Application of a Model of Animals' Growth to Study Slowly Growing Pigs

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Abstract

The aim of this study was to investigate a problem in pig farming by applying results of pigs' growth modelling. The problem this study deals with is a large amount of variation in weight between animals within groups with growing-finishing pigs with strongly negative effect of slowly growing pigs on farm efficiency. The target is to find out a breeding scheme, which can eliminate the slowly growing phenotype from commercial farms.

This study was carried out by applying a mathematical model. The model is species-specific; it was built to analyse growth of pigs. In the study, the model has not been developed, it was published elsewhere. The model's results are used to clarify some aspects of pigs' growth under industrial conditions. The model implies that in the pig, there are three growth phenotypes that have distinct growth performances. In the study, a main theme is variation in weight between growth phenotypes in pigs.

The results of the study suggest that the slowly growing pigs have a certain growth phenotype. A method to identify the phenotype, and a breading scheme to eliminate the slowly growing phenotype from commercial farms are suggested.

Keywords: quantitative trait, growth phenotype, growth trajectory, genetic determination, variation in weight, species-specific model

1. Introduction

In industry, the growth performance of growing-finishing pigs strongly influences efficiency and productivity of commercial farms. The performance of pigs in batches depends on many factors (Calderón Díaz et al., 2017) including variation in weight between pen mates (He et al., 2016). On farm, the smaller the variation in weight the larger is the profit (López-Vergé et al., 2018a). It is essential to develop strategies to improve the performance of lightweight animals since they significantly contribute to batch inefficiency (Huting et al., 2017). In this study variation in weight and the growth rate of pigs were analysed by applying a mathematical model.

1.1 Variation in the Growth Rate

Variation in the growth rate of pigs starts from conception, with pigs of the same litter often varying considerably in birth weight. This variation in pig growth performance both within and between litters continues through their lifetime (Magowan et al., 2007). Many factors such as housing, environmental conditions, and feeding systems influence variation in weight in groups with pigs. Applying feeding strategies based on the average pig to a group of pigs implies that requirement will be met for not more than 50% of the pigs in the group. Accounting for differences among pigs within a group is essential in precision farming, which can improve economic performance (Vautier et al., 2013). Feeding strategies need to be adjusted to cover the requirements of the most efficient animals (Saintilan et al., 2015).

Most of the economic consequences of a higher variability among batches have to do with the quality classification mainly due to the lightest pigs within the same batch. There are many factors that affect pig performance, and pigs with a delayed growth are the consequence of several factors, such as environment, nutrition, and genetic potential, among others. The target is to reduce production costs by improving batch homogeneity (López-Vergé et al., 2018b). Before weaning, weight and growth rate of animals are influenced by a number of factors (Pardo et al., 2013; López-Vergé et al., 2018b). Many authors found that low birth weight, or low weaning weight had no evident negative impact on growth potential, quality of pigs or growth performance

(Pardo et al., 2013; Huting et al., 2018). Other studies did not find positive effects of increasing the weaning weight in the growth to slaughter (López-Vergé et al., 2018b). It is understandable; animals can resist the harmful effects, overcome a number of negative factors (Huting et al., 2018; López-Vergé et al., 2018a) and later grow in line with their phenotypes. This statement is supported by finding that variation in the performance of pigs from different herds was also noted when they were managed in the common environment, with variation being similar to that observed on farm (Magowan et al., 2007).

Reportedly, the variation in weight between pen mates tends to decrease with age; however, decrease in weight variation with age could be a consequence of the different management practices implemented in the farms, like sorting pigs by body weight (López-Vergé et al., 2018b). Though, it is not always the case. Sorting growing-finishing pigs by weight fails to improve growth performance or weight variation (O'Quinn et al., 2001; Nyachoty et al., 2004). In conclusion, large variation in growth rate between pigs within herds or groups is a major contributor to poor performance and reduced profitability. Research should focus on strategies to manage such variation and ultimately to maximise the full genetic growth rate potential of pigs (Magowan et al., 2007).

The main part of pigs in industry are healthy and without complications at birth or weaning. In growth stage after weaning, the genetic determined differences in the growth between pigs become noticeable in weight approximately 45 kg. The pigs, which do not grow as fast as other pen mates due to the genetic determination are healthy animals and neither veterinary investigations nor laboratory analyses can reveal health problems. It is understandable; the pigs grow in line with their phenotype, though slower than pen mates with distinct phenotypes.

1.2 A genetic Aspect of Pig Growth

To explain variations in growth rate between pigs a mathematical model of animals' growth has been used. In this section one aspect of the growth determination has been discussed, namely the growth rate phenotypes. Rapid growth in domestic pigs has been observed between 30 kg and 96 kg live weight. In this weight range, growth rate maxima have been reported in most pigs. In the pig the growth rate maximum is inherent quality, it is genetically determined and physiologically conditioned. Identification of the growth phenotypes in pigs is associated with finding the growth rate maximum in individual animals over a stage of the rapid growth. A growing pig unavoidably has individual growth rate maximum, which characterises both its ontogenetic trajectory and the growth phenotype. The model says that in the pig, there are three growth rate phenotypes (Stass, 2019). Phenotype *BB* has growth rate maximum in weight approximately 70 kg, phenotype *Bb* has growth rate maxim in weight approximately 60 kg, and phenotype *bb* has growth rate maximum in weight approximately 45 kg. This result is supported by Green et al. (2003) findings. Slowly growing pigs have phenotype *bb*; in this study, growth of animals with this phenotype has been analysed.

2. Materials and Methods

The growth of pigs is discussed and modelled in terms of body weight and daily gain. The performance of a phenotype, a trait, is considered as a function of the underlying causal factors. Identification of such factors or variables is a separate task to complete prior to formulate a model. The method that has been used in this study was mathematical modelling.

2.1 Data Set

The data set was obtained in experiments with growing domestic pigs, LW, fed from 30±6 kg up to 96±4 kg live weight. The pigs were housed and fed under non-industrial conditions, either in a pig testing station or in research facilities. The animals were kept loose in groups of up to four to a pen, or individually in pens. Pigs were fed a dry commercially available balanced feed with unlimited access to water contingent on the experiment design, *ad libitum*, or a constrained diet. The quantity of the feed was adjusted once a week in accordance with the animals' current body weight. The experiments were performed in compliance with Declaration of Helsinki, National legislation, and institutional rules.

2.2 A Model of Pig's Growth

A detailed analysis of data set was used to build a mathematical model of pig's growth. The modelling technique enabled the formulation of a model that describes the growth of individual pig. The growth of pigs is considered as a dynamic system; it is based on a functional relation between studied traits. The model was formulated as a set with nonlinear equations with discrete current time (Stass, 2019). In this section only necessary for this study equations are given.

$$K = \frac{M_t}{m_0(2t - t_0)} \tag{1}$$

where, M denotes current weight, and m denotes initial considered weight; under the model conditions $m_o = 30$ kg. t denotes current discrete time measured in days from animal birth, t_o corresponds to m_o. The following two equations may be useful to see the process of growth.

$$\frac{1}{m_o} \cdot \frac{\Delta M}{\Delta t} = \frac{1}{t} \cdot \frac{ZK(2K+1) - 2K^2}{Z(K+1) - 2K} \tag{2}$$

$$\frac{1}{m_o} \cdot \frac{\Delta M}{\Delta t} = \frac{1}{t} \cdot \frac{m_o[Z(2K+1) - 2K]}{m_o[Z(2K+1) - 2K] - MZ} \tag{3}$$

where, Z denotes current feed conversion coefficient, Z corresponds to M.

3. Results

In this section data published by He et al. (2016), and results published by Stass (2019) were used. Together, the above-mentioned studies lead to a possible explanation of growth variation in batches with pigs. In the experiments, slow growers accounted for 10% of pigs marketed, average growers accounted for 49% of pigs marketed, and fast growers accounted for 41% of pigs marketed (He et al., 2016). Similar result has been reported by other researchers (Calderón Díaz et al., 2017). Indirectly, the finding was supported by Vautier et al. (2013) data.

3.1 Genetic Interpretation of the Data

A data set obtained in experiments and published by He et al, (2016) was used. Between analysed pigs (n = 440), 10% were slowly growing, 49% average growing, and 41% fast-growing animals. The genetic interpretation of the data set is given in Table 1.

Table 1. Distribution of phenotypes

Frequencies of alleles	$B = 0.65$; $b = 0.35$		
Frequencies of phenotypes	*bb*	*Bb*	*BB*
	0.12	0.46	0.42

The interpretation was comparable with the results of He et al. (2016). This interpretation approves the opinion that the distribution of animals by growth rate can be well explained (Stass, 2019). The above genetic explanation of the He et al, (2016) finding confirms the genetic determination of growth rate by phenotypes of two allelic gene *B*. It follows that slowly growing pigs have phenotype *bb*, average growing pigs have phenotype *Bb*, and fast-growing pigs have phenotype *BB*. This is in full agreement with earlier research (Stass, 2019) (Figure 1).

3.2 Growth Phenotypes

The above result, Table 1, explains qualitative aspect of growth phenotypes distribution. Namely, the growth rate of pigs is inherently determined by the growth phenotypes. However, quantitative description of the growth phenotypes is needed as well. The quantitative explanation of the growth phenotypes trajectory in pigs follows from the model (Stass, 2019). The growth trajectories of the three identified phenotypes are shown in Figure 1.
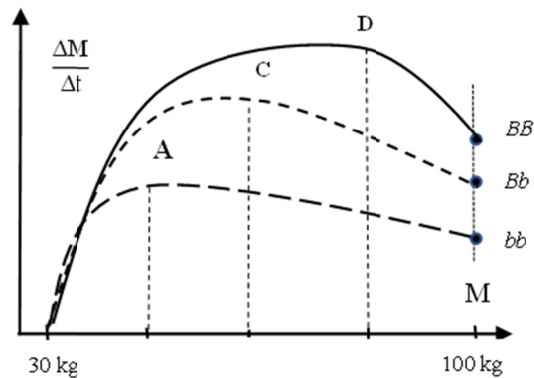
Figure 1. Growth rate of three phenotypes *BB*, *Bb*, *bb*

Note. Phenotype *bb* has maximum growth rate in the point A, in weight about 45 kg; Phenotype *Bb* has maximum growth rate in the point C, in weight about 60 kg; Phenotype *BB* has maximum growth rate in the point D, in weight about 70 kg.

From Figure 1 follows that the reason *bb* phenotype is slowly growing is that this phenotype has growth rate maximum in weight approximately 45 kg. After reaching 45 kg, growth rate of pigs with *bb* phenotype decreases while animals with other phenotypes continue to grow with the increasing rate. This finding explains the main part of variation in weight between animals in batches with growing-finishing pigs.

The fact that the growth phenotypes have distinct growth rates with different maxima explains why regrouping pigs by weight has usually no positive result. Sorting growing-finishing pigs by weight fails to improve growth performance or weight variation (O'Quinn et al., 2001; Nyachoty et al., 2004). Under industrial conditions regrouping or sorting pigs by weight has been carried out after weaning, in weight around 20 kg. In this weight, differences in growth rate between pigs arise mainly due to health, housing, feeding, or environmental conditions. In this weight, differences in growth rate due to the genetic determination are not noticeable. As a result, animals with different growth phenotypes have been grouped at random, and without the desired outcome.

4. Discussion

In experiments, when pigs were brought to a common environment, the only differences were genotype, pre-weaning environment and health status and weight at entry, yet large variations in growth rate still occurred between pigs. When pigs were housed individually many of the commercial stressors were absent and large differences were still observed (Magowan et al., 2007). A strategy to deal with this problem is to identify factors associated with the occurrence of pigs with a delayed growth (He et al., 2016) and offer a solution. This study supports the opinion that segregation of pigs by growth rate has been caused by genetic determination (Stass, 2019); other reasons (Pardo et al., 2013; Calderón Díaz et al., 2017; López-Vergé et al., 2018b) are considered co-factors that influence animals' health. If feeding strategies have to meet the requirements of the fast-growing pigs (Saintilan et al., 2015) then the task is to eliminate the slowly growing phenotype from commercial farms.

4.1 Growth of Pigs

Farm animals are of interest for identifying genes that control growth, energy metabolism, development, appetite, reproduction, and behaviour, as well as other traits that have been manipulated by breeding (Anderson, 2001). Across breeds, diversity is an important source of variation to rescue problematic populations and to introgress new variants (Toro et al., 2011). Under industrial conditions, large amount of variations in growth rate in groups with pigs is a disturbing factor. Diversity in weight in batches with growing pigs under on farm conditions significantly contribute to batch inefficiency (Huting et al., 2017). Slowly growing pigs are more at risk to be delayed in all-in-all-out systems, resulting in remixing, increasing the potential for disease transmission, but most importantly contributing to considerable production losses. It is therefore important to identify which pigs are most likely to remain light throughout the production cycle (Huting et al., 2018). The study supports the opinion that variation in weight between pigs has been brought about by quite a few factors including genetics (Nyachoty et al., 2004; López-Vergé et al., 2018b) though has been determined by animal's growth phenotype.

Breeding programmes are aimed to produce best phenotypes. In this respect the question is whether distribution of the growth phenotypes shown in Figure 1 is consistent. Some doubts raise the consideration that the animals that perform superior growth might not fit in this distribution. Analyses of the model (Stass, 2020) suggests that

the distribution of animals' phenotypes that perform superior growth is qualitatively similar to the earlier found distribution; it is shown in Figure 2.
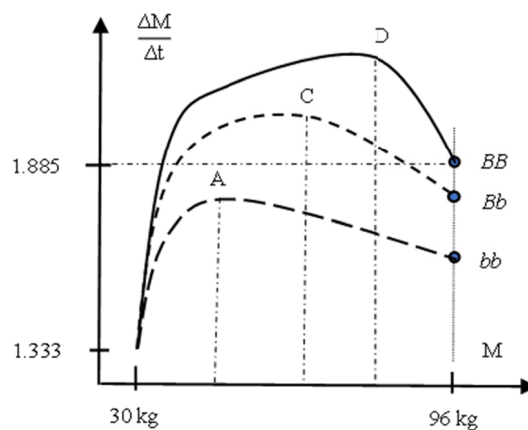

Figure 2. Growth of pigs with superior performance

Note. Only phenotype *BB* can perform superior growth with maximum average growth rate 1.885 kg a day and maximum growth rate 2.530 kg a day in the point D.

It follows that Figure 2 is qualitatively similar to Figure 1. This means that animals that perform superior growth have growth rate maxima in the same weight as other pigs with the same growth phenotypes. This result delivers reassurance that selection work and breeding programmes are applicable to all animals including those that can perform superior growth. Pigs that perform superior growth do not form a set with distinct growth phenotypes. It follows that the animals, which can perform superior growth fit in *BB* growth phenotype. It is important to note that all animals with BB phenotype cannot perform superior growth. Actual expression of a quantitative trait, for example growth rate, mediated by gene B, is associated with other traits. The actual growth rate is a result of an association $BB \cdot X_1 \cdot X_2 \cdot X_3, \ldots X_n$, where, X_n denotes sets with genes that influence growth rate. It has the consequence that only phenotype BB in association with certain genes X_n, it is $BB \cdot X_n$, can perform superior growth (Stass, 2020). It is reasonable to infer that selection work for animals with superior growth should be carried out in pigs with *BB* growth phenotype.

In technological stages after weaning, differences between pen mates in growth rate become noticeable in weight of about 45 kg. These differences in growth was attributed to animals' growth phenotype. Genetic interpretation of the above results explains why sorting growing pigs by weight fails to improve variation in weight in batches with pigs. Differences between pigs in growth rate due to genetic determination become apparent in weight of about 45 kg. In this weight, growth rate of pigs with phenotype *bb* reaches maximum, levels off, and starts to decrease while other phenotypes continue to grow with the increasing rate. In weight of about 50 kg, differences in weight between pigs in a same batch become obvious by visual evaluation. With age, differences in weight between phenotypes only increase.

4.2 Growth Phenotypes and a Breeding Scheme

If commercial farms are to have chance to enhance results, they need to eliminate the slowly growing phenotype. In pigs, identification of the growth phenotypes has been carried out by comparing value of parameter *K* in the point the growth rate reaches maximum with certain values of parameter *K* (Stass, 2019), Equation (1). How to identify growth phenotypes is clear from Figure 1. The method is obvious and technically simple. The task is to find the weight in which the growth rate of individual growing pig reaches maximum. Phenotype *bb* has growth rate maximum in weight approximately 45 kg, phenotype *Bb* has growth rate maximum in weight approximately 60 kg, and phenotype *BB* has growth rate maximum in weight approximately 70 kg. This result is supported by Green et al. (2003) findings. To carry out the genetic analyses with the aim to identify animal's growth phenotype, it is necessary to find the weight in which the growth rate of individual tested animal reaches maximum. This task has a technical solution. The solution is to use an automated system designed as a station with one slot feeder combined with a platform balance (Parsons et al., 2007); such systems are commercially available (Saintilan et al., 2015). The typical facilities where this task may be done are pigs testing stations. The

stations usually have the necessary equipment. To start and complete the task, in many cases only adjustment of software is needed. Second option to identify growth phenotypes is that used by He et al, (2016). However, this method is less precise and can produce bias. The aim is to identify the growth phenotypes of boars and sows on breeding farms by testing their progeny, it is by analysing their growth phenotypes, and apply an appropriate breeding scheme. The breeding scheme is suggested in Figure 3.

$$\boxed{\begin{array}{c} \male BB \times \female BB \\ F_1 \quad \downarrow \\ BB \end{array}} \quad \boxed{\begin{array}{c} \male BB \times \female Bb \\ F_1 \quad \downarrow \\ BB, Bb \end{array}}$$
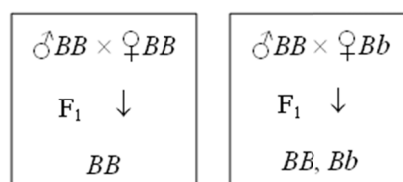
Figure 3. Two types of crosses to exclude slowly growing phenotype bb

One can see that applying this breeding scheme to pigs in breeding farms it is possible to eliminate *bb* phenotype from commercial farms. This is the way to decrease variation in weight between pigs in batches, and increase effectiveness of commercial farms.

It is important to note that this breeding scheme by no means is a substitution of a selection scheme in herds. However, the selection work should be redesigned since the difference in growth rate between *BB*, and *Bb* growth phenotypes is smaller compared with their differences to *bb* phenotype.

5. Conclusions

✓　In the pig, there are many factors that contribute to the rate of growth, though it is the animal's phenotype, which determines the trajectory of the growth rate.

✓　The study confirms the genetic determination of growth rate by phenotypes of two allelic gene *B*. In pigs, a distinction between the growth phenotypes become noticeable in weight of about 45 kg.

✓　Slowly growing pigs have phenotype *bb*. This phenotype has growth rate maximum in weight of about 45 kg.

✓　In batches with growing-finishing pigs a large amount of variation in weight brings about phenotype *bb*.

✓　In growing pigs, animals with phenotype *bb* have low growth rate. To eliminate this phenotype from commercial farms the following breading scheme was suggested: $BB \times BB$ and $BB \times Bb$.

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