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FEEDING BEHAVIOR AS THE NEW BREEDING TRAITS IN PIGS

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Abstract

Pig selection by fattening, meat and reproductive qualities as the main breeding criteria has been implemented in breeding practice long time ago. However, the used productivity traits do not involve a number of important economic indicators, in particular feed efficiency and behavioral characteristics of animals. The selection response for such traits is expected to give an additional increase in the accuracy of the breeding value of young animals when used at large nucleus farms. Currently, the transition to mass testing of animals at automatic feeding stations is the most accurate method for evaluating feed conversion rate and related indicators of feeding behavior. In the presented work, opportunity to use values of residual feed consumption to increase individual's selection effectiveness with direct consideration of parameters of fodder behavior has been determined on the Russian population of pigs of the duroc breed. With the same growth intensity, there are animals, which use fodder energy differently. These differences genetically cause about 20% of variability, which confirms the significance of the indicator in tandem selection of pigs for simultaneous improvement of fodder behavior and feed conversion characteristics. This work aimed to study the genetic features of feeding behavior and growth traits of Duroc boars in relation to the residual feed intake (RFI) for use in the breeding process. The studies were carried out at Nucleus Farm TopGene for a population of 800 animals breeds of Duroc labeled with electronic chips. Individual records for feed intake were collected using automatic feeding stations. Additionally, parameters of feeding behavior, average daily gain (ADG), and feed conversion rate (FCR) were recorded. To eliminate the influence of growing factors on the studied traits, a regression analysis was performed to correct feed conversion rate, as well as the calculation of genetic and paratypical variances. The RFI values were obtained based on the difference between the actual and predicted average daily feed intake, considering the average metabolic weight, and the body weight gain of animals according to the multiple linear regression equation. The average values and heritability of the main breeding traits were as follows: feed conversion rate 2.20 kg/kg ($h^2 = 0.214$, for the adjusted value), average daily feed intake 2.51 kg ($h^2 = 0.221$), number of visits per day 7.9 units ($h^2 = 0.494$), feed intake per visit 0.37 kg ($h^2 = 0.284$), time spent in feeding per visit 11.3 min ($h^2 = 0.168$), feeding rate 35.4 g/min ($h^2 = 0.269$). For RFI, the ratio of genetic variation was $h^2 = 0.215$. According to the ratio of RFI and ADG, the groups of Duroc boars were selected for desirable negative or low RFI values of –254.9 and –276.2 g vs. +266.8 and +353.9 g for positive RFI. Individuals that showed high gains (1057 g per day) with reduced feed intake (2.34 kg/day) can serve as the basis for developing a specialized line of pigs (group I) capable of efficient using feed energy for body growth. Boars with positive RFI values significantly differed for FCR_{corr} (–0.15 and 0.24 kg/kg), back fat (–1.90 and –2.49 mm), muscle eye area (+4.57 and +6.10 cm^2); for feeding behavior, the differences were –2.8 and –8.0 minutes for time spent in feeding per day, +1.7 and +2.0 visits per day, and –2.7 and –4.2 minutes for time spent in feeding per visit. That is, the more frequent visits to feeding stations at less time spent in feeding per visit, the more efficient the use of feed. The estimation of breeding value showed the similar RFI pattern for the desired group of animals. The higher estimates for feed intake compensated the existing differences between the phenotype and genotype for the number of visits per day and feeding rate due to the identified genetic correlations with RFI, $r_g = 0.702$ and $r_g = 0.033$, respectively. Thus, the feeding behavior traits of pigs along with the residual feed intake (RFI) are genetically determined and can be used to improve pig populations for economically important and productive characteristics.

Keywords: pigs, Duroc breed, feeding behavior, feed conversion rate, RFI, fattening productivity, heritability, breeding value

Intensive pig breeding for a limited number of traits, practiced in recent decades, leads to the achievement of the so-called breeding plateau when the selection process cannot provide further genetic progress in improving the traits. New strategies in animal breeding are required to solve this problem. The authors consider the search and evaluation of breeding indicators related to economically significant traits directly or indirectly as one of the promising approaches [1]. The integration of additional indicators into breeding programs will improve the accuracy of the assessment of the breeding value of the animal by the economically important characteristics associated with them and, as a result, accelerate the genetic progress in breeding. The development of automated computerized systems (feed stations, or feedlots) made it possible to account for indicators of feeding behavior of pigs [2], such as time spent at the feeding station per day (time in the feeding station per test day, TPD), the amount of feed consumed per day (average daily feed intake, ADFI), the number of visits to the feeding station per day (NVD), the average duration of one visit (time in the feeding station per visit, TPV = TPD/NVD), average feed intake per visit (feed intake per visit, FPV), feed consumption rate (FR = DFI/TPD) [3]. These indicators are considered as additional features for inclusion in pig breeding programs and can become one of the elements of the management system in pig breeding.

The analysis of indicators of feeding behavior revealed the presence of breed-specific features [4], as a result of which Fernández et al. [5] suggested that an increase in feed efficiency could be achieved by developing specific feeding strategies for pig breeds based on the genetic conditioning of these traits. It was found that the feeding behavior was characterized by a moderate degree of heritability. The h^2 values depending on the breed (Yorkshire, Landrace, Duroc) were 0.44-0.51 for NVD, 0.48-0.56 for TPD, 0.55-0.59 for FR, 0.49-0.57 for FPV, and 0.47-0.51 for TPV [6]. In the work of Kavlak et al. [7], the heritability coefficients of feeding behavior ranged from 0.17 to 0.47, with ADFI values highly correlated with production traits. Variations of the heritability coefficient of the daily feed consumption indicator in Landrace pigs of the Dutch breeding depending on the growing period were revealed, i.e., from $h^2 = 0.53$ on day 5 to $h^2 = 0.24$ on day 95 of the control growing [8].

The use of feeding behavior traits in breeding programs requires knowledge of the genetic relationships between indicators. In this regard, the correlations between the traits in pigs of different breeds were studied. For example, Do et al. [6] in a large-scale study conducted on Yorkshire, Landrace, and Duroc pigs of Danish breeding showed an improvement in feed conversion rate (FCR) with an increase in ADFI (r_g = 0.43-0.74) and NVD (r_g = 0.39-0.50) and a decrease in FCR with an increase in TPV (r_g from –0.35 to –0.43) and FPV (r_g from –0.27 to –0.40). An increase in ADFI and, as a result, in average daily gain (ADG) was found with an increase in FR [6]. It is consistent with the data of de Haer et al. [3] and Rauw et al. [9] who previously established that pigs that consumed feed quickly were characterized by higher feed efficiency, increased growth intensity, and accumulate more fat. Andretta et al. [10] showed that the feed intake rate and the number of feed station visits per day were most closely related to productive qualities. In addition, the amount of feed consumed per day and the rate of feed consumption are negatively correlated with feed efficiency [10]. In recent studies of Carcò et al. [11], performed on hybrid young boars, the traits of feeding behavior were highly correlated with fattening productivity and indicators of carcass quality. Thus, ADFI was positively correlated with ADG, TPD was negatively correlated with ADG and positively correlated with FCR, FPV and ADG were directly correlated, FR had a strong association with ADG and ADFI.

The greatest interest is the use of indicators of feeding behavior to assess feed consumption efficiency. The traditional assessment is based on the determination of feed conversion rate as the ratio of the consumed feed (or dry matter consumed) to the increase in live weight over a certain time. In the authors' previous studies, the association of some feeding behavior traits with FCR was shown [12, 13]. However, when using this indicator in breeding, it is necessary to take into account its strong correlation with the amount of feed consumed and the average daily increase in live weight of the animal. In other words, two animals may have the same FCR values, but differ greatly in feed consumption and live weight gain. On the contrary, the same animal with different feed intake will be characterized by different FCR values, although the hereditary basis does not change.

An alternative indicator for assessing the feed consumption efficiency, which is widely used in different types of farm animals, including pigs, is the residual feed intake (RFI), or deviations from the predicted feed intake. In pigs, RFI can be calculated as the residual value of the feed consumption model equation, which includes the traits of growth rate (average daily gain) and fat depth as independent variables, and possibly the metabolic bodyweight of the animal [14-16]. In other words, this indicator can be defined as the difference between the actual feed intake and the expected feed requirements due to the need to maintain body weight and increase growth. Unlike FCR, the RFI indicator does not depend on the average daily weight gain; therefore, it serves to more accurately assess the feed consumption efficiency since it is based on the energy needs of the animal.

It was found that animals of different lines and selected for low RFI (LRFI) values had desirable indicators for fertility and lactation activity of sows, but worse values for fatness and a negative energy balance during lactation [17]. According to Colpoys et al. [18], young boars with LRFI were characterized by reduced behavioral reactivity when exposed to various stress factors, which allows better utilization of feed energy. For the preliminary selection of young animals by RFI, it is proposed to use the IGF-1 hormone as a physiological marker [19]. It was reported that direct selection by RFI was accompanied by changes in other traits, with the highest correlation between RFI and the content of IGF-1 in the blood, i.e., IGF-1 is genetically associated with fattening efficiency [19]. It is also shown that the diet, which differs from that used in the breeding of pigs with LRFI (high energy content and low fiber content), does not allow the maximum realization of the genetic potential of species according to RFI [20].

In this work, the possibility of using the residual feed consumption indicator to increase the selection efficiency with direct consideration of the feeding behavior parameters of species was established for the first time in the Russian population of Duroc pigs. With the same intensity of pig growing, some animals use feed energy in different ways. These differences genetically determine about 20% of the variability, which confirms the indicator significance in the tandem selection of pigs for the simultaneous improvement of the feed behavior and feed conversion characteristics.

The work objective was to study the genetic relationship of the feeding behavior traits with the feed consumption efficiency, estimated by the residual feed consumption indicator.

Methods. The studies were carried out based on the genetic and selection center Top Gen (Voronezh Region, Verkhnyaya Khava, 2017-2019) on 800 Duroc boars (*Sus scrofa*) labeled with electronic chips. The animals at the beginning of fattening aged 78 days, at the end 156 days. Boars were kept in groups of 15 animals in machines with slotted floors (floor area of 1.30 m^2/animal) at 18 °C, had unlimited access to feed and water. Individual feed consumption accounting was carried out using automatic feed stations MLP-RAP (Schauer Agrotronic AG, Switzerland) and GENSTAR (Cooperl, France).

The diets were the same for all groups of boars and varied depending on the fattening period, SK-52 in the first, SK-6 in the second, and SK-7 in the third (final) period. Composition of diets: SK-52 — dry matter (80%), metabolic energy (13.14%), crude protein (16.70%), crude fat (4.38%), crude fiber (4.39%), lysine (1.11%), methionine + cysteine (0.67%), calcium (0.55%), phosphorus (0.52%); SK-6 — dry matter (80%), metabolic energy (13.02%), crude protein (14.59%), crude fat (3.57%), crude fiber (4.12%), lysine (0.95%), methionine + cysteine (0.58%), calcium (0.55%), phosphorus (0.48%); SK-7 — dry matter (80%), metabolic energy (12.61%), crude protein (13.10%), crude fat (2.17%), crude fiber (4.49%), lysine (0.83 %), methionine + cysteine (0.51%), calcium (0.51%), and phosphorus (0.49%).

According to the results of quality control of individual and group (for all selection) parameters of feeding behavior for the normality of distribution (the minimum number of control records during the test is not less than 14, but not more than 144), 766 animals were selected for analysis with a total number of observations during the fattening periods of 49,577 with an average value of 64.7 records per 1 animal. The parameters of ADG (g), ADFI (g/day), TPD (min/day), NVD (units), FPV (g), FR (g/h), TPV (min), FCR (kg/kg), and RFI (g), BF, BF100 (fat depth above the 6-7 vertebra, absolute and reduced to a live weight of 100 kg, mm); LD, LD100 (muscle eye area, absolute and reduced to a live weight of 100 kg, cm) were studied.

The FCR values were calculated for each animal as the ratio of the amount of feed consumed to the live weight gain over the entire growing period. Taking into account the differences in the length of the growing period between groups, the following regression equation was used to obtain comparable feed conversion values, which was obtained using the STATISTICA 10 program:

$$FCR_{corr} = -4.2361 + 0.0890x_1 + 0.0922x_2 - 0.0841x_3 + 0.0057x_4, \quad (1)$$

where x_1 is the period of fattening at the automatic feeding station, day; x_2 is live weight at the start of fattening, kg; x_3 is live weight at the end of fattening, kg; x_4 is the average daily weight gain, g.

The calculation of genetic and paratypic correlations was performed using the REMLF90 program [21, 22] according to the following equation of the mixed model:

$$y = \mu + YM + DFSM + Party\ (Batch) + Period + b_1BW_{start} + animal + e, \quad (2)$$

where μ is population constant; YM is the year and month of birth of the animal, fixed effect; DFSM is start date × feed station × week, the fixed effect of the animal start at the feed station; Party (Batch) is evaluation batch at the feed station of animal groups, fixed effect; Period is duration of the animal evaluation, fixed effect; b_1BW_{start} is the start live weight, regression effect; animal is animal effect, randomized; e is a residual variance of the model.

The heritability coefficient was calculated based on the ratio of the additive genetic variance to the total phenotypic variability of the trait according to the variational components of the analysis:

$$h^2 = \frac{\sigma_a^2}{\sigma_a^2+\sigma_e^2}, \quad (3)$$

where σ^2_a is variance between groups of descendants, σ^2_e is variance within a group of descendants, or the residual variance.

The deviation from the predicted feed intake (RFI) was determined according to the approach by Cai et al. [23] and Ding et al. [24] based on multiple linear regression:

$$RFI = ADFI - (a + b_1 MWT^{0.75} + b_2 ADG),$$
$$RFI = ADFI - (888.00 + 40.33 \times MWT^{0.75} + 0.64 \times ADG) \quad (4)$$

where a is constant term of the linear equation; b_1 and b_2 are regression coefficients; $MWT^{0.75}$ is the average metabolic mass representing the active mass of the body tissues of the animal that need to be provided with energy $[(BW\_start + BW\_end)/2]^{0.75}$, kg; BW_start and BW_end are live weights at the beginning and the end of the test fattening, respectively; ADG is average daily gain, g.

Statistical processing was performed in Microsoft Excel. The average, minimum, and maximum values for the entire sample were obtained using descriptive statistics, and the variation coefficient was calculated using the formula:

$$Cv = \sigma/M \times 100, \quad (5)$$

where σ is standard deviation, M is mean value of the trait.

Results. The study of feeding behavior using automatic feeding stations is of interest for understanding the feeding efficiency and feed digestibility. In this research, the average live weight of boars before fattening was 35.7 kg, the fattening period was 78.1 days. The phenotypic variability (*Cv*) of feeding behavior and feed conversion within the closed pig population ranged from 14.5 to 40.5%, which indicates potential selection opportunities (Table 1). The variability of the actual feed conversion values was 25.4%, corrected value was 9.1%, while the average value of the indicator remained the same (2.20 kg/kg). For the RFI indicator, the variation coefficient was not calculated since the sum of the values was 0.

A comparative analysis of the authors' data with the results obtained by other authors showed the presence of breed-specific features. If the indicators of feed efficiency (average daily consumption and conversion) were relatively stable (there was a progressive decrease in feed conversion over the past 15 years, due to intensive selection and improvement of diets), then the indicators of feed behavior varied greatly (Table 2).

1. Characteristics of the phenotypic parameters of the studied selection of boars (*Sus scrofa*) of the Duroc breed (*n* = 766; genetic and selection center Top Gen, Voronezh Region, Verkhnyaya Khava, 2017-2019)

Indicator	*M*±SEM	SD	Min	Max	*Cv*, %
ADG	957±5	139	424	1508	14.5
ADFI	2.51±0.14	0.40	1.14	4.45	15.9
TPD	74.9±0.5	13.8	45.7	139.9	18.5
NVD	7.9±0.1	2.6	3.5	16.3	32.2
TPV	11.3±0.2	4.5	4.0	26.0	39.8
FR	35.4±0.3	8.5	16.6	74.5	24.1
FPV	0.372±0.005	0.151	0.145	0.799	40.5
FCR	2.20±0.02	0.56	0.40	5.70	25.4
FCR_{corr}	2.21±0.01	0.20	1.80	3.70	9.1
RFI	0.00±13.46	372	–1227	1964	–

N o t e. ADG — average daily live weight gain, g; ADFI — average daily feed intake, kg/day; TPD — average time spent at the feed station, min/day; NVD — number of feed station visits per day, units; FPV — amount of feed eaten per visit, kg; TPV — duration of food intake per visit, min; FR — feed consumption rate, g/min; FCR — feed conversion rate, kg/kg; FCR_{corr} — corrected feed conversion rate, kg/kg; RFI — deviation from the predicted feed consumption, g. Dash means that the indicator was not calculated.

In our study, the number of visits to feeding stations for Duroc boars was 1.4 times less than in pigs of the same breed [6], with approximately equal values of ADFI and FCR (the differences were 4.6-5.0%), while the duration of one visit was 1.3 times longer. In addition, Duroc pigs consumed 1.5 times more feed per visit, and FR was 15.6% higher compared to the same values set by Do et al. [6].

2. Feed consumption efficiency and feeding behavior of pigs (*Sus scrofa*) of different breeds, described in the literature, in comparison with the indicators obtained for the Duroc breed in this work (n = 766; genetic and selection center Top Gen, Voronezh Region, Verkhnyaya Khava, 2017-2019)

Indicator	Duroc (n = 766)	PIC L-26 × C-15 [25]		Large White [4]	Landrace [4]	Pietrain [4]	PIC C-22 [26]	Duroc (D) [6]	Landrace (L) [6]	Yorkshire (Y) [6]	Финальный гибрид (Y×D)×L [27]	Maxgro [28]
Sex	X	B	G	B	B	G	B and G	B and G	B and G	B and G	B and G	H
ADG, g	0.957±0.01	0.997	0.980	0.87±0.08	0.85±0.08	0.71±0.07	–	1.03±0.10	1.00±0.09	0.93±0.09	–	-
ADFI	2.51±0.14	3.19	2.88	2.21±0.19	2.28±0.20	1.70±0.14	–	2.40±0.38	2.38±0.38	2.15±0.35	–	2.73±0.32
NVD	7.90±0.09	11.8	11.8	–	–	–	5.6±0.61	11.07±5.25	8.81±4.36	18.19±10.88	13.12±3.99	4.29±0.90
FPV	0.37±0.06	0.302	0.272	–	–	–	–	0.25±0.09	0.31±0.11	0.15±0.01	–	0.64
TPV	11.3±0.2	9.5	8.9	–	–	–	11.3±1.1	8.58±3.40	9.36±3.67	4.44±2.36	5.35±1.61	14.44
FR	35.4±0.3	32.1	32.0	35.90±6.50	35.30±6.50	30.70±5.20	–	30.61±0.66	34.81±0.78	36.69±0.84	–	45.38±8.79
FCR	2.20±0.01	3.13	2.94	2.57±0.18	2.68±0.22	2.40±0.17	–	2.31±0.34	2.36±0.30	2.29±0.29	–	2.26±0.23

N o t e. B — barrows, G — gilts, H — hogs; ADG — average daily live weight gain, g; ADFI — average daily feed intake, kg/day; NVD — number of visits to feed station per day, units; FPV — amount of feed eaten per visit, kg; TPV — duration of feeding per visit, min; FR — feed consumption rate, g/min; FCR — feed conversion rate, kg/kg. Dash means that the indicator is not shown.

3. Genetic and paratypic correlations of feeding behavior and feed conversion in Duroc boars (*Sus scrofa*) (n = 766; genetic and selection center Top Gen, Voronezh Region, Verkhnyaya Khava, 2017-2019)

Indicator	ADFI	TPD	NVD	TPV	FR	FPV	FCR	FCR_{corr}	RFI
ADFI	0.221[c]	0.385	0.230	–0.001	0.375	0.327	0.372	–0.369	0.928
TPD	0.390	0.290[c]	0.148	0.582	–0.639	0.132	0.153	–0.202	0.355
NVD	0.641	0.536	0.494[c]	–0.597	0.030	–0.715	0.143	0.013	0.254
TPV	–0.307	0.286	–0.593	0.168[c]	–0.554	0.679	–0.063	–0.079	–0.016
FR	0.303	–0.760	–0.094	–0.501	0.269[c]	0.123	0.129	–0.086	0.358
FPV	–0.047	–0.465	–0.721	0.532	0.457	0.284[c]	0.007	–0.199	0.288
FCR	–0.062	0.454	0.147	0.115	–0.538	–0.462	0.058[c]	0.257	0.546
FCR_{corr}	–0.287	0.530	0.002	0.298	–0.772	–0.467	0.861	0.214[c]	–0.099
RFI	0.910	0.575	0.702	–0.281	0.033	–0.293	0.311	0.113	0.215[c]

N o t e. ADFI — average daily feed intake; TPD — time in the feeding station per day; NVD — number of visits to feed station per day; TPV — duration of food intake per visit; FR — feed consumption rate; FPV — amount of feed eaten per visit; FCR — feed conversion rate; FCR_{corr} — corrected feed conversion rate; RFI — residual feed intake (deviation from predicted feed intake). The heritability coefficients h^2 is along the diagonal marked with the upper index c, paratypical correlations are above the diagonal, and genetic correlations are under the diagonal.

The authors found moderate heritability for TPV (h^2 = 0.168), FCR_{corr} (h^2 = 0.214), RFI (h^2 = 0.215), and ADFI (h^2 = 0.221) (Table 3). The values of the heritability coefficients for FR, FPV, and TPD were higher and ranged from 0.269 to 0.290. The lowest genetic variance was found for the actual FCR (h^2 = 0.058), while the highest was found for the NVD (h^2 = 0.494).

The analysis of genetic correlations showed that the more often the animals visited the feeding stations, the longer they were there (r = 0.536), while the average duration of one visit decreased (r = –0.593), as well as FR (r = –0.760). In other words, the more often the animals visited the station, the less food they consumed per visit (r = –0.721). FCR increased with increasing duration of time at the station (r values 0.454 and 0.530) and decreased with increasing FR (r values –0.538 and –0.772), which was also associated with the digestibility and quality of feed. The influence of paratypic (environmental) factors on feeding behavior was noticeable in the relationship between the number of visits to the feeding station and the duration of one visit: the more often the animal visited the feedlot, the less time it was there (r = –0.597) and ate less food per visit (r = –0.715), which is also due to behavioral characteristics.

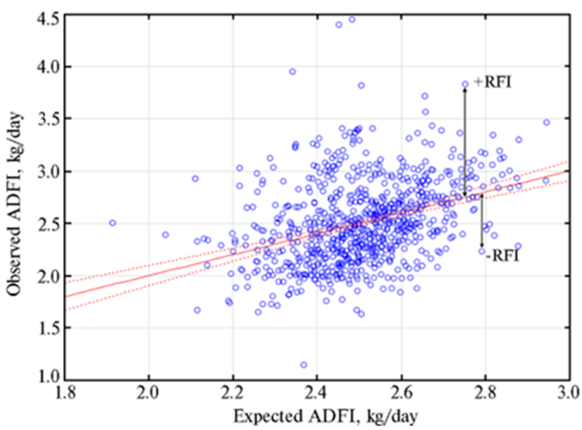

Fig. 1. Distribution of the initial and predicted values of the average daily feed intake (ADFI) by the Duroc boars (*Sus scrofa*) obtained by calculating the RFI based on multiple linear regression (genetic and center Top Gen, Voronezh Region, Verkhnyaya Khava, 2017-2019).

Figure 1 shows a graph of the initial and predicted ADFI values, the difference between which reflects the deviation from the predicted feed intake (RFI).

The effect of regression coefficients ($MWT^{0.75}$, ADG) on the value variable (ADFI) was significant at $p < 0.001$. Negative RFI values meant that the animals spent less feed energy on live weight gain and maintaining the body vital activity during the test period than predicted. On the contrary, a positive value of RFI indicated an excess of feed consumption or lower efficiency of its consumption for the needs of the body.

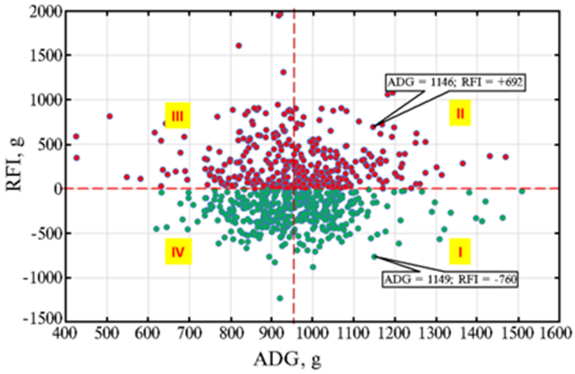

Fig. 2. Groups of boars (*Sus scrofa*) of the Duroc breed (I-IV) **distinguished by the ratio of phenotypic values of average daily gain** (ADG) **and deviations from the predicted feed consumption** (genetic and selection center Top Gen, Voronezh Region, Verkhnyaya Khava, 2017-2019).

Following the calculated values of RFI, ADFI, and ADG, groups of boars were identified with the most desirable RFI/ADG ratio (the groups I and IV with negative or low RFI values) and with the least desirable ratio (the groups II and III with positive or high RFI values) (Fig. 2).

The distribution of animals between groups I-IV was 25.3, 24.3, 22.1, and 28.3%, respectively. Therefore, group I, or about a quarter of the animals, could be selected as breeding replacement young that were successfully assessed on their productivity (high ADG values with reduced feed intake). Pigs of groups II, III, and partly IV with a low RFI value are recommended for use in commercial production (ranking).

4. Phenotypic indicators of fattening productivity and feeding behavior of Duroc boars (*Sus scrofa*) in groups, depending on the ratio of RFI (deviation from the predicted feed consumption) **and ADG** (average daily live weight gain) (genetic and selection center Top Gen, Voronezh Region, Verkhnyaya Khava, 2017-2019)

Indicator	Group I (*n* = 194)	Group II (*n* = 186)	Group III (*n* = 169)	Group IV (*n* = 217)
Fattening productivity				
RFI	–254.9±12.7	266.8±17.1$^{a)***}$	353.9±26.3$^{b)***}$	–276.2±12.0
ADG	1057±7$^{b)*** c)***}$	1069±7	844±8	864±5
ADFI	2.34±0.01$^{c)***}$	2.89±0.02$^{a)***}$	2.75±0.03$^{b)***}$	2.14±0.01
FCR	1.89±0.03	2.37±0.03$^{a)***}$	2.57±0.05$^{b)***}$	2.04±0.03$^{c)***}$
FCR_{corr}	2.12±0.01	2.10±0.01	2.36±0.02$^{b)***}$	2.27±0.01$^{c)***}$
BW_start	35.9±0.4$^{b)*}$	36.3±0.4	34.7±0.4	35.7±0.4
BW_end	114.8±0.7$^{b)*** c)***}$	118.7±0.8$^{a)***}$	103.5±0.8	103.4±0.6
BF	17.43±0.54$^{c)**}$	19.92±0.67$^{a)**}$	19.33±0.81^{t}	15.24±0.47
LD	79.95±1.21$^{b)* c)***}$	84.20±1.64$^{a)*}$	75.38±1.40	73.85±0.91
BF100	15.25±0.52	16.60±0.70	18.72±0.80$^{b)***}$	14.80±0.48
LD100	68.36±1.08	66.52±1.32	72.10±1.42$^{b)*}$	71.48±0.87$^{c)***}$
Period	75.0±0.7	77.3±0.7$^{a)*}$	81.9±0.7$^{b)***}$	78.5±0.6$^{c)***}$
Age_end_off	153.6±0.7	156.3±0.7$^{a)**}$	158.8±0.8$^{b)***}$	156.3±0.6$^{c)**}$
BWG	78.9±0.6$^{b)* c)***}$	82.4±0.8$^{a)***}$	68.8±0.8	67.8±0.6
FI_all	149.0±2.8$^{c)**}$	195.0±2.8$^{a)***}$	175.6±3.5$^{b)***}$	137.4±2.2
Feeding behavior				
TPD	72.3±0.8	75.1±0.9$^{a)*}$	80.3±1.2$^{b)***}$	72.9±0.9
NVD	8.9±0.2$^{a)*** b)***}$	7.2±0.2	6.9±0.2	8.5±0.2
TPV	9.5±0.3	12.2±0.3$^{a)***}$	13.7±0.4$^{b)***}$	10.2±0.3
FR	33.8±0.4$^{c)***}$	41.2±0.7$^{a)***}$	36.8±0.7$^{b)***}$	30.9±0.4
FPV	0.304±0.010	0.464±0.011$^{a)***}$	0.456±0.011$^{b)***}$	0.289±0.007

N o t e. The distribution of animals into groups is illustrated in Fig. 2. RFI — deviation from the predicted feed consumption (residual feed intake), g; ADG — average daily live weight gain, g; ADFI — average daily feed intake, kg/day; FCR — feed conversion, kg/kg; FCR_{corr} – corrected feed conversion, kg/kg; BW_start, BW_end – live weight at the start and the end of fattening, kg; BF, BF100 — fat depth over the 6-7-th vertebra, absolute and reduced to a live weight of 100 kg, mm; LD, LD100 — the muscle eye area, absolute and reduced to a live weight of 100 kg, cm^2; Period — the duration of fattening at the station, days; Age_end_off — the age of the animal at the end of fattening, days; BWG — the increase in live weight during the fattening period, kg; FI_all — feed consumption during the testing period at the station, kg; TPD — the average time spent at the feed station, min/day; NVD — the number of visits to the feed station per day, units; TPV — the duration of the meal per visit, min; FR — the feed consumption rate, g/min; FPV — the amount of feed eaten per visit, kg. The number of animals counted according to the characteristics of BF, BF100, LD, and LD100 in groups I-IV is 122, 112, 93, and 158, respectively.
*, **, *** Differences between groups ($^{a)}$ for I and II, $^{b)}$ for I and III, $^{c)}$ for I and IV) when comparing the average indicators are statistically significantat $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively, $^{t}p < 0.1$ (trend).

Boars of group I had significantly more favorable economic values of fattening productivity indicators compared to other groups (Table 4): for RFI +523.9 and +608.8 g (groups II and III, respectively, $p < 0.001$), for ADG +193 and +213 g (groups II and III, $p < 0.001$), for ADFI –0.41 and –0.55 kg/day (groups II and III, $p < 0.001$), for FCR –0.48, –0.68, and –0.15 kg/kg (groups II, III, and IV, $p < 0.001$), for FCR_{corr} –0.15 and –0.24 kg/kg (groups III and IV, $p < 0.001$), for BW_end +11.3 and +11.4 kg (groups III and IV, $p < 0.001$), for BF –1.90 and –2.49 mm (groups II and III, $p < 0.1$-0.01), for LD +4.57 and +6.10 cm^2 (groups III and IV, $p < 0.05$-0.001), for BWG +10.1 and +11.1 kg (groups III and IV, $p < 0.05$-0.001), and for FI_all –26.6 and –46.0 kg (groups II and III, $p < 0.001$). According to feeding behavior traits, the differences with other groups were –2.8 and –8.0 min/day for TPD (groups II and III, $p < 0.05$-0.001); +1.7 and +2.0 units for NVD (groups II and III, $p < 0.001$), and –2.7 and –4.2 min for TPV (groups II and III, $p < 0.001$). At the same time, the animals of group I were inferior to their herdmates from some groups in terms of BW_end (–3.9 kg, group II, $p < 0.001$), LD (–4.25 cm^2, group II, $p < 0.05$), BWG (–3.5 kg, group II, $p < 0.001$), FR (–3.0 and –7.4 g/min. groups II and III, $p < 0.001$), and FPV (–0.152 and –0.160 kg. groups II and III, $p < 0.001$).

The revealed differences between the groups indicated an optimal combination of qualitative characteristics of carcasses and economic indicators of cultivation in animals of group I. More frequent visits to feed stations with a shorter stay in it contributed to a more efficient consumption of the feed mixture. It is worth noting that the species of groups I and IV tended to minimize feed costs and did not significantly differ in terms of feeding behavior (except for the FR).

5. Genetic indicators of fattening productivity and feeding behavior of Duroc boars (*Sus scrofa*) in groups, depending on the ratio of RFI (deviation from the predicted feed consumption) **and ADG** (average daily live weight gain) (genetic and selection center Top Gen, Voronezh Region, Verkhnyaya Khava, 2017-2019)

Indicator	Group I (*n* = 194)	Group II (*n* = 186)	Group III (*n* = 169)	Group IV (*n* = 217)
		Fattening productivity		
RFI	–28.9±4.1	+14.1±4.3$^{a)***}$	+19.3±5.6$^{b)***}$	–28.5±4.4
ADFI	–12.0±5.0$^{c)***}$	+23.4±4.7$^{a)***}$	+7.25±5.9$^{b)***}$	–39.7±5.0
FCR	–0.029±0.002	–0.007±0.003$^{a)***}$	+0.021±0.004$^{b)***}$	+0.006±0.002$^{c)***}$
FCR_{corr}	–0.018±0.002	–0.007±0.002$^{a)***}$	+0.015±0.003$^{b)***}$	+0.010±0.002$^{c)***}$
		Feeding behavior		
TPD	–1.79±0.25	+0.12±0.25$^{a)***}$	+1.36±0.32$^{b)***}$	–0.50±0.27$^{c)***}$
NVD	–0.282±0.043	–0.001±0.041$^{a)***}$	+0.068±0.045$^{b)***}$	–0.252±0.046
TPV	–0.10±0.03	+0.03±0.04$^{a)***}$	+0.07±0.04$^{b)***}$	+0.16±0.03$^{c)***}$
FR	+0.67±0.11$^{a)*\ b)***\ c)***}$	+0.29±0.11	–0.54±0.14	–0.38±0.11
FPV	+11.46±1.11$^{a)***\ b)***\ c)***}$	+4.31±1.50	–3.70±1.62	+2.17±1.23

N o t e. ADG — average daily live weight gain, g; RFI — deviation from the predicted feed consumption (residual feed intake), g; ADFI — average daily feed intake, g/day; FCR — feed conversion rate, kg/kg; FCR_{corr} — feed conversion corrected for multiple regression, kg/kg; TPD — average time spent at the feed station, min/day; NVD — number of visits to the feed station per day, units; TPV — time of feed consumption per visit, min; FR — feed consumption rate, g/min; FPV — the amount of feed eaten per visit, kg.

*, **, *** Differences between groups ($^{a)}$ for I and II, $^{b)}$ for I and III, $^{c)}$ for I and IV) when comparing the average indicators are statistically significant at $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively.

Indicators of fattening productivity and feeding behavior in genetic terms (assessment of the breeding value of animals) had similar dynamics of change in groups (Table 5). The desired type of pigs according to RFI, ADFI, FCR, and FCR_{corr} was characterized by significantly more favorable values of fattening productivity and feed conversion. Feeding behavior traits showed a generally similar distribution, but since genetic correlations were taken into account, and the desired genotypes were evaluated by negative RFI values, a decrease of –0.283, –0.214, and +0.030 units was observed for NVD (groups II, III, and IV, $p < 0.001$), and significantly higher values were obtained for FR and FPV, by 0.38-1.21 g/min and 7.15-15.16 g (groups II, III, and IV, $p < 0.001$), respectively. Despite the differences between the phenotypic and genetic expression of some feeding behavior traits, the selection of boars according to the breeding value of traits that determine the feed consumption efficiency will allow obtaining animals with economically justified consumption (ADFI) and conversion (FCR) of feed, the 2.1-2.4 kg/day and 1.9-2.1 kg/kg, respectively. Tandem selection (the time spent at the feed station, the increase in FR, and the amount of feed consumed per visit) will increase the feed efficiency.

The results of this study are generally consistent with the published data. The ADFI of Duroc boars in our experiments was slightly higher (2.51 kg/day) than that noted by Do et al. (2.40 kg/day) [6], but in PIC L-26 × C-15 and Maxgro animals [25, 28], this indicator had the maximum values (2.88 and 3.19 kg/day in pigs and castrates PIC L-26 × C-15, respectively, and 2.73 kg/day in Maxgro boars). The number of visits to the feeding station per day, in all probability, depends on the technical characteristics but our results (7.90 units) occupied an intermediate position between the values for castrates and Landrace pigs (8.81 units) and PIC C-22 hybrids (5.6 units) [6, 26]. The amount of feed consumed per visit in our studies was the highest (0.37 kg) after that observed in Maxgro boars (0.64 g) [28]. The feeding time was 11.3 min which generally exceeded the average values for purebred animals. Let us note that the FCR value itself in this study had one of the lowest values compared to its analogs (see Table 2). It did not depend on how often the animals could visit the feeding station (the maximum for Yorkshire and the minimum for Maxgro) and how much time they spent eating feed. We believe that the feed consumption efficiency depends not only on the behavioral reactions of the animal but also on the proportion between the growing period duration and an animal age at the start and the end of fattening. Achieving the highest intensity of average daily live weight gains contributes to the production of early-maturing animals with good economic indicators of feed consumption efficiency.

Thus, the justification of the joint use of the feeding behavior traits and the feed consumption efficiency by the Duroc boars to increase the effectiveness of breeding has been proved. The heritability (h^2) of the studied economically valuable indicators varied from 0.168 to 0.494, which confirms the potential possibility of ranking and selecting species based on productivity characteristics. In an isolated Russian pig population, a new selection parameter for individual selection by both phenotype and breeding value (by deviation from the predicted feed consumption RFI) was studied. This indicator is significantly associated with the fattening productivity traits, which will allow getting pork with more expressed meat qualities, optimal fat depth, and muscle eye area. Feed conversion efficiency will be 1.89-2.04 kg/kg, and the feeding behavior of animals will ensure a rational loading of feed stations. The obtained results will be used in the work of the selection center to increase the intensity of breeding Duroc pigs to reproduce high-value genotypes and increase the economically significant productivity.

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