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Selection index for Duroc pigs based on average daily gain, feed conversion ratio, and intramuscular fat content

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Abstract:

This study was conducted to compare the genetic gain per sow per year of Duroc pigs in twelve scenarios. These scenarios were based on the number of traits used such as average daily gain (ADG), feed conversion ratio (FCR), intramuscular fat content (IMF) and were also based on the number of records of phenotype for these traits from the individual animal and its relatives. The values of all relevant genetic and economic parameters were selected from the literature and applied to the multiple trait (MT) index model to calculate the index selection accuracy and response per trait. The results showed that the economic value of FCR was much larger than the economic value of ADG and IMF. The selection response in units of ADG was higher when using phenotypes measured using ADG and FCR only while selection response per unit of IMF was the opposite. The economic weight of the response for IMF using three traits (ADG, FCR, and IMF) information was doubled when using ADG and FCR trait information. The standard deviation (SD) index and genetic gain per year when using information from the three traits were higher than those when using information from ADG and FCR. Within the same number of traits measured, the genetic gain per sow per year was highest at $568.05 when using information of the three traits from the individual animal's phenotype and their progeny. It was the lowest at $473.06 when using ADG and FCR information from only the animal itself.

Keywords: **average daily gain, Duroc pig, feed conversion ratio, intramuscular fat, selection index.**

Classification numbers: **3.1, 3.4**

1. Introduction

The pig industry is one of the main livestock in Vietnam with the world's fifth largest pig inventory and its pork production being the sixth highest on a global scale [1]. According to the General Statistics Office of Vietnam, in January 2021, there were 22,028 million pigs raised in Vietnam that produced 4,036 tons of meat [2]. Pig production accounted for 60% of total livestock output in Vietnam's economy [3]. It is a source of livelihood for approximately three million households of which 77% were smallholders [4]. Also, pork is the most important types of meat produced and consumed in Vietnam, representing 70% of total meat output.

Over the last two decades, Vietnamese pig breeders have focused on efficient lean meat production in pig-intensive systems [5]. As a result, current pig genetic types deposit less fat and are much leaner at market weight than traditional breeds. Because the genetic correlation between IMF and lean content is negative, the selection for increased lean efficiency has led to a decrease in IMF to levels below what is recommended. A.G.D. Vries, et al. (1994) [6] reported that when selection increases by 1% in lean meat, it would lead to a decrease of 0.07% in IMF. A study of L.P. Dai (2017) [7] indicated that IMF of pure breeds, hybrid breeds, local pig breeds, and exotics breeds in Vietnam were low. Pietrain breeds had the lowest IMF with 1.48%, followed by the Mong Cai breed (1.87%), Landrace (2.20%), Yorkshire (2.21%), and Duroc (2.98%). The IMF of commercial pig breeds in Vietnam ranged from 2.04 to 3.05% depending on the parenting breeds and the slaughter weights [7]. Those values of IMF of pig breeds in Vietnam were very low in comparison with other IMFs of other pigs on a global scale. In Europe, breeders select pork with greater than 3% of IMF [8-9] and in the United States, IMF in pork ranges from 3 to 4% [10]. In China, Japan, and South Korea, consumers require the IMF of pork to be greater than 5% [11]. Therefore, this prompted Vietnamese pig breeders to consider IMF as a breeding objective trait in their breeding program. In the pig breeding program, breeders also focus on increasing the lean growth rate,

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pork marbling, and reducing the FCR [12]. In other words, breeders try to address the question of how to simultaneously improve lean growth efficiency, IMF, and reduce FCR. To answer this question, the selection index for multiple traits is applied.

The breeding objective traits are ADG, FCR, and IMF. ADG is the average weight a pig gains in a day. ADG is one of the most important traits in production. ADG depends on the feed regimes and increases with an increase in energy intake and metabolizable energy intake. K.G. Santiago, et al. (2021) [13] found a high correlation, 0.8, between feed intake and ADG. FCR is a ratio of the efficiency with which the bodies of animals convert feed into the desired output. IMF is the amount of fat located throughout skeletal muscles. It is a major quality trait of meat affecting sensory attributes such as flavour and texture. IMF is directly related to the juiciness and tenderness of meat [14]. Pork with higher IMF tends to have better flavour, juiciness, and tenderness, resulting in higher overall acceptability [15].

In the early stage of breeding, breeders intentionally selected animals mainly based on the individual animal's phenotype performance to achieve a genetic gain for target traits [16]. After the best linear unbiased prediction was proposed by Henderson [17], breeders also used phenotypic and pedigree information of full/half-siblings, offspring, and relatives to select potential animals [18]. The covariance among full/half-siblings is assumed to be proportional to the pedigree relationship, but the relative may be further correlated because they share a common environment [19]. The information from the offspring was valuable due to it reflecting the true value of breeding value from their parents in a certain environment. However, recording phenotypic data from offspring was time consuming and cost intensive because evaluating offspring phenotypes was often expensive, and phenotyping can be only done when the offspring grow up [16]. Therefore, in the selection index, the breeders could consider different sources of information.

The objective of this study was to evaluate the genetic gain of Duroc pigs in twelve scenarios based on the three traits (ADG, IMF, and FCR) from different sources of information (individual animal's information or including its siblings, relatives, and offspring).

2. Materials and methods

2.1. Economic value

The breeding objective included ADG, FCR, and IMF. The mean and SD of these traits from literature review were summarized in Table 1. These studies were conducted in Duroc breeds. The average of ADG, FCR, and IMF were 919.68 (g/d), 2.69 (kg), and 3.23 (%). The average SDs of these traits were 121.43 (g/d), 0.29 (kg), and 1.45 (%), respectively.

Table 1. The mean and phenotypic SD of the three traits.

Authors	ADG (g/d)		FCR (kg)		IMF (%)	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
Y. Ramayo-Caldas, et al. (2019) [12]	890	110	3.16	0.31	5.23	2.06
L. Tusell, et al. (2016) [20]	938.5		2.29		1.14	
Y. Miar, et al. (2014) [21]	976.6	145	2.64	0.3	1.26	0.83
K. Suzuki, et al. (2005) [22]	873.6	109.3	2.65	0.27	4.25	1.46
Average	919.68	121.43	2.69	0.29	3.23	1.45

To calculate the economic value for ADG, FCR, and IMF traits, we modelled a production system and also used the parameter values for the production system as summarized in Table 2. D.D. Luc, et al. (2013) [23] reported that the number of Duroc pigs born alive was 9.0 piglet/litter. A recent study on reproductive traits of Duroc pig noted that the number born alive of this breed was 9.39 piglets/litter [24]. These studies on Duroc pigs were conducted in Vietnam. The Duroc pigs were fed with premixed pig food and raised on intensive farms in a closed house with tunnel ventilation. In this case study, we selected a value for the number of Duroc pigs born alive (NBA) to be 9.2 piglets. Days to slaughter (DS) is the age of a pig from birth to slaughter and it was 185 days. The sow index is the number of litters per sow per year. The sow index of the Duroc breed was much lower than Landrace and Yorkshire breeds [13]. In this study, we selected the sow index of the Duroc breed from the T.H. Son, et al. (2019) [24] study, which was 2.1.

Table 2. The constant values and prices for the production model.

Constants	
Number born alive (pig)	9.2
Days to slaughter (day)	185
Average daily feed intake (kg)	1.46
Survival rate from birth to slaughter (%)	85
SD of IMF (%)	1.45
Threshold of price for IMF (%)	3.5
Sow index (litter/sow/year)	2.1
Prices	
Pork price per kg when its IMF <=3.5% ($AUD)	4.38
Pork price per kg when its IMF >3.5% ($AUD)	4.06
Feed cost per kg ($AUD)	1.42
Annual cost per sow ($AUD)	40.00
Proportion below threshold (3.5%)	0.57

The principle of calculation of the profit: income = total profit - total cost. Firstly, we calculated the profit per pork and then calculate the profit/sow/year. The cost and benefit per pig and per sow per year were calculated in Excel version 2019. The income per pig is calculated as:

Income per pig = profit/pork - cost/pork

where profit per pork = body weight (BW) at slaughter x price/kg. The BW was calculated based on the ADG, FCR, DS, and average daily feed intake (ADFI). The price of pork depended on the proportion of IMF in the BW. This proportion could be different based on the actual value of IMF, which can be measured by the population. In this simulation, we used the NORMDIST function in Excel 2016 to calculate the proportion of IMF in a population and this proportion of IMF below the threshold was 0.57. It meant that in this population, 57% of Duroc pigs had an IMF equal to or lower than 3.5% and these pigs would be sold for $4.06 AUD/kg. The rest of the population, 43%, had an IMF greater than 3.5% and were sold at $4.38 AUD/kg.

The following equation:

Cost per pork = DS x ADFI x feed cost per kg

was based on the cost of the feed. Other costs such as housing, electricity, vaccines, and labour would be added to the annual cost per sow per year and in this case, it was assumed to be $40. Therefore, the equation of total income becomes:

Total net income per sow per year = income per pork x NBA x sow index x survival rate from birth to slaughter - annual cost per sow.

The economic values of three traits (ADG, FCR, and IMF) were calculated in the production model in the MTindex program of van der Werf (http://www.personal.une.au/~jvanderw). In the production model, the mean of those traits in Table 1 and constant values and prices in Table 2 were used to calculate the economic value. The economic value for a trait is defined as the change in profit as that trait was an increase of one unit while all other traits were unchanged.

2.2. Heritability

The heritability of ADG, FCR, and IFM traits for Duroc pigs were selected from the literature review and are summarized in Table 3. The heritability for those traits varies from the studies. The average heritability for ADG was 0.33, and it varied from 0.15 to 0.43. The average heritability of FCR and IMF were 0.19 and 0.34, respectively. The heritability for ADG and IMF were moderate while the heritability for FCR was low.

Table 3. Heritability of ADG, FCR, and IFM for Duroc pigs.

Authors	ADG	FCR	IMF
M. Alam, et al. (2021) [25]	0.36		
H.E. Willson, et al. (2020) [26]	0.33		
O.F. Christensen, et al. (2019) [27]	0.15	0.1	
Y. Miar, et al. (2014) [21]	0.3	0.2	0.26
K. Suzuki, et al. (2005) [22]	0.47		0.39
X. Fernandez, et al. (1999) [15]	0.43		0.38
S. Hermesch 1996 [28]	0.27	0.26	
Average	**0.33**	**0.19**	**0.34**

Index calculations were performed using the MTindex program of van der Werf (http://www.personal.une.au/~jvanderw). The component for MTindex was described in Table 4.

Table 4. The parameters needed for MTindex for ADG, FCR, and IMF.

Trait	Name	Units	Phenotypic SD	Heritability	Economic value
1	ADG	g/d	121.43	0.33	7.49
2	FCR	kg	0.29	0.19	-1866.73
3	IMF	%	1.45	0.34	136.74

There are phenotypic and genetic correlations between traits, which can be a positive or negative correlation. Phenotypic correlation is a term that indicates an association between animals with high values of one trait to those that have high or low values for other traits. An association between two traits can be caused by a gene that affects both traits simultaneously and is called a genetic correlation. These correlations are very important to animal breeders. The genetic correlation between traits is presented in Table 5.

Table 5. Phenotypic and genetic correlation between ADG, FCR, and IMF.

	Phenotypic correlation		Genetic correlation	
	FCR	*IMF*	*FCR*	*IMF*
ADG				
Y. Ramayo-Caldas, et al. (2019) [12]	-0.276	0.205	-0.261	0.402
Y. Miar, et al. (2014) [21]	0.31	0.32	-0.19	0.69
M. Bergamaschi, et al. (2020) [29]			-0.21	0.24
K. Suzuki, et al. (2005) [22]		0.06		0.25
X. Fernandez, et al. (1999) [15]				-0.19
S. Hermesch (1996) [28]			-0.2	
Average	**0.017**	**0.195**	**-0.215**	**0.278**
FCR				
Y. Ramayo-Caldas, et al. (2019) [12]		0.138		0.162
M. Bergamaschi, et al. (2020) [29]				-0.14
K. Suzuki, et al. (2005) [22]				0.21
Average		**0.138**		**0.077**

The average phenotypic correlation between ADG with FCR was 0.017. This correlation was negative in the study of Y. Ramayo-Caldas, et al. (2019) [12], but it was strongly positive in the study of Y. Miar, et al. (2014) [21]. The average phenotypic correlation between ADG and IMF was 0.195 and the phenotypic correlation between FCR and IMF was 0.138. The average genetic correlation values were positive between IMF with ADG (0.278) and FCR (0.077). The genetic correlation between ADG and FCR was negative in all studies with an average value of -0.215.

2.3. Selection intensity

It was assumed that the genetic gain was measured for a nucleus farm with 400 Duroc sows. The survival rate and NBA were based on Table 2. The mating ratio was one boar to twenty sows.

The number of piglets per litter for this farm was 400x9.2x0.85=3128 pigs. Assume that the sex ratio was 1:1. Then, the number of weaned males and females was 1564 (pig).

The proportion of males (need 39.1 boars per year, rounding down to 39 boars) was determined as 39/1564x100%=2.49% => i_m=1.96.

The proportion of females (need 50%) was calculated as 170/1564x100%=10.87% => i_f=1.254.

2.4. General interval

Assume that boars are used for the first time at age 13 months, then L_m=13/12=1.083.

The first litter of sows occurred at the age of 18 months, then L_f=18/12=1.5.

2.5. The genetic gain

$$R = \frac{i_m + i_f}{L_m + L_f} \text{ x } {}^{\delta}i = \frac{1.96 + 1.254}{1.083 + 1.5} \text{ x } {}^{\delta}i = 1.244 \text{ x } {}^{\delta}i$$

2.6. The scenarios

Twelve scenarios were based on the number of traits measured and the number of records from different sources. The IMF was a trait that was hard to measure, and it was only measured late in the lifespan (at the slaughter time or on the carcass). Scenarios 1, 3, 5, 7, 9, and 11 were based on two traits measured, which were ADG and FCR. The other scenarios were based on the three traits measured. Scenarios 1 and 2 were based on the individual animal's records. In Scenarios 3 through 12, we used information from the breeders' individual animal records combined with other information resources, which are described in Table 6.

Table 6. Twelve scenarios based on the traits measured and the information sources.

Scenarios	Trait measured	Number of records				
		Indiv.	*Sire*	*Full sibs.*	*Half sibs.*	*Progeny*
1	ADG + FCR	1				
2	ADG + FCR + IMF	1				
3	ADG + FCR	1	1			
4	ADG + FCR + IMF	1	1			
5	ADG + FCR	1		4		
6	ADG + FCR + IMF	1		4		
7	ADG + FCR	1			40	
8	ADG + FCR + IMF	1			40	
9	ADG + FCR	1				4
10	ADG + FCR + IMF	1				4
11	ADG + FCR	1	1	1	1	1
12	ADG + FCR + IMF	1	1	1	1	1

Based on the NBA and the survival rate in Table 2, we assumed that 50% of the animals, which was 4, were tested. Therefore, the number of animals that were used in Scenarios 5, 6, 9, and 10 was 4. In Scenarios 7 and 8, we used 40 half-siblings.

3. Results and discussion

3.1. The economic value

The economic value of this study is presented in Table 7.

Table 7. The economic value achievement per sow per year when increased one unit by selection.

Traits	Units	Economic value ($)
ADG	g/d	7.49
FCR	kg	-1866.73
IMF	%	136.74

There was a difference in economic value for each trait when increasing one unit of the selection. The highest economic value was found in the IMF trait after an increase of 1%, reaching $136.74. The economic value of ADG trait was $7.49. The FCR had the lowest economic value, at minus $1866.73.

The economic values of FCR were dominant in the other traits in this study. An increase of 1 unit of FCR was equal to an increase of 37.2% of the mean FCR. This trait is the average kg of feed per weight. In addition, the cost of the feed made up to 70% of the profit. Therefore, increasing 1 unit of FCR in the selection led to a big weight of economic value for this trait. Meanwhile, increasing 1 unit of ADG accounted for only a 0.1% raise of the mean of this trait. This means that an increase of 1 unit in ADG trait did not significantly change the economic value in comparison with the FCR trait. The IMF trait was only influencing the price of the pork at slaughter.

The three traits ADG, FCR, and IMF have been proposed as a selection index in Thuy Phuong Pig Research and Development Centre (Ha Noi, Vietnam) for the Duroc breed. This breed was mainly used as the terminal sire [22]. The breed had a high growth rate, but the FCR index was high in comparison with the Landrace and Yorkshire breeds. These three traits have a high economic value that is directly related to feed cost and profit. The FCR trait affected the total feed that a pig consumed during its lifespan. The higher the value of FCR, the higher the cost of feed. The IMF was a direct measurement of the lean meat content. Pork with higher IMF tends to have better flavour, juiciness, and tenderness, resulting in higher overall acceptability [27]. Therefore, the most sensible step to start this research was to examine the changes in response if the newly derived economic values were placed in this index. The results demonstrated that the economic value of FCR was dominant in ADG and IFM.

3.2. Response to selection per unit

The selection response per unit of the three traits ADG, FCR, and IMF in different scenarios are described in Table 8.

Table 8. The selection response per unit of ADG, FCR, and IMF in twelve scenarios.

Scenarios	ADG (g/d)	FCR (kg)	IMF (%)
1	39.57	-0.04	0.11
2	39.47	-0.04	0.23
3	41.62	-0.04	0.12
4	41.47	-0.04	0.24
5	44.98	-0.04	0.13
6	44.7	-0.04	0.25
7	44.13	-0.04	0.12
8	43.84	-0.04	0.24
9	46.17	-0.04	0.13
10	45.88	-0.04	0.25
11	69.12	-0.04	0.13
12	45.83	-0.04	0.25

In the twelve scenarios, the selection response per unit was different in ADG and IMF traits while the selection response per unit of FCR was unchanged. The selection response per unit of ADG was the lowest in Scenario 2 where selection response was measured based on information of individual animal's phenotype of ADG, FCR, and IMF. The highest value of selection response per unit of ADG was found in Scenario 11, where the selection response was measured for ADG and FCR based on all sources of information. Meanwhile, the selection response per unit of IMF ranged from 0.11 to 0.25. However, in twelve scenarios, the selection response per unit of FCR was unchanged whereas this selection response was measured based on the phenotype from individual animal's records or from the relative record of two traits (ADG, and FCR) or calculated based on three traits (ADG, FCR, and IMF). The value of selection response per unit of FCR was -0.04. In the breeding program, the target of the producers was increasing ADG and IMF, while decreasing the FCR.

Within the same source of information, the selection response per unit of ADG based on two traits (ADG and FCR) was higher than this index when it was calculated based on information of three traits (ADG, FCR, and IMF). For example, the selection response per unit of ADG using information from two traits in Scenario 5 was 0.28 (g/d) higher than this response in Scenario 6. The difference in selection response per unit of ADG traits based on two traits went from 0.1 to 23.29 g/d, higher than this selection response based on three traits. In contrast, the selection response per unit of IMF trait was higher when the phenotype of IMF recordings was used. On average, the selection response per unit of IMF when using phenotype measured of three traits (ADG, FCR, and IMF) in different information sources was 0.12% higher than those only based on two traits (ADG and FCR). In the same number of records, the selection response per unit of ADG was higher when using phenotypes measured from ADG and FCR while the selection response per unit of IMF was better when IMF was used in the MTindex model.

When using the trait measure ADG and FCR, the selection response per unit of ADG was different depending on the information source. The selection response per unit of ADG was the lowest (39.57 g/d) in Scenario 1 when using only the phenotype of the animal and it was the highest in Scenario 11 (69.12 g/d) when using information from all relatives such as sire, full-sibling, half-sibling, and progeny. Within the same number of records (5 records), the selection response per unit of ADG using just the animal and all relatives (Scenario 11) was higher than this response using the information of itself and from progeny (Scenario 9). The selection response per unit of ADG based on the information about itself and progeny (Scenario 9) was 1.19 g/d higher than this response based on information about itself and full siblings (Scenario 5) even though the number of records was similar. The selection response per unit of ADG using information from full siblings (Scenario 5) was slightly higher than the response based on ten times the number of records containing half-sibling information (Scenario 7). Therefore, within the same number of traits were measured, the selection response per unit was highest to lowest when using information from all relatives, progeny, full-siblings, half-siblings, sire, and just the single animal's data.

3.3. Response to selection by dollar value

The response for ADG, FCR, and IMF by economic value was different (Table 9). The economic value for ADG ranged from $295.65 (Scenario 2) to $345.79 (Scenario 11). The economic value for FCR was the lowest in Scenario 2 with $65.75 and the highest was found in Scenario 11 with $81.25. On average, the economic value of ADG was 4.33 times greater than the economic value of FCR and 14.56 times greater than the economic value of IMF. The economic value of FCR was an average of 3.38 times greater than the economic value of IMF. The reason was that the profit achievement was illustrated by the price of pork, which depends on the proportion of IMF in the carcass. Pork with IMF greater than the threshold of 3.5% was sold at 5000 VND (equal to $0.3125) per kg higher than pork with an IMF lower than the threshold. The response in economic value for ADG was the highest and was the lowest for IMF in all scenarios.

Table 9. The selection response of ADG, FCR, and IMF in twelve scenarios by dollar value.

Scenarios	ADG	FCR	IMF	SD index
1	296.35	68.48	15.44	380.27
2	295.65	65.75	31.10	392.50
3	311.75	72.41	16.22	400.38
4	310.58	69.65	32.20	412.43
5	336.87	79.24	17.45	433.57
6	334.79	76.53	33.67	444.99
7	330.52	78.6	17.07	426.19
8	328.34	76.13	32.66	437.13
9	345.79	81.24	17.92	444.96
10	343.61	78.45	34.57	456.63
11	345.46	81.25	17.90	444.62
12	343.25	78.48	34.47	456.20

The economic value of ADG (Fig. 1) had a similar trend as response per unit of ADG. Within the same number of records and from different sources of information, the economic value of ADG based on two traits (ADG, and FCR) was higher than the economic value of this trait based on information from three traits (ADG, FCR, and IMF). The economic values of ADG in Scenarios 1, 3, 5, 7, 9, and 11 were higher than the economic value of ADG in Scenarios 2, 4, 6, 8, 10, and 12, respectively. The economic value of ADG in Scenario 1, for instance, was $0.70 higher than in Scenario 2. The difference in economic value of ADG using two traits rose from 0.70 to $2.21 when the economic value of ADG was calculated using three traits. The economic weight for FCR (Fig. 2) had a similar trend with the economic weight of ADG, and the economic weight of FCR based on three traits measured was lower than the calculation based on two traits. The variation in economic value of the FCR trait in all scenarios was smaller than those of ADG. This difference varied between scenarios for FCR traits, ranging from 2.47 to $2.79. The economic values of ADG and FCR were higher when using information from measured ADG and FCR.

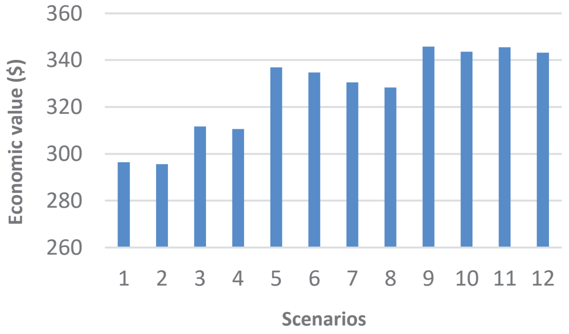

Fig. 1. Economic value ($) of ADG for Duroc pigs in twelve scenarios.

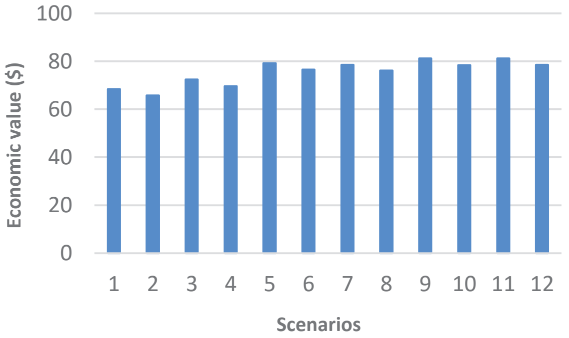

Fig. 2. Economic value ($) of FCR for Duroc pigs in twelve scenarios.

Using information from two traits, ADG and FCR, the economic value of IMF was lower than its value when including the information from IMF in the model (Fig. 3). The economic value of IMF using the three traits was almost double its value when using information from two traits (ADG, and FCR). For example, using the information of the individual animal's phenotype, the economic value of IMF in Scenario 2 was $31.10, which is double the $15.44 in Scenario 1. The economic value of IMF based on three traits measured varied from 31.10 to $34.57, and the economic value of IMF based on two traits measured (ADG, FCR) ranged from 15.44 to $17.92.

The SD index was different among scenarios (Fig. 4). The SD was the total economic value of each trait involved in multiple trait selection. The SD index in this case study varied from 380.27 to $456.63. Scenario 10 had the highest SD index, followed by Scenario 12, and the lowest in Scenario 1.

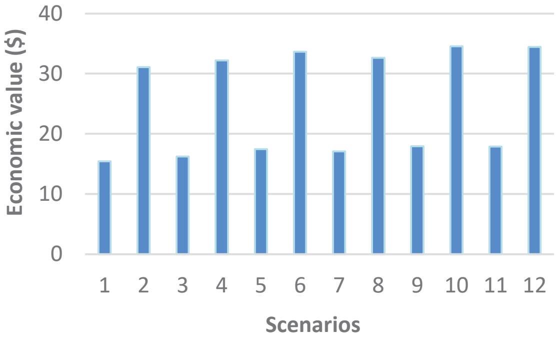

Fig. 3. Economic value ($) of IMF for Duroc pigs in twelve scenarios.

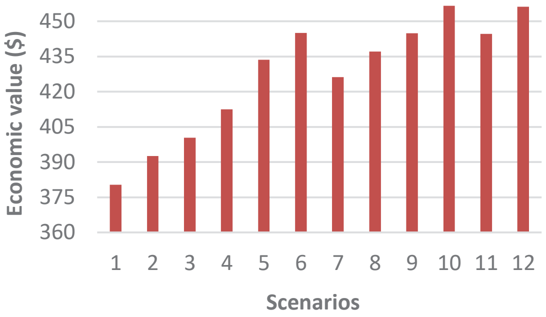

Fig. 4. SD indexes for Duroc pigs based on ADG, FCR, and IMF in twelve scenarios.

Within the same number of records and the same source of information, the SD index calculated based on ADG, FCR, and IMF was higher than the index calculated based on ADG and FCR. Using information from the single animal and all relatives, the SD index based on three traits (Scenario 12) was $11.58 higher than the index based on ADG and FCR (Scenario 11). The SD index based on ADG and FCR was lower (ranged from $10.94 to $12.23) than the index based on three traits. Therefore, the information from three traits gave a higher SD index than only two traits (ADG, FCR).

In the six scenarios (2, 4, 6, 8, 10, and 12) using information from three traits, different sources of information lead to differing SD indexes. Using information from their animal record combined with four records from their progeny (Scenario 10) produced the highest SD index. Using information from all relatives and animal records (Scenario 12), the index was $0.43 lower than that of Scenario 10. However, the SD index in Scenario 12 was $11.21 higher than the index in Scenario 6 using the information from full siblings and the animal itself.

3.4. The genetic gain per sow per year

The accuracy and genetic gain per year of Duroc pigs differed among the scenarios (Table 10). The genetic gain per sow per year of Duroc pigs varied from $473.06 to $568.05. Similar to the SD index, the genetic gain per year of Duroc sows was highest in Scenario 10, followed by Scenario 12, and the lowest occurred in Scenario 1. Scenario 10 had the highest accuracy with a value of 0.7, which was also the case for Scenario 12. Therefore, Scenarios 10 and 12 are the best options for producers and breeders.

Table 10. The accuracy and genetic gain per year of twelve scenarios.

Scenarios	Accuracy	Genetic gain per year ($)
1	0.58	473.06
2	0.60	488.27
3	0.61	498.07
4	0.63	513.07
5	0.67	539.35
6	0.68	553.57
7	0.65	530.18
8	0.67	543.79
9	0.68	553.53
10	0.70	568.05
11	0.68	553.10
12	0.70	567.51

The genetic gain depends on the number of traits involved in the multiple indexes and the correlation between these traits. J. Daigle, et al. (2010) [30] reported the multiple traits used in the Canadian Duroc population were growth rate, FCR, lean depth, loin eye area, and IMF. In this study, the genetic gain of IMF per year for Duroc pigs was 0.27%. C.R. Schwab, et al. (2010) [31] reported that IMF had a strong genetic relationship with BF and the loin eye area. Direct genetic response in the measure of IMF corresponded to a significant decrease in EBV for loin muscle area (with a decrease of 0.9 cm^2 per generation) and an increase of 0.98 mm EBV for backfat thickness in Duroc pigs. In addition, genetic responses in ADG and backfat were favourable. M.

Alam, et al. (2021) [25] reported that, after two decades (from 2000 to 2020), Korean Duroc pigs had significant improvement in both traits (ADG and age at 105 kg body weight) from which the estimated breeding value of ADG increased from -5.23g (2000) to 45.16g (2020) and age at 105 kg body weight decreased to 10.07 days between 2000 and 2020. Improvements of genetics for ADG and BF traits were also reported by J.S. Fix, et al. (2007) [32]. The author reported that ADG improved by 12% (from 0.72 kg/day to 0.81 kg/day) and backfat reduced by approximately 17% (from 2.64 cm to 1.91 cm) from 1980 to 2008. Therefore, we could consider the obtained backfat thickness as a breeding objective trait.

The number of traits and interesting traits in the selection index of the pig industry differs between studies. For example, O.F. Christensen, et al. (2019) [27] reported that different lines in the pig industry have different traits involved in their breeding selection. Some interesting traits for maternal lines included longevity, reproduction traits such as number born alive, number of piglets weaned, and the weaning weight, whereas sire lines were more focused on the growth rate (ADG), feed efficiency (daily feed intake, FCR), and meat content (lean meat percentage, loin eye area). M. Alam, et al. (2021) [25] mentioned that in Korea, they used ADG, age at 105 kg body weight, and BF for Duroc breeds as a sire line whilst using age at first farrowing, total number born, and number born alive for maternal lines such as Landrace and Yorkshire breeds. W.H. Cáceres, et al. (2020) [33] reported using the three traits ADG, backfat thickness, and FCR as objective traits in the selection index for Duroc pigs in Spain. In addition, the Duroc breed had a lower number born alive in comparison with the Landrace and Yorkshire breeds [23]. The number born alive affects the profit of a sow per year. The higher the number born alive, the higher the profit sows made during a year. J.B. Ferraz, et al. (1993) [34] noted that the genetic gain for the number born alive in pigs was 0.012 pigs/year. On the other hand, M.J. Kaplon, et al. (1991) [35] reported that the genetic trend for the number born alive was 0.6 pigs/year.

4. Conclusions

This study investigated the selection index for Duroc pigs based on three traits (ADG, FCR, and IMF) from different sources of information. Among the three traits, the economic value of FCR dominated over the other two traits. The economic weight of IMF based on the information of three traits in the selection index almost doubled its value when only using the information of ADG and FCR. However, when only using the information of ADG and FCR, the economic weight of ADG and FCR was higher than those using information from all three traits.

The yearly genetic gain and the selection response per unit based on ADG, FCR, and IMF for Duroc pigs was the highest in Scenario 10, (where using the record of those traits of the animal itself and its offspring), followed by Scenario 12 (using the information of the animal itself and all relatives). In both scenarios, the accuracies for yearly genetic gain were high at 0.7. Therefore, breeders/producers could choose one of these scenarios for their Duroc breeding program.

COMPETING INTERESTS

The author declares that there is no conflict of interest regarding the publication of this article.

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