MODELLING OF PERFORMANCE AND PROTEIN AND FAT DEPOSITION IN PIGS: A REVIEW

NAČIN OBLIKOVANJA I TALOŽENJE BJELANČEVINA I MASNOĆE U SVINJA – PREGLED

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ABSTRACT

The aim of this paper was to provide a review of growth modelling in growing and fattening pigs and the results of studies conducted in this field. The authors present the various types of models, the history of growth modelling, the basic principles underlying their development, the factors effecting modelling accuracy and the areas where such models can be applied. It is concluded on the basis of available data that mathematical models enable a safer, more predictable and less erratic production as a result of which the economics of meat production can be substantially improved. Models make it possible to determine the nutrient requirements of animals and to predict the performance of fattening pigs. It is very important to further improve the modelling accuracy in the future, for which task it is indispensable to obtain a more thorough knowledge of the physiological, biochemical processes taking place in the animal body. Another possible challenge in modelling may be to provide an adequate estimate of the actual quality and quantity of meat at slaughter time.

Key words: pig, growth model, nutrient requirement, protein deposition, fat deposition

1. INTRODUCTION

Predictability of production is one of the prerequisites for achieving good production economics and high quality animal products (meat). With the progress of data processing and a better knowledge of biological science the assessment of animal growth and nutrient requirements aided by mathematical modelling has become, during the last two decades, a dynamically developing field of nutrition research. The mathematical modelling of biological processes can be defined in general as one of the most efficient means for determining the nutrient requirements of animals, and predicting the impact of feed intake on growth at a given point of time or in a given time interval. In the model the biological processes of the animal body are described with a system of mathematical which equations are based on the knowledge of the genetic, biochemical, physiological processes and the environmental impact (Halas and Babinszky, 2000).

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There are several types of growth models applied in pig nutrition presently, both in the field of scientific research and in practice as well. No uniform position exists as to which of these is the most suitable.

This review of the literature, therefore, is aimed at providing an overview of the mathematical modelling of the performance of growing and fattening pigs, presenting the various types of models, and also the basic principles to be relied on when developing such models. A further objective of this paper is to summarise the factors which have a major impact on the accuracy of models and their scope of application, and also to shed light on the problems which still await to be solved in this field.

2. TYPES OF MODELS

Models can be described broadly as either static or dynamic, as either deterministic or stochastic, and as either empirical or mechanistic (Black, 1995b).

2.1. Static and dynamic models

Dynamic models describe time explicitly as opposed to static models that represent the requirements and the performance for only one instant of time. The first animal models were statistic ones calculating, for example, the lysine requirement of the pig weighing 60 kg. Computer simulating models are by their nature dynamic, the state of the system is continually predicted over time (Black, 1995b).

2.2. Deterministic and stochastic models

Deterministic models have only one output representing the average of the population. These kind of models predict only one animal. Stochastic models, however, contain not only the mean but also the variation of the population. A distinction is to be made between genetic and environmental variation. Describing the genetic variance it should be known that estimates are obtained of the magnitude of the total variation. Environmental variation can be modelled by varying, for example, the level of energy demanding or supplying parameters which often cause major differences in values over the growth trajectory (Knap, 1995).

It is necessary to note, however, that no sufficiently accurate stochastic models have been developed even with the aid of today's sophisticated computer data processing. Thus the solution at present is offered by the expansion of deterministic models with stochastic elements, for the purpose of which there are two options available. If we increase the number of inputs of the model the individual animals of a given group will be described by a broader scope of the observed input variables, as a results of which we get an estimate on the population. In case we increase the number of outputs of the model we can present the mean and variation for variables which affect the economics substantially (e.g. backfat thickness) (Black et al. 1986). A significant shortcoming of the models so modified, however, is that in the course of calculations the so-called intermediate equations of the model are not expanded by the stochastic elements.

2.3. Empirical and mechanistic models

An empirical model describes the response of an animal to a given set of circumstances and usually attempts to develop predictive equations from experimental data sets using biometric procedures. The other type of model might be termed as the mechanistic model. Mechanistic models focus more on the metabolic processes within the animal. They may operate at tissue, cellular or molecular level. Such models are more flexible and may be expected to predict responses and requirements over a wide range of conditions (Close, 1996).

3. EVOLUTION OF MODELS

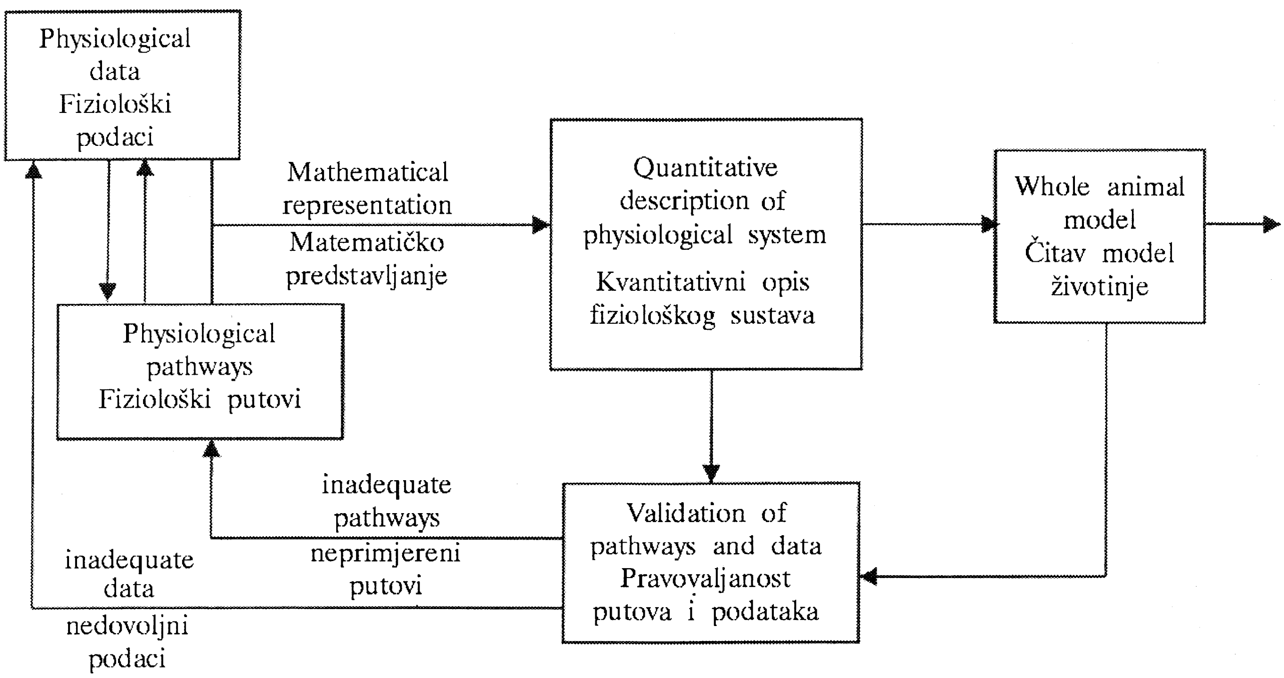
The first models were developed between 1940 and 1960 and those were factorial representations of energy and protein utilization and were used primarily to calculate requirements for animals at specific body weight. The calculations were based on empirical equations and as a result a static-empirical model was developed by Blexter (1962). Baldwin (1970) and later Baldwin and Smith (1971) developed the first computer simulation model based primarily on a representation of biochemical mechanisms as known at that time. The first pig growth model was developed by Whittemore and Fawcet (1974; 1976), which influenced largely the models developed later. It was based mainly on empirical equation, but the protein utilization was represented in a mechanistic manner (Black, 1995b). As a result of the progress in computer data processing, the more thorough knowledge of biological processes existing in the animal and the ever more accurate determination of its requirements the mathematical models developed can predict the animal performance with increasing accuracy.

The models of today are developed on the basis of metabolic processes occurring within the animal. Burlacu et al. (1989) have developed a model eliminating many of the imperfections of earlier ones. A valuable trait of the model is that it follows the distribution of nutrients in the body. Furthermore it takes into account the biological value of the protein in the utilization of crude protein. Nevertheless, the model prediction is wide ranged and the accuracy is not high enough (Burlacu et al., 1989).

4. THE MODELLING PROCESS

The philosophy behind the use of computer models to simulate animal systems has been described by Baldwin and Koong (1980), France and Thronley (1984) and Whittemore (1986). Despite the fact, that physiological processes existing within the animal are more or less known, it has become clear that the combined impact of several factors can change these processes and can thus influence the performance as well (Black, 1995a).

Figure 1. The modelling process (adapted from Black, 1995a)
Slika 1. Proces načina oblikovanja (prilagođeno iz Black, 1995a.)



The major steps in modelling process can be seen in Figure 1. The animal is a physiological system with measurable features (physiological data) and biological processes (physiological pathways). The first step in the modelling process is to carry out an investigation to collect basic data such as weekly body weight readings, daily protein and fat deposition or daily feed intake, etc. The physiological process and the control of the system are then developed from this information. Traditionally in science, these two steps are repeated many times until the system can be described at some uniform level of detail (Black, 1995a). The concepts and data are transformed into mathematical equations by algorithms that can be solved rapidly by computer to provide a quantitative and dynamic approach of the system.

The next step is to check the validity of the model with regard to pathways and data, by comparing predictions with the trial results. Whenever there is a considerable difference between the model predictions and experimental observations, new approaches of pathway and equation parameters can be devised and tested within the model. The modelling process begins again in that case. When model outcome and the experiences agree over a wide range of different circumstances, some confidence in the understanding of the system is obtained (Black, 1995a), that this could be the final model.

5. PRINCIPLES OF MODELS

There are four main principles to determine the growth models (Close, 1996):

5.1. Characterisation of the animal

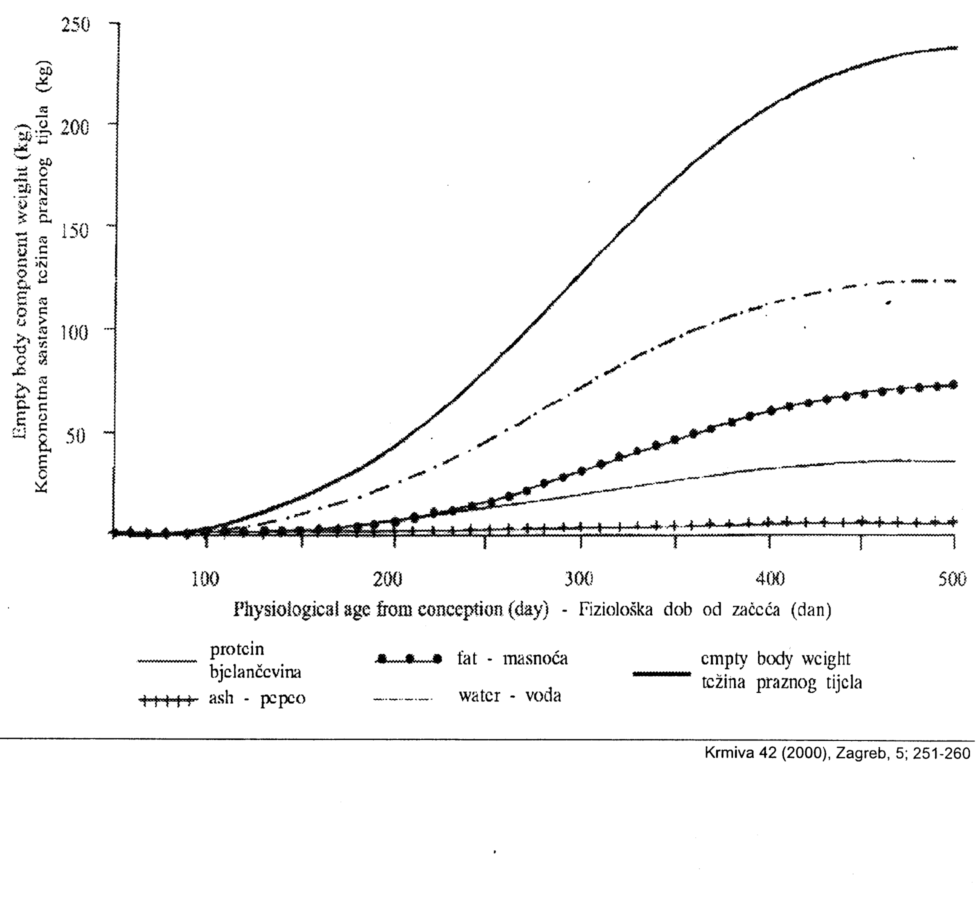
For models to operate satisfactorily and accurately, it is important to characterise the animal as well as possible. To achieve this we have to know which features are the main determinants of animal production. Studies conducted so far show, that production parameters are determined primarily by the following characteristics:

a) Relationship between the age and the body weight of the pig

The growth of an animal is often measured in terms of change in size (either dimensions or weight) with time. Historically, S-shaped or sigmoid curves have been used to describe this phenomenon in mathematical terms (Figure 2). The equation parameters are animal-specific and should be determined for each group within any species being described (Bridges et al., 1986). Moreover, change in body weight can be estimated by adding up body protein, ash, water and fat content.

Figure 2. Empty body weight (EBW) and the weight of chemical body components of the body as a function of age (Bridges et al., 1986)

Slika 2. Težina praznog tijela (EBW) i težina kemijskih komponenata tijela kao funkcije starosti (Bridges i sur.,1986.)



Increase in certain body components as a function of physiological age was approached curvilinearly by Bridges et al. (1986). Empty body weight can be seen as the sum of the component growth curves.

b) The effect of sex and genotype on the animal performance.

The genotype is one of the most defining factors influencing the amounts of body tissues deposited during growth. In investigations performed by Quiniou and Noblet (1995) six groups were used to represent differences between types and sex: lean pigs, obese pigs and conventional genotype within boar, gilts and barrows. The above authors demonstrated that the difference between the amounts of adipose tissue deposited in obese pigs and in lean pigs at the same empty body weight was mainly due to differences between amounts of external adipose tissue. The latter was found to be more important than differences in amounts of intermuscular adipose tissue. The lipid content of empty body weight was observed to differ widely among genotypes, whereas protein content was more constant. Consequently, the water content was lower in the obese pigs than in the lean or conventional pigs, while the ash content was similar for all the groups (Quiniou and Noblet, 1995).

The amount of adipose tissue was higher in gilts by 5% and in barrows by nearly 15% compared to boars ($P \leq 0,05$). The amounts of bone and skin were higher in all males than barrows and gilts of the same live weight, and also boars had the highest amount of offal. Quiniou and Noblet (1995) found that sex had no effect on total body protein content. In contrast, however, Yen et al. (1986) and Batterham et al. (1990) published strong sex effect in relation to protein deposition. Females and barrows contain more lipid and less water than boars, and approximately the same amount of ash (Quiniou and Noblet, 1995).

c) Appetite potential of the animal

The appetite potential is usually defined as energy intake capacity and it is related to the body weight. Close (1994) from a review of the literature, suggested that for modern genotypes the relationship between DE intake and body weight (BW) was best described as: DE (MJ/day) = 3.44 BW $(kg)^{0.54}$

BW – body weight

DE – digestible energy

NRC (1998) uses another third degree equation:

DE (kcal/day) = $1,250 + 188\ BW - 1.4\ BW^2 + 0.0044\ BW^3$

d) Effect of health state on the animal performance

Health state has a major influence on both the feed intake of the animal and its rate of lean tissue growth (Close, 1996). At a lower level of health state animals can not realise their genetic potential.

5.2. Characterisation of the diet

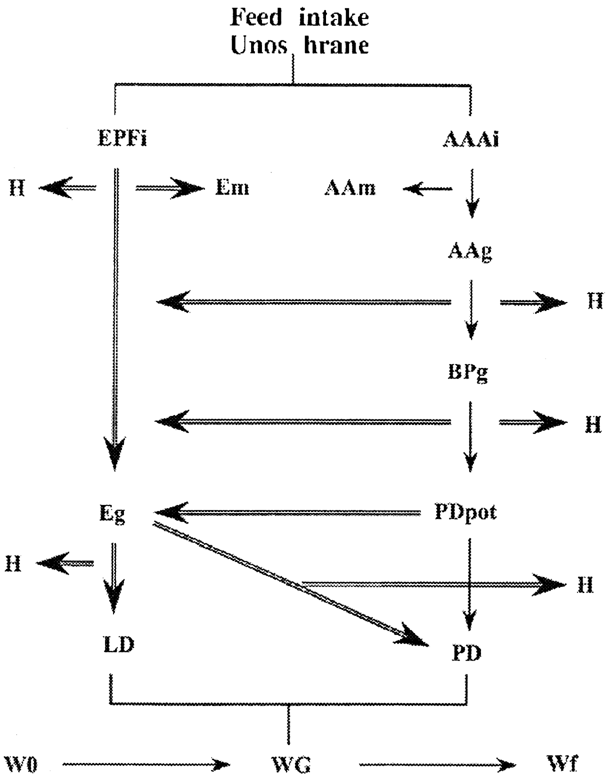
The most important parameters of feed are the energy content (DE or ME) and the amino acid content. The amino acid content of feed can be expressed as either total or digestible (fecal or ileal digestible) amino acid content. In diet formulation the concept of "ideal protein" should also be used. Thus, depending upon whether the objective is to determine the response or the requirements of the animal, either the nutrient intake of the animal is calculated from feed intake and nutrient composition of feed, or the energy and lysine requirements are calculated from which the quantity and type of diet may be determined (Close, 1996).

5.3. Distribution of the nutrients

The principles of nutrient distribution and growth as included in a simple model were described by Whittemore and Fawcet (1976); ARC (1981); Whittemore (1983); Moughan and Smith (1984); Moughan et al. (1987); Moughan and Verstegen (1988); Stanks et al. (1988). It is known that the nutrient requirements for maintenance always have a priority, and may represent up to 40% of the energy and 10% of the amino acid intake in case of adequate nutrient supply (Close, 1996). As it can be seen in Figure 3 two main categories can be set up for the nutrients in feed: protein free energy and protein (de Lange, 1995). The balance remaining after satisfying the energy and amino acid requirement for maintenance is utilized for protein and fat deposition. At each stage of the transformation process heat loss is to be expected. Body protein deposition exists from the available amino acids via balanced protein using a part of the energy for gain. Weight gain can be calculated as the sum of fat deposition and protein deposition and equals the difference between the final and initial body weight.

Figure 3. **Partitioning of the nutrients (de Lange, 1995)**

Slika 3. **Razdioba hranjivih tvari (de Lange, 1995.)**

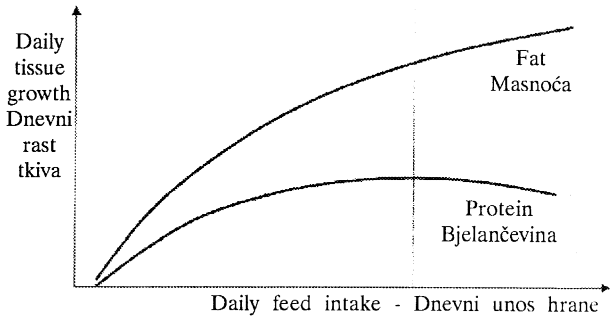


5.4. Describing the impact of dietary nutrients on animal performance

In general an increasing daily feed intake increases the daily tissue growth. This does not mean, however, that the deposition of the two predominant components of growth, i.e. protein and fat, would be continuous during the entire fattening period. Lean tissue deposition increases until it reaches the peak genetic capacity, fat deposition, however, does not have this kind of linear-plateau response (Figure 4). The key issue is to define the optimal feed intake. Optimal feed intake is considered to be the value beyond which protein deposition does not increase any longer. However, an important factor beside the quantity of feed is the nutrient content of diet.

Figure 4. **Relationship between daily feed intake and protein and fat deposition (Close, 1996)**

Slika 4. **Odnos između dnevnog unosa hrane i taloženja bjelančevina i masnoće**



The rate of protein deposition is determined by the level of energy and amino acid supply, and in case of pigs especially by the first limiting amino acid, lysine. The daily protein and fat deposition increases linearly with the dietary DE intake (Campbell et al.,1983; Campbell et al., 1985; Campbell and Traverner; 1988). The limiting factors of protein deposition in case of adequate energy supply are the amount of available amino acids, and the peak level of genetically determined protein deposition.

The relationship between daily protein or lysine intake and protein deposition is described linearly by Zhang et al. (1984), as a two-phase-linear function by Batterham et al. (1990), curvilinearly by the Agricultural Research Council (ARC, 1981) and by Fuller and Garthwaite (1993), and as a linear-plateau response by Campbell et al. (1984, 1985), de Greef (1992) and Bikker (1994). The limiting factors of protein deposition - in case of an adequate energy supply - are the amount of available amino acids, and the peak rate of genetically determined protein deposition. The relationships of the model should be adjusted for the herd in question, that is the factors in the various equations should be replaced by the values characteristics of the given population.

Several studies (Bikker, 1994; Halas, 2000) have shown, that there is a close correlation between ileal digestible (ID) lysine intake and the average daily gain, the daily protein deposition and the feed conversion ratio (Table 1). Halas (2000), moreover, found that when increasing the ID lysine intake up to 12.6 g/day and 17.6 g/day at pig live weights of 30-60 and 60-105 kg, respectively, a linear lysine response was shown in respect of the foregoing three performance traits (Table 2). Batterham et al. (1990a) found similar results when studying a 23 broader range of intake (1.53 g/kg - 12.27 g total lysine/kg diet and 15.3 MJ/kg diet), namely, weight gain and within that protein deposition can be safely increased ($P \leq 0,01$) and the quantity of feed used for 1 kg of weight gain, and the daily fat deposition can be reduced ($P \leq 0,01$) by increasing the lysine intake. The authors suggest a strong quadratic effect of the lysine intake on the daily gain and feed conversion ratio. Extremes of the curves exist at the end of the current range. Among others these relationships should be put into the models to estimate the animal response to a given diet.

Table 1. **Correlations between dietary ileal digestible lysine intake and average daily gain, protein deposition and feed conversion ratio (Halas, 2000)**

Tablica 1. **Korelacije između hranidbenog lizina probavljivog u ileumu i prosječnog dnevnog prirasta (ADG), taloženja bjelančevina (PD) i omjera konverzije hrane (FCR) (Halas, 2000.)**

	Correlation - Korelacija		
	ADG (g/day - dan)	PD (g/day - dan)	FCR (kg/kg)
30-60 kg	r=0.94	r=0.78	r=-0.94
60-105 kg	P=0.0001	P=0.0010	P=0.0001
	r=0.89	r=0.77	r=-0.87
	P=0.0001	P=0.0013	P=0.0001

ADG: average daily gain; PD: protein deposition; FCR: feed conversion ratio

Table 2. **The effect of dietary ileal digestible lysine intake on the average daily gain protein deposition and feed conversion ratio (Halas, 2000)**

Tablica 2. **Učinak unosa hranidbenog lizina probavljivog u ileumu na prosječni dnevni prirast (ADG), taloženje bjelančevina (PD) i omjer konverzije hrane (FCR) (Halas, 2000.)**

		Y=a*Lys+b		r
		a	b	
30-60 kg	ADG (g/d)	25.3	186.5	0.94
	PD (g/d)	5.06	25.4	0.78
	FCR (kg/kg)	-0.18	5.36	0.94
60-105 kg	ADG (g/d)	24.0	248.2	0.89
	PD (g/d)	4.86	-0.25	0.77
	FCR (kg/kg)	-0.13	6.27	0.87

6. PRACTICAL APPLICATIONS OF THE MODELS

Models offer the means to develop alternatives over a range of management, husbandry, environmental and dietary conditions. Using them it is possible to predict the growth rate and performance of animals even within a broad range of body weight. Furthermore, quality can also be predicted in case the body fat content, or the protein/fat ratio is taken into account in the calculations as a quality trait.

Getting an accurate prediction to the profitable traits of animal production is a key issue for producers (de Lange and Schreurs, 1995). Models establish nutrient requirements, diets and feeding strategies at all stages of growth and allow for an economic analysis of current and alternative feeding strategies.

Table 3 shows the nutrient requirements of pigs in a farm at different stages of the fattening period (Close, 1996). The following example well illustrates, that with the aid of the model the nutrient supply of the animals required to achieve the given performance can be predicted. The prediction demonstrates how the growth rates and the protein and fat gains change with increase in body weight, and as a consequence, how energy and lysine requirements and hence lysine/energy ration in diets, vary. The problem can also be reversed, i.e. in case of an adequate nutrient supply the animal performance can be predicted by models. Predictable production is the basis of profitability. Table 4 (Close, 1996) shows a comparison of economics among farms with different conditions. It appears from the figures, that genotypes with a lower level of growth rate could reach a smaller lean percentage. All of the genotypes need optimal nutrient supply to realise their maximal level of genetically determined performance. As a consequence in case of suboptimal nutrient intake the production costs are higher and the profitability of pig production decreases as shown by Table 4.

Models aid the comparison of the performance actually achieved on a farm with the genetic potential of animals. Any shortfall will be an indication for the farmer that external factors should be modified in order to improve production.

Finally the models can help the feed manufacturer in the development and testing of new diets, products and feeding regimes with which the animal requirements can be better satisfied.

Table 3. Predicted nutrient requirement and feed efficiency (Close, 1996)
Tablica 3. Predviđene hranidbene potrebe i djelotvornost hrane (Close, 1996.)

	30-50 kg	50-70 kg	70-95 kg	Overall
Time taken (days) - Potrebno vrijeme (dana)	29	24	28	81
Growth rate (g/day) - Stopa rasta (g/dan)	700	825	900	800
Protein gain (g/day) - Prinos bjelančevina (g/dan)	130	154	161	143
Fat gain (g/day) - Prinos masnoće (g/dan)	95	117	170	138
Energy (MJ DE/day) - Energija (MJ DE/dan)	20.4	24.9	30.2	26.4
Lysine (g/day) - Lizin (g/dan)	18.7	21.8	22.8	21.7
Feed efficiency (kg/kg) - Djelotvornost krme (kg/kg)	2.26	2.40	2.92	2.57

Table 4. Predicted nutrient requirement and changing in productivity for animals growing at different rates between 30 and 90 kg body weight (Close, 1996)
Tablica 4. Predviđene hranidbene potrebe i promjena u proizvodnosti životinja različite stope rasta između 30 i 90 kg tjelesne težine (Close, 1996.)

Growth rate (g/d) Stopa rasta (g/d)	650		700		750		800			850		
Lean %* - Mršavo %*	54	56	54	56	56	58	56	58	60	56	58	60
Carcass lean (g/d) Mršavo truplo (g/d)	275	290	296	312	334	352	356	375	394	379	399	419
DE (MJ/d)	25.4	24.2	26.5	25.1	26.1	24.7	27.1	25.6	24.1	28.1	26.5	25.0
Lysine - Lizin (g/d)	17.4	18.4	18.4	19.1	20.2	21.0	21.2	22.2	23.0	22.2	23.2	24.0
Feed intake (kg/d)** Unos hrane (kg/d)**	1.93	2.01	2.01	1.91	1.99	1.88	2.06	1.95	1.93	2.14	2.02	1.90
FCR (kg/kg)	2.97	2.83	2.87	2.73	2.65	2.51	2.58	2.44	2.30	2.52	2.38	2.25
Relative cost (%) Relativni trošak (%)	100	95	97	92	89	85	87	82	77	85	80	76

* Assumes maximum carcass lean tissue growth of 420 g/d

** Diet contains 13.8 MJ DE/kg - Krma sadrži 13.8 MJ DE/kg

To conclude, the growth of animals can be estimated by a good approximation, by taking into account the animal and environmental factors affecting the growth model. The sensitivity of these models is influenced by sex, age, the genotype of the animal and the standard of feeding. In the evaluation of a model these factors should be considered. There is limited information available for predicting with accuracy protein and fat deposition and content in growing and fattening pigs as one of the features of carcass quality. It is important to develop a mathematical model capable of predicting more accurately the protein and fat deposition in growing and fattening pigs, as this could contribute substantially to a more cost-effective and better quality pig production.

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SAŽETAK

Svrha je ovog rada dati pregled oblikovanja rasta svinja u rastu i tovu te rezultate proučavanja na tom području. Autori daju razne vrste modela, povijest načina oblikovanja rasta, glavne principe njihovog razvoja, čimbenike koji utječu na točnost načina oblikovanja i područja gdje se takvi modeli mogu primijeniti. Na osnovi raspoloživih podataka zaključuje se da matematički modeli omogućuju sigurniju, predvidljiviju proizvodnju s manje pogrešaka na temelju čega se ekonomičnost proizvodnje mesa može znatno poboljšati. Modeli omogućuju određivanje hranidbenih potreba životinja i predviđanje performance tova svinja. Ubuduće vrlo je važno još više poboljšati točnost načina oblikovanja, a za taj je zadatak neophodno još bolje poznavanje fizioloških, biokemijskih procesa što se odvijaju u tijelu životinja. Drugi moguć izazov u načinu oblikovanja može biti pribavljanje odgovarajuće procjene stvarne kakvoće i količine mesa kod klanja.

Ključne riječi: svinja, model rasta, hranidbene potrebe, taloženje bjelančevina, taloženje masnoće