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STUDY OF GENETIC AND ENVIRONMENTAL FACTORS, CHARACTERIZING THE FEED EFFICIENCY IN DUROC PIGS

A.A. BELOUS, A.A. SERMYAGIN, O.V. KOSTYUNINA, E.A. TREBUNSKIKH, N.A. ZINOVIEVA

Ernst Federal Science Center for Animal Husbandry, Federal Agency of Scientific Organizations, 60, pos. Dubrovitsy, Podolsk District, Moscow Province, 142132 Russia, e-mail belousa663@gmail.com, alex_sermyagin85@mail.ru, kostolan@yandex.ru, terramio7@mail.ru, n_zinovieva@mail.ru (✉ corresponding author)
ORCID:
Belous A.A. orcid.org/0000-0001-7533-4281
Sermyagin A.A. orcid.org/0000-0002-1799-6014
Kostyunina O.V. orcid.org/0000-0001-8206-3221
Trebunskikh E.A. orcid.org/0000-0002-5208-3376
Zinovieva N.A. orcid.org/0000-0003-4017-6863
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Abstract

Feed efficiency is the most important economically relevant factor in swine breeding. The values of daily feed intake (DFI) and feed conversion rate (the ratio of feed intake to the body weight gain for a certain period, FCR). A group of factors that can affect the feed efficiency is the feeding behavior. In this regard, it is relevant to study the genetic and environmental variability of a number of factors that affect the growth, feed efficiency, and ethological features of feed intake in Duroc pigs based on the automatic feeding station data records. The aim of our study was to select at test population the factors which can be associated with feed efficiency, including following traits: body weight (BW, kg), average daily gain (ADG, g), daily feed intake (DFI, g/day), time spent at the feeding station (TPD, min), the number of visits to the feeding station per day (NVD, times), feed intake per visit (FPV, g), feed rate (FR, g/min), and the time at the feeding station per visit (TPV, min). Three different approaches were applied to calculate the feed conversion rate: (1) the ratio of feed intake to the body weight gain for the whole feeding period (FCR_1); (2) the ratio of feed intake to the body weight for 10-day feeding periods (FCR_2); (3) the calculation based on daily data records taking into account the daily fluctuations of BW and DFI (FCR_3).The values of average daily gain (ADG_1, ADG_2, ADG_3) were calculated according to FCR_1, FCR_2, and FCR_3, respectively. The initial dataset of individual records included 99867 observations of each trait for 71 boars. After the evaluation of data for normal distribution and presence of at least 60 % of records, 60 boars were selected for the further analysis. The final dataset included 4138 daily values for every boar. The decomposition of phenotypic variability was performed using the analysis of variance without interaction. The analysis of variance parameters of genetic and environmental types and the evaluation of relationships between variables were based on REML method with a multi-variable model. Boars accessed the feeding station at the age of 74.2±1.0 days (*Cv* = 10.6 %), the age at the body weight of 100 kg was 149.9±1.0 days (*Cv* = 5.0 %). Average values of FCR differed depending on the calculation approach and ranged from 2.52 kg/kg to 3.08 kg/kg. The higher variability was observed for FCR_2 and FCR_3 — 23.2 % and 19.2%, respectively. The variability of feeding behavior (TPD, NVD, FPV, FR, and TPV) was 13.7 %, 27.4 %, 21.6 %, 17.7 %, and 21.8 %, respectively. The genetic ratio of parent boar was maximal for the following factors: FCR_2 (11.7 %), FCR_3 (15.4 %), TPD (28.2 %), and NVD (30.8 %). The heritability coefficient of FCR_3 was low (0.019), while the related variables of feeding behavior and body weight revealed more reliable results: h^2 = 0.134-0.368 and h^2 = 0.744. The higher level of genetic correlations were observed between FCR_3 and TPD (0.585), FR (-0.368), FPV (–0.274), and NVD (0.368). ADG_2 and FCR_2 were characterized by negative correlation. Our results can be used in the developing the breeding programs based on genetic and genomic evaluation of pigs for a number of traits.

Keywords: pig, Duroc breed, feed conversion, feeding behavior, body weight, average daily

gain, heritability, variability

Feed efficiency is the major aspect of the economic attractiveness of pork production. To assess this feature, indicators of daily feed intake (DFI) and feed conversion rate (FCR) as the ratio of feed consumed to body weight gain over a certain period of time are used. A positive correlation (*r* from 0.32 to 0.70) was established between DFI and average daily gain (ADG) [1]. Varying DFI may account for up to 59% of the ADG variability [2]. The variability of feed efficiency indicators is due to both external and internal factors. The external factors include the composition and energy nutrition of the feeds, management and climatic conditions. Internal factors are associated with various physiological processes (appetite regulation, intestinal absorption, nutrient availability, thermal regulation, muscle activity, etc.), as well as the status of anabolic and catabolic metabolism [3].

However, from the point of view of population genetic studies, indicators of feed efficiency are of interest in the context of factors of the pig feeding behavior. If you have information on the patterns of inheritance and variability of ethological characteristics, you can regulate the functional needs of animals using technological methods, based on the breed-specific features. The development of computerized feeding systems (feed stations, feedlots) enabled an automatic, high-precision daily individual accounting of not just feed consumption rate and weight gain, but also signs of feeding behavior [4]. This information opens up new horizons in investigating its characteristics in pigs in conjunction with feed efficiency indicators.

It is known that the efficiency of feed use and feeding behavior vary among different breeds of pigs [1, 5, 6]. If feed conversion by breed is relatively stable (there has been a steady decline over the past 15 years, due to extensive selection by this indicator and diet improvements), the values of feed behavior in different studies demonstrate a great inter- and intrabreed variability [7-9]. It has been established that indicators of feed conversion and feeding behavior are characterized by moderate and high degree of heritability [10-12], however, the use of the latter in breeding requires information about their relationships with signs of feed use. Although the conducted studies showed the presence of correlations between the above indicators, in most cases, the identified patterns were of breed and population-specific nature [1, 13, 14]. The studies previously performed on Russian populations of pigs were mainly aimed at identifying the relationship between feed conversion and other economically useful traits not taking into account their variability [15, 16]. Studies conducted on other types of farm animals show the prospects of including feed conversion in the characteristics of the meat and fattening qualities of the livestock [17, 18].

In the present study, for the first time in Russia, results were obtained that characterize the features of the feeding behavior of Durok young hogs in relation to the indicators of feed use at automatic feed stations.

Our goal was to investigate the impact of genetic and paratypical factors on the efficiency of feed use and the feeding behavior of pigs of the Russian reproduction.

Techniques. Studies were conducted from July 2017 to March 2018 (SGC, LLC selection and genetic center, Verkhnyaya Khava, Voronezh region). The accounts were performed using GENSTAR test feeding automatic stations (Cooperl, France). Animals received complete feed stuff PK-56-1 made according to GOST 21055-96 (Full-ration mixed feeding stuffs for bacon feeding of pigs) according to recipes SK-6, SK-7 and SK-52 (Verkhnekhavsky Elevator OJSC, Russia). The content of the main nutrient components in the diet varied over the follow-up within the limits allowed by the technical requirements of the standard, and was 12.61-13.59 MJ/kg of the metabolic energy, 14.16-16.77% of the mass fraction of crude protein, 3.83-4.49% of fiber, 0.81-1.14% of lysine, 0.51-0.73% of methionine and cystine, and 0.15-0.21% of tryptophan.

The population included 71 young Duroc hogs of the Russian-based reproduction. All animals were assigned with an individual identifier (electronic chip). Growing of animals at the stations was carried out in groups of 10-15 animals (in batches) at the age of 70 days (live weight of 29 to 33 kg). The duration of the control growing varied and ended at the age of 138 to 174 days. During the entire period of the control growing, we estimated the body weight (BW, kg), average daily feed intake (DFI, g/day) and indicators of feeding behavior, including the total time of visits to a feed station per day (TPD, min/day), number of daily feeder visits (NVD, units), average feed intake per visit (FPV, g), feeding rate (FR, g/min; FR = DFI/TPD), average duration of a visit (TPV, min; TPV = TPD/NVD). The abbreviations of terms correspond to generally accepted acronims in feed conversion, growth, and feed behavior [5].

Three approaches were used to evaluate the feed conversion rate (FCR, kg/kg). The first one involved the calculation of the indicator based on the initial and final live weight for the control growin and the amount of feed consumed:

$$\overline{\mathrm{FCR}_1} = \frac{\sum_{i=1}^{1} \mathrm{CR}_{i=n}}{(\mathrm{W}_n - \mathrm{W}_1)}, \quad (1)$$

where $\overline{\mathrm{FCR}_1}$ is the feed conversion for the entire growing period, $\sum_{i=1}^{1} \mathrm{CR}_{i=n}$ is the amount of feed consumed over n observations, starting with $i = 1$; $(\mathrm{W}_n - \mathrm{W}_1)$ is the gain in live weight during the growing period, W_n is the live weight at the end of the period, W_1 is the live weight at the beginning of the period.

The second approach was based on an estimate of the average values of body weight, its average daily gains and feed conversion obtained during 10-day periods:

$$\overline{\mathrm{FCR}_2} = \sum\left(\frac{\sum_{i=0}^{10} \mathrm{CR}_{i=0\,(i+1 \ldots i+10)}}{(\mathrm{W}_{i+10} - \mathrm{W}_{i+1})}\right)/\mathrm{t}\ , \quad (2)$$

where $\overline{\mathrm{FCR}_2}$ is an indicator of feed conversion by 10-day periods per animal; $\sum_{i=0}^{10} \mathrm{CR}_{i=0\,(i+1 \ldots i+10)}$ is the total feed intake by an animal over a 10-day period; W_{i+10} is the live weight of an animal on Day 10 of each 10-day period; W_{i+1} is the live weight of an animal on Day 1 of each 10-day period, i is a 10-day period step with $\mathrm{t} > 1$, t is the number of 10-day periods.

In the third case, the parameters of the daily assessment of the pig productivity were used along with adjustments of the feed conversion rate by negative values (correction for an average value of the positive variances), taking into account daily fluctuations in live weight and feed intake:

$$\overline{\mathrm{FCR}_3} = \sum_{i=1}^{i}\left(\frac{\mathrm{CR}_i}{\mathrm{W}_{i+1} - \mathrm{W}_i}\right)/i, \quad (3)$$

where $\overline{\mathrm{FCR}_3}$ is the daily feed conversion rate per animal, CR_i is the total daily feed intake, W_{i+1} is the live weight of the animal at the time of observation, W_i is the live weight of the animal at the previous observation, i is the observation number.

The calculation of average daily gains (ADG_1, ADG_2, ADG_3) was performed for FCR_1, FCR_2, FCR_3. To assess the growth rate of young hogs, the age of attaining a live weight of 100 kg (AGE_{100}, days) was determined.

The primary information on the control growing of young hogs was collected into electronic files, based on which a database was formed with elements of the logical control of input information, such as dates, repetitions, a lack of one of the estimated parameters. Initially, an array of 99867 entries was monitored for compliance with the law of normal distribution of the analyzed indicators (individual measurements). The detected outliers in the daily data for each animal, exceeding the threshold of a ±10.0% deviation from the previous value, were excluded from further processing. The analysis included only individual animals, the number of test values (based on the sum of the recorded values) in which was not lower than 60.0%. The final sample size consisted of 60 young hogs (descendants of 13 sires and 37 dams), with an average quality indicator for data collecting and recording at 91.2% (limits of 63.3 to 99.5%). The database included 4,138 daily average values for each parameter studied. When assessing the feed conversion rate, an analysis of the indicator variability magnitude was performed involving a sample size of seven 10-day periods from the beginning to the end of growing, which included 413 observations.

To assess the effects of genetic and environmental nature, an equation was chosen that is characterized by the least variance value of unaccounted factors (error variance) using the fixed-effects analysis of variance with no factor interaction. Then, the least square method (LSM) using STATISTICA 10 (StatSoft, Inc., USA) was used to calculate the average values of the estimates:

$$y = \mu + \text{Feeding Station}_i + \text{Batch}_k + \text{Age}_{l(1)} + \text{Sire}_j + e_{iklj}, \quad (4)$$

where y are indicators of feed conversion rate (DFI, TPD, NVD, FPV, FR, TPV, FCR, BW, ADG); μ is an average population constant; Feeding Station_i is an effect of the feeding station (i = 1 ... 3); Batch_k is an effect of the lot number of the control growing (k = 1 ... 4); Age_l is an effect of the initial age of the control growing (l = 1 ... 18) or in a similar model $\text{Age}_{l\ (1)}$ is an effect of the age of the animal for the entire period of the control growing ($l_{(1)}$ = 1 ... 102), Sire_j is a genetic effect of the a hog breeder (sires of the offspring being estimated) (j = 1 ... 13), e_{iklj} is a random error (unallocated variance).

The values of genetic and paratypical variantces of individual animals for obtaining selection and genetic parameters were calculated using a similar model through information on hogs' parents to construct an additive relationship matrix according to the restricted maximum likelihood approach (REML, n = 110 animals, including 60 with indicators of their own productivity):

$$y = \mu + \text{Test-day}_e + \text{Feeding Station}_i + \text{Batch}_k + \text{Age}_l b_1 + \text{Animal}_j + e_{eiklj}, \quad (5)$$

where Test-day_e is a fixed effect of observation during the entire period of the experiment (e = 1 ... 226); $\text{Age}_l b_1$ is the initial age of control growing, b_1 is a linear regression coefficient, Animal_j is a randomized effect of an animal, having a normal distribution with a mean at 0, and a variance at $A\sigma a^2$, where A is an additive relationship matrix (j = 1 ... 110), e_{eiklj} is a random error (unallocated variance).

Estimates of values by traits were calculated based on the least square method using STATISTICA 10 (StatSoft, Inc., USA). The reliability of the effect of organized groups of factors, included in the model, was determined based on the MANOVA method. When applying descriptive statistics (indicators of variance), as well as decomposition of phenotypic variability, generally accepted approaches [19] were used, BLUPF90 software family was used for analyzing variances and calculating correlations by a model for a number of interrelated features [20].

Results. The average age of the start of the test fattening-off using feed stations was 74.2±1.0 days (Cv = 10.6%). The young hogs adapted well, which enabled obtaining high average daily gains in body weight (950±19 g) (Fig. 1). The patterns of its increase over 10-day periods were uniform. The age of attaining a live weight of 100 kg averaged 149.9±1.0 days (Cv = 5.0%). Phenotypic variability remained within the biological limits, reaching a maximum of variance in the second and third ten-days of fattening, at 15.9 and 16.1%, respectively, and a minimum in the first (13.7%) and last (12.0%) periods.

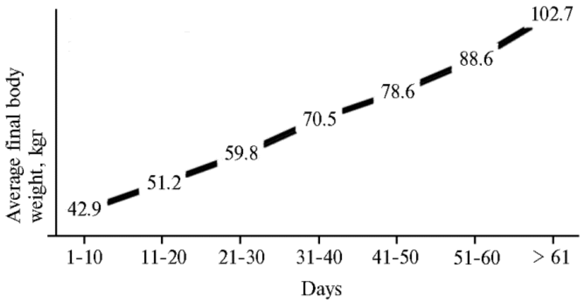

Fig. 1. Patterns of live weight gains in Duroc pigs (*Sus scrofa*) by periods of growing at feed stations (SGC, LLC selection and genetic center, Verkhnyaya Khava, Voronezh region, July 2017 to March 2018).

Among the parameters of feeding behavior, the lowest variability was recorded for the time spent at the feeding station (TPD, 85.3 min/day, C_v = 13.7%) (Table 1). The intermediate position was noted for the feed feeding rate (FR, 27.6 g/min), with *Cv* at 17.7%. For the average visit duration (TPV, 19.6 min) and the amount of feed consumed per visit (FPV, 499.1 g), the phenotypic variation was within 21.6 to 21.8%. The highest variability (*Cv* = 27.4%) was typical for the number of daily feed station visits (NVD, 5.2 units).

We used three different approaches to calculate feed conversion rates (FCR). Fluctuations in the live weight of pigs, caused by the impact of technological, paratypical factors, and by the state of animal health, can be significant. In the first version of the calculation (FCR_1), both high daily average gains and weight losses are disguised. The second method of calculation (FCR_2) is focused on determining the feed conversion rate by ten-day periods, which allows smoothing out fluctuations in the average daily changes in the live weight and more reliably estimate the very parameter. The third approach (FCR_3) suggests involving in the calculations the daily data on feed consumption and weight gains in pigs, taking into account positive values of the variability magnitude for feed conversion.

Parameters of the feed conversion rates, calculated using three above methods, were characterized by the different variability (Table 1). Indeed, in the FCR_2 and FCR_3 methods, the value of *Cv* was 23.2 and 19.2%, respectively, with means of 3.08 and 2.52 kg/kg. For FCR_1, a low degree of the value variation was found (12.3%), with its close mean at 2.55 kg/kg.

1. Parameters of feed use efficiency and feed behavior in a population of Duroc pigs (*Sus scrofa*) (SGC, LLC selection and genetic center, Verkhnyaya Khava, Voronezh region, July 2017 to March 2018)

Parameter	*M*±SEM	σ	*Cv*, %
AGE_{100}, days	149.9±1.0	7.5	5.0
ADG_1, g	950±19	150	15.8
ADG_2, g	892±21	162	18.2
ADG_3, g	986±24	187	19.0
DFI, g/day	2309.1±36.5	282.7	12.2
FCR_1, kd/kg	2.55±0.04	0.31	12.3
FCR_2, kd/kg	3.08±0.09	0.72	23.2
FCR_3, kd/kg	2.52±0.06	0.48	19.2
TPD, min/day	85.3±1.5	11.7	13.7
NVD, u.	5.2±0.2	1.4	27.4
FPV, g	499.1±13.9	107.6	21.6
FR, g/min	27.6±0.6	4.9	17.7
TPV, min	19.6±0.6	4.3	21.8

N o t e. The abbreviations correspond to generally accepted cuttings for indicators [5].

The impact of the genetic factor of the sire of the studied offspring for feed conversion parameters was within 4.5-15.4% of the total variance taken into account by the model (Table 2). For FCR_2 and FCR_3, the largest proportion of the sire effect was noted, with 11.7% and 15.4%, respectively, moreover, the model equation for FCR_3 had a reliable distribution of all components of variability by impact (F= 2.32; $p < 0.05$; R^2 = 73.3%). At the same time, no significant determination was established for FCR_2 (F = 1.47; R^2 = 63.5%). Of interest, for FCR_1, highly significant results were obtained (F = 4.57; $p < 0.001$), which explain up to 84.4% of the total phenotypic variability in the model. In other words, the linear dependence of the predicted (expected) results for feed conversion in the first method of the calculation compared to the observed ones is limited by strictly selected components of the dispersion at the minimum variance error.

2. Separation of the components of phenotypic variability (%) for a set of traits of feed conversion in fractions of genetic and environmental factors for a population of Duroc pigs (*Sus scrofa*) (SGC, LLC selection and genetic center, Verkhnyaya Khava, Voronezh region, July 2017 to March 2018)

Parameter	Component of variability						
	sire	feeding station	batch	age	e	R^2	F
			Growth indicators				
BW	8.2	0.5	3.4	13.2	18.3	81.7	3.77***
ADG_1	7.6	4.9	0.9	15.4	15.8	84.2	4.49***
ADG_2	9.0	4.9	0.5	13.9	25.5	74.5	2.46**
ADG_3	6.5	3.5	0.6	8.7	23.0	77.0	2.83**
			Feed efficiency indicators				
DFI	10.2	4.7	4.5	21.3	16.9	83.1	4.15*
FCR_1	4.5	0.2	2.1	12.7	15.6	84.4	4.57***
FCR_2	11.7	7.1	0.0	29.1	36.5	63.5	1.47
FCR_3	15.4	4.8	1.6	28.9	26.7	73.3	2.32*
			Feed behavior indicators я				
TPD	28.2	0.0	2.3	18.2	29.9	70.0	1.98***
NVD	30.8	4.4	0.7	6.2	26.7	73.3	2.32*
FPV	9.4	10.7	2.2	5.9	15.8	84.2	4.51***
FR	9.8	2.6	4.9	12.3	26.9	73.1	2.29*
TPV	9.4	5.6	0.2	13.8	36.8	63.2	1.45

N o t e. The abbreviations correspond to generally accepted cuttings for indicators [5]; e is the residual (unallocated) variance of the model, R^2 is the coefficient of determination, F is the Fisher test.
*, **, *** The contribution of the impact of the variability component on the parameter is statistically significant at $p < 0.05$, $p < 0.01$ and $p < 0.001$, respectively.

3. Population and genetic constants for parameters of feed use efficiency and feed behavior in a population of Duroc pigs (*Sus scrofa*) (SGC, LLC selection and genetic center, Verkhnyaya Khava, Voronezh region, July 2017 to March 2018)

Parameter	BW	DFI	FCR_3	TPD	NVD	FPV	FR	TPV
BW	0.744^c	0.565	-0.067	–0.233	0.037	0.000	0.588	–0.516
DFI	0.155	0.079^c	0.099	0.200	0.587	0.187	0.292	–0.017
FCR_3	–0.223	0.219	0.019^c	0.585	0.368	–0.274	–0.368	0.145
TPD	0.010	0.839	0.083	0.134^c	0.584	0.057	–0.138	0.133
NVD	0.163	0.370	0.017	0.242	0.218^c	–0.827	0.029	–0.629
FPV	0.012	0.037	0.086	–0.127	–0.393	0.258^c	0.145	0.577
FR	0.280	0.534	0.041	–0.696	–0.018	0.367	0.458^c	–0.226
TPV	–0.120	–0.402	0.045	0.484	–0.336	0.702	–0.678	0.368^c

N o t e. The abbreviations correspond to generally accepted cuttings for indicators [5]; c — diagonally are located the heritability coefficients h^2 (below the diagonal, there are genetic correlations, above the diagonal, there are paratypic correlations).

However, paratypical factors, such as the feeding station and the batch number of the control growing, had a minimal effect (0.0-7.1%) in all FCR variants. The exception was the age of putting for a test fattening-off: the high dependence of this factor seems to be related to the initial live weight of animals in groups at feeding stations. For FCR_3 compared with FCR_2 and FCR_1, a significant impact of the male parent genotype was shown, which was higher in its contribution than the compared indicators by 10.9 percentage points (pp) and 3.7 pp, respectively. It is fair to say that the database being accumulated will allow attracting seasonal fluctuations into an organized group of factors (the effect of the year, month and day of indicator monitoring).

The additive genetic group determines 6.5-9.0% effects of the average daily gains for ADG (1 ... 3) and the body weight of fattening hogs, with R^2 = 74.5 to 84.2% (F = 2.46-4.49; p <0.01...0.001).

The heritability of the feed conversion rate (FCR_3) is low (h^2 = 0.019), which, in our view, is due to the high proportion of daily (environmental) variation of the trait in the studied sample (Table 3). Moderate heritability coefficients were obtained, with FR 0.458, TPV 0.368, FPV 0.258, NVD 0.218. A low value was noted for TPD, such as 0.134. A high proportion of the genetic component was found for the indicator of body weight (h^2 = 0.744), which was generally typical for the traits of meat productivity in the special Duroc breed.

The correlations between feed behavior, feed conversion and live weight varied in their directions and were moderate in magnitude. In pigs, the live weight was mostly predetermined by the DFI values (r_g = 0.565) and FR (r_g = 0.588). An inverse genetic relationship is found for TPV (r_g = –0.516), that is, the choice of animals with a long stay at the feeding station per visit will not allow for effective selection by live weight. The choice based on FCR_3 will be more effective with the following parameters of animal feeding behavior taken into account: a shorter daily stay at the feeding station (TPD, r_g = 0.585), high feed intake per visit (FPV, r_g = –0.274) and a high feeding rate (FR, r_g = –0.368), a lower number of the feeding station visits per day (NVD, r_g = 0.368). In this regard, the development of a selection index, which takes into account a set of two factors, such as the feeding behavior and the feed conversion rate, is most preferable for the Duroc pig breeding program.

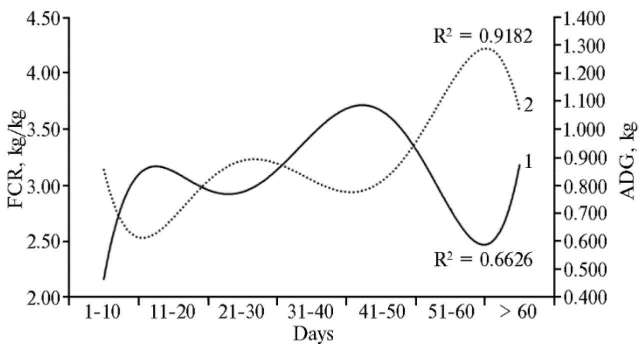

Fig. 2. Dependence of feed conversion rates (FCR_2, 1) **and average daily weight gains** (ADG_2, 2) **in a population of Duroc pigs (*Sus scrofa*) by control ten-days of growing** (SGC, LLC selection and genetic center, Verkhnyaya Khava, Voronezh region, July 2017 to March 2018).

An analysis of variations in the accounted indicators by 10-day cycles (Fig. 2) reveals a step-wise growth pattern: respectively, from 851±51 g for ADG_2 and 2.19±0.13 kg/kg for FCR_2 at the beginning of fattening-off (days 1 to 10) up to 1,072±41 g and 3.31±0.18 kg/kg at the end of the test (> day 61). The trend in the feed conversion rate (the fifth degree polynomial) was in a form of a sinusoidal curve, the change patterns of which was described with an accuracy by period R^2 = 66.3%. A similar distribution was obtained for the ADG_2 parameter trend (the fifth degree polynomial), which was inversely ("mirror-like") related to FCR_2 (r_p = –0.592). Consequently, high gains in live weight were provided with the best results if based on the feed conversion rate.

To smooth out the environmental effects (the feeding station and the batch number of the tested hogs), we obtained the least squares (LSM) estimates. The results (Fig. 3) are described using a third-order polynomial (according to the model equation, the forecast accuracy is R^2 = 73.5%). From the date of putting to the fattening-off and up to 100 days, a smooth increase in the feed conversion was observed due to the high rates of growth and development of animals. Further, during Days 100 to 140, the feed conversion value was stabilized and a so-called plateau was formed with a minimum variation (2.52-2.54 kg/kg). From the age of 140 days, there was a sharp increase in the trend curve, indicating a decrease in the efficiency of fattening-off of the pigs due to the fat deposition. The growth tempo and relative gains slowed down, indicating the completion of the physiological and biological growth phase in animals.

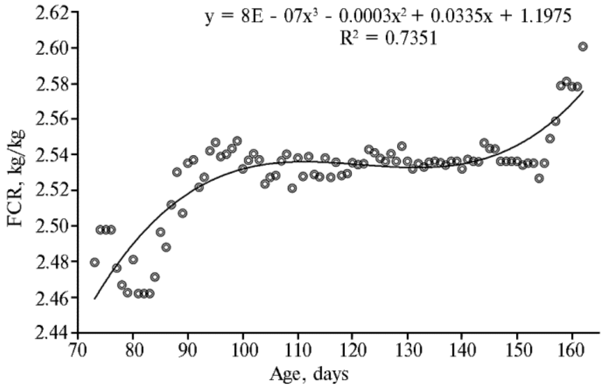

Fig. 3. Patterns of LSM (least square means) values of feed conversion rates (FCR_3) **depending on the age of the test fattening-off of Duroc pigs (*Sus scrofa*)** (SGC, LLC selection and genetic center, Verkhnyaya Khava, Voronezh region, July 2017 to March 2018).

Individual differences in the feed use efficiency and feeding behavior caused by genetic factors allow identification of valuable molecular biomarkers for predicting these traits, as well as their use in pig breeding [8, 9, 21]. In addition, observations related to feeding behavior can be used as a tool in automated monitoring systems to assess the health of animals and better detect diseases, in order to control management [8, 22, 23]. Our findings can be applied in the development of genomic selection programs, which are currently associated with genetic advances in livestock breeding [24, 25].

Therefore, in fattening pigs at automatic feeding stations, the impact of genetic factors determined 15.4% of the total variability by the feed conversion rate indicator, FCR_3, while for the parameters of feeding behavior, the additive variation was 28.2% (the total time spent at the feeding station per day, TPD) and 30.8% (the number of daily feeding station visits, NVD). The analysis of genetic correlations between traits demonstrates the promise of using the parameters of feeding behavior to increase the reliability of the feed conversion rate estimate. The pattern of changes in the feed conversion rate due to the age of animals tends to increase, despite the degree of fluctuations in average daily gains by fattening period. The use of a daily variation in the feed conversion rate (FCR_3) along with the conventional indicator estimate (FCR_1) will allow to more effectively choice of terminal hogs through engaging some selection parameters such as feeding behavior.

REFERENCES

1. Do D.N., Strathe A.B., Jensen J., Mark T., Kadarmideen H.N. Genetic parameters for different measures of feed efficiency and related traits in boars of three pig breeds. *J. Anim. Sci.*, 2013, 91(9): 4069-4079 (doi: 10.2527/jas.2012-6197).
2. Young R.J., Lawrence A.B. Feeding behaviour of pigs in groups monitored by a computerized feeding system. *Anim. Prod.*, 1994, 58(1): 145-152 (doi: 10.1017/S0003356100007182).
3. Maselyne J., Saeys W., Van Nuffel A. Review: Quantifying animal feeding behaviour with a focus on pigs. *Physiol. Behav.*, 2015, 138: 37-51 (doi: 10.1016/j.physbeh.2014.09.012).
4. Hyun Y., Ellis M. Effect of group size and feeder type on growth performance and feeding patterns in finishing pigs. *J. Anim. Sci.*, 2002, 80(3): 568-574 (doi: 10.2527/2002.803568x).
5. Baumung R., Gerhard G., William A., Söelkner J. Feed intake behaviour of different pig breeds during performance testing on station. *Arch. Tierz., Dummerstorf.*, 2006, 49(1): 77-88.
6. Lewis C.R.G., McGlone J.J. Modelling feeding behaviour, rate of feed passage and daily feeding cycles, as possible causes of fatigued pigs. *Animal*, 2008, 2(4): 600-605 (doi: 10.1017/S1751731108001766).
7. Rohrer G.A., Brown-Brandl T., Rempel L.A., Schneider J.F., Holl J. Genetic analysis of behavior traits in swine production. *Livest. Sci.*, 2013, 157(1): 28-37 (doi: 10.1016/j.livsci.2013.07.002).

8. Brown-Brandl T., Rohrer G., Eigenberg R. Analysis of feeding behavior of group housed growing—finishing pigs. *Comput. Electron. Agr.*, 2013, 96: 246-252 (doi: 10.1016/j.compag.2013.06.002).
9. Reyer H., Shirali M., Ponsuksili S., Murani E., Varley P.F., Jensen J., Wimmers K. Exploring the genetics of feed efficiency and feeding behaviour traits in a pig line highly selected for performance characteristics. *Mol. Genet. Genomics*, 2017, 292(5): 1001-1011 (doi: 10.1007/s00438-017-1325-1).
10. Herd R., Arthur P. Physiological basis for residual feed intake. *J. Anim. Sci.*, 2009, 87(Suppl. 14): E64-E71 (doi: 10.2527/jas.2008-1345).
11. Hall A.D., Hill W.G., Bampton P.R., Webb A.J. Genetic and phenotypic parameter estimates for feeding pattern and performance test traits in pigs. *Anim. Sci.*, 1999, 68: 43-48.
12. Chen C., Misztal I., Tsuruta S., Herring W., Holl J., Culbertson M. Influence of heritable social status on daily gain and feeding pattern in pigs. *J. Anim. Breed. Genet.*, 2010, 127(2): 107-112 (doi: 10.1111/j.1439-0388.2009.00828.x).
13. Morgan C.A., Emmans G.C., Tolkamp B.J., Kyriazakis I. Analysis of the feeding behavior of pigs using different models. *Physiol. Behav.*, 2000, 68(3): 395-403 (doi: 10.1016/S0031-9384(99)00195-X).
14. Rauw W.M., Soler J., Tibau J., Reixach J., Gomez Raya L. Feeding time and feeding rate and its relationship with feed intake, feed efficiency, growth rate, and rate of fat deposition in growing Duroc barrows. *J. Anim. Sci.*, 2006, 84(12): 3404-3409 (doi: 10.2527/jas.2006-209).
15. Tagirov Kh. Kh., Asaev E.R. *Izvestiya Orenburgskogo gosudarstvennogo agrarnogo universiteta*, 2007, 1: 118-120 (in Russ.).
16. Larina O.V., Aristov A.V., Kudinova N.A. *Vestnik Ryazanskogo gosudarstvennogo agrotekhnologicheskogo universiteta im. P.A. Kostycheva,* 2017, 2: 26-29 (in Russ.).
17. Gal'pern I.L., Dzholova M.N. *Genetika i razvedenie zhivotnykh*, 2015, 1: 30-34 (in Russ.).
18. Levakhin B.I., Azhmuldinov E.A., Titov M.G., Lasygina Yu.A., Ryabov N.I. *Vestnik Kurskoi gosudarstvennoi sel'skokhozyaistvennoi akademii*, 2015, 7: 145-146 (in Russ.).
19. Kuznetsov V.M. *Osnovy nauchnyh issledovanii v zhivotnovodstve* [Fundamentals of scientific research in animal husbandry]. Kirov, 2006 (in Russ.).
20. Misztal I., Tsuruta S., Strabel T., Auvray B., Druet T., Lee D.H. BLUPF90 and related programs (BGF90). *Proc. 7th World Congress on genetics applied to livestock production.* Montpellier, Communication No. 28-27, 2002, 28: 21-22.
21. Ding R., Yang M., Wang X., Quan J., Zhuang Z., Zhou S., Li S., Xu Z., Zheng E., Cai G., Liu D., Huang W., Yang J., Wu Z. Genetic architecture of feeding behavior and feed efficiency in a Duroc pig population. *Frontiers in Genetics*, 2018, 9: 220 (doi: 10.3389/fgene.2018.00220).
22. Weary D., Huzzey J., Von Keyserlingk M. Board-invited review: using behavior to predict and identify ill health in animals. *J. Anim. Sci.*, 2009, 87(2): 770-777 (doi: 10.2527/jas.2008-1297).
23. Cross A.J., Keel B.N., Brown-Brandl T.M., Cassady J.P., Rohrer G.A. Genome-wide association of changes in swine feeding behaviour due to heat stress. *Genet. Sel. Evol.*, 2018, 50: 11 (doi: 10.1186/s12711-018-0382-1).
24. Sermyagin A.A., Gladyr' E.A., Kharitonov S.N., Ermilov A.N., Strekozov N.I., Brem G., Zinov'eva N.A. Genome-wide association study for milk production and reproduction traits in Russian Holstein cattle population. *Agricultural Biology* [*Sel'skokhozyaistvennaya Biologiya*], 2016, 51(2): 182-193 (doi: 10.15389/agrobiology.2016.2.182eng).
25. Zinov'eva N.A., Sermyagin A.A., Kostyunina O.V. *Zhivotnovodstvo Rossii*, 2018, tematicheskii vypusk «Svinovodstvo»: 53-55 (in Russ.).