Original Paper

Selection of dam breeds under stable and declined conditions

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Reproductive selection index of two dam pig breeds was established five years ago to enhance the reproductive ability of sows. Since then, positive genetic progress in the population and some economic disorders (e.g. the input and output prices disproportion) appeared in the swine sector. The study aimed to revise index according to the current circumstances and further ensure the desired gain. In three index constructions, the current, optimal, and adjusted trait proportion was assessed. Economic weights (EWs) of the breeding objective traits were applied in two alternatives to evaluate the index for future stable and deteriorated conditions. Under the current index construction and stable EWs, the favourable selection gain in piglets born alive (NBA) and slight extension of farrowing interval (FI) is indicated. The optimal index construction would result in a favourable gain of both traits in one breed. The adjusted index maintained the increasing litter size equal to the current index and achieved favourable gain in FI in both breeds. The same was true for deteriorated economic conditions except for the optimised index, where expected higher genetic progress in one breed. Nevertheless, this genetic gain was insufficient to compensate the declined EW of traits, and the overall financial benefit was almost half of those in stable conditions. For both alternatives of evaluated economic conditions, the current index should be revised in terms of a slightly higher proportion of FI to reach favourable genetic gain in both breeding goals.

Keywords: litter size, farrowing interval, breeding goal, economic value, genetic gain

1 Introduction

The pig breeding process is based on crossing different breeds or populations (dam and sire breeds and lines) in the so-called hybridization program. Breeds' position and specific performance parameters are fundamental to achieving a desirable genetic gain. The selection of dam pig breeds primarily focuses on the traits associated with reproduction (Kasprzyk, 2007; Houška et al., 2004; Quinton et al., 2006). To provide a more comprehensive and sustainable selection, the number of traits of interest is continuously increasing (Wallenbeck et al., 2015; Hermesch et al., 2014).

Survivability of piglets (e.g., until weaning), some of the interval traits (e.g., from weaning to conception), litter birthweight, lifetime efficiency (functional), teat number and vulva size measured in replacement gilts can represent the novel functional traits in dam breeds which can improve the overall productive and reproductive ability of sows (Quinton et al., 2006; Paixão et al., 2019; Corredor et al., 2020; Vargovic et al., 2021; Sell-Kubiak, 2021). For instance, selection for farrowing interval would be of positive impact on the turnover rate and overall production of piglets per sow and year (Krupa et al., 2016a). Selection for number of teats can ensure the adequate nutrition of all piglets by the sows because dam breeds have been generally bred for a higher litter size for a long time. Improving this trait could also bring welfare and managements benefits (e.g., reducing stress, nutritional imbalance, and technology investment; Baxter et al., 2013). Similarly, the selection for vulva size can improve the litter size, survivability and subsequent farrowing performance (reviewed by Corredor et al., 2020). The inclusion of these traits, often labelled as welfare-related, can advance the overall genetic and economic progress in selected populations (Vargovic et al., 2021). Moreover, the regular updating of selection criteria is widely suggested to consider the relevant production and economic parameters of the population (Houška et

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al., 2004) as well as to reach the desired genetic gain in the breeding objective traits (Wolfová et al., 2001).

Breeding of the dam pig population in the Czech Republic has been for more than two decades, focused on growth, meat quality, and litter size (CPBA, 2022) while applying the breeding values estimated for the appropriate selection criteria (determined by, e.g., Wolf et al., 1999 and Krupa et al., 2016a). Likewise, the economic importance (economic weight; EW) was calculated for many breeding objective traits (e.g. Wolfová et al., 2017, 2019; Krupa et al., 2020) to consider economic aspects in selection. Based on this background, the reproductive selection index was established in 2017 to enhance the genetic and economic gain in litter size and eliminate the extension of the FI of sows (Krupová et al., 2017a). The population has been changed from this time, and an encouraging genetic trend in the breeding objective traits was achieved (Figure 1). Simultaneously, the production and economic conditions of the pigs' sector have undergone substantial changes (CPBA, personal communication). It mainly comprises the COVID pandemic, African Swine Fever, declaimed demand for production and increased duty by China, lowered number of pigs in most Europe countries (in total as well as those of breeding animals), the dropped market prices of pigs (often below the production costs), and the increased price of inputs (e.g., energy, fuel). The last mentioned are demonstrated in Figures 2 and 3. Therefore, the aim of our study was to evaluate the genetic and economic parameters of the traits of interest and properly revise the reproductive index of the Czech dam pig breeds. Economic importance of the breeding objective traits was applied here in two alternatives to estimate the index suitability for the future constant and for deteriorated (declined) conditions.

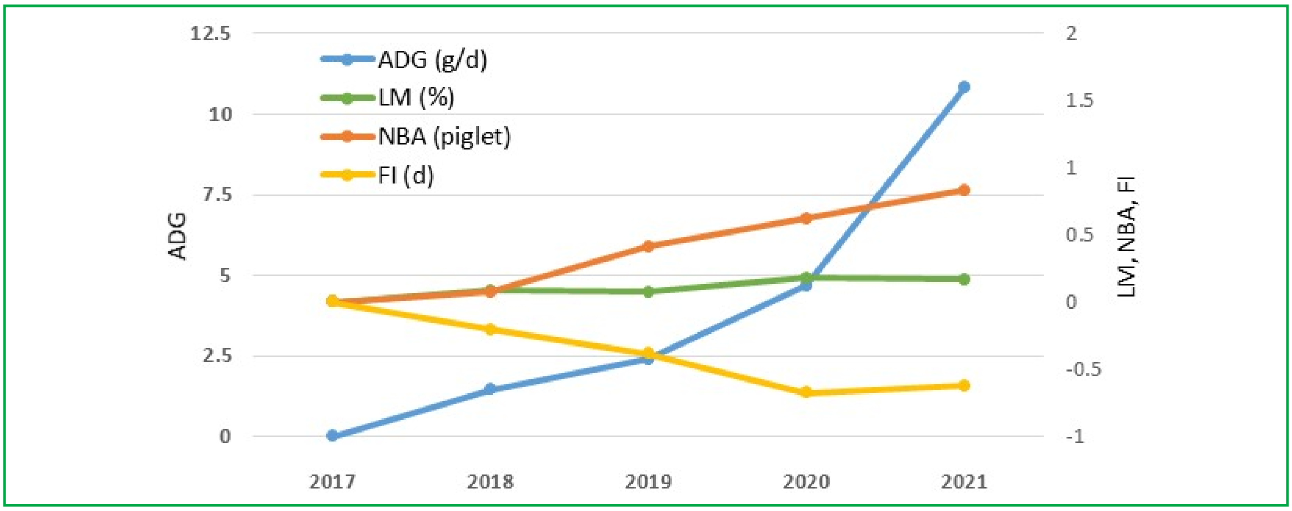

Figure 1 Genetic trend in the breeding objective traits of the Czech dam pig breeds
Source: own calculation
ADG – average daily gain; LM – lean meat content; NBA – number of piglets born alive; FI – farrowing interval

Figure 2 Average price of slaughter pigs (SEU class) in the Czech Republic over the last five years
Source: SZIF (2022)

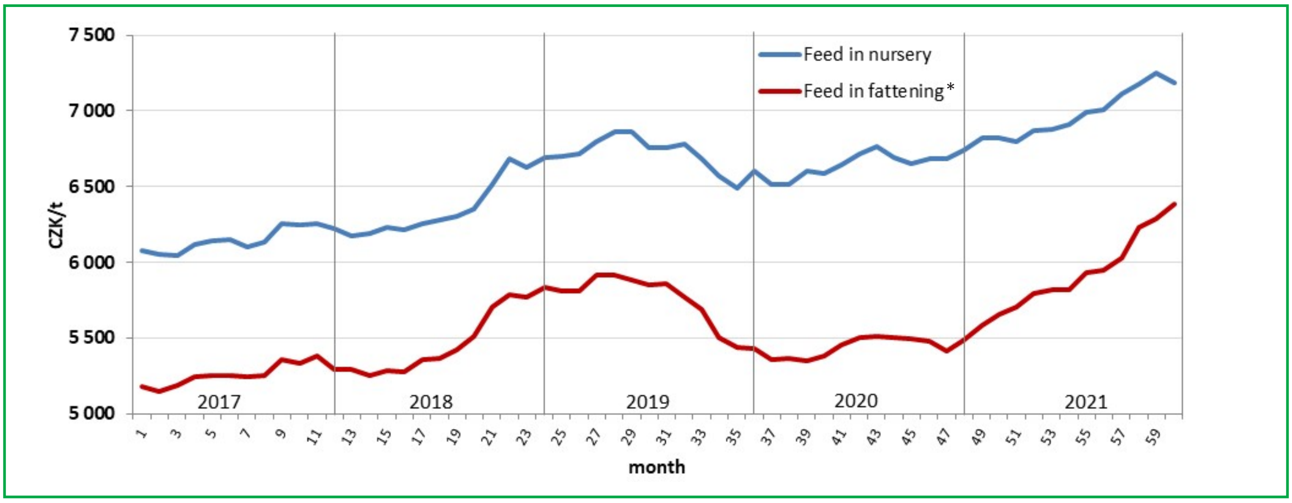

Figure 3 Average price of compound feed of pigs in the Czech Republic over the last five years
Source: SZIF (2022)
* price of feed for pigs with a live weight over 65 kg

2 Material and methods

The Czech Large White (CLW) and Czech Landrace (CL) breeds are involved in the local dam pig population. Breeds are generally characterised by outstanding reproductive parameters, excellent growth ability with good feed conversion and meat performance, and maintaining the exterior consistent with the dam lines (CPBA, 2022). Currently, 1756 (CLW) and 559 (CL) purebred dams are included in the nucleus herds of the National pig breeding program called CzePig (CPBA, 2022). The target values of the main breeding objective traits defined for the year 2030 are presented in Table 1. Although the FI is not directly mentioned there, it is pointed through the number of piglets annually weaned per sow. Moreover, FI was defined as the trait of interest for local breeders (Krupová et al., 2017b) and, therefore, should be considered in the breeding process of dam breeds.

The current reproductive index of the Czech dam pig breeds involves three litter size traits, namely the number of piglets born in total (TNB), piglets born alive (NBA), and piglets weaned (NW), and one trait related to the turnover of herd represented by the length of the FI of sow. When calculating the current index value, the traits' breeding values are weighted selectively to the dam breed (Krupová et al., 2017a). The index is aimed to improve the reproductive ability of sows represented by the NBA and FI as two of the main breeding objective (goal) traits. The index updating presented in the study included: calculation of the economic importance (economic weights, EW) of breeding objective traits, estimation of current genetic parameters for all of the traits of interest, and calculation of expected selection response in the breeding goal traits.

The EWs of breeding goal traits expressed the change in annual profit per unit of the trait (i.e., per piglet born alive and per day of FI) and per sow of dam breed used in the local hybridisation program while maintaining the constant level of other traits. EWs of traits take into account the number of discounted gene expressions of parents of the CLW and CL breed summarised within all links of the crossbreeding system in the 8-year investment period. The bio-economic model of the program EWPIG2 and program GFPIG, considering the gene flow procedure, were employed to calculate the trait EW (e.g. Wolfová et al., 2017; 2019). Base principles integrated into the bio-economic model when modelling the production

Table 1 Target values for the main breeding objective traits in dam pig breeds until 2030

Breeding objective (unit)	Abbreviation	Breed	
		CLW	CL
Piglets born alive (piglets/litter)	NBA	15.5	14.8
Piglets weaned per sow (piglets/year)	PWpS	33.0	31.0
Average daily gain (g/d)	ADG	750	770
Lean meat (%)	LM		58.0

Source: CPBA (2022)
CLW – Czech Large White; CL – Czech Landrace breed

system and calculating the economic efficiency and the EWs were presented in detail in above mentioned studies. Following the unfavourable economic situation occurring in the pig farms in the last months (outlined in the introduction section and described more in detail in the results and discussion section), two alternatives of EWs were assessed in the present study. In alternative A, the trait EW was calculated under the stable setting of the production system; in alternative B, the trait EW declined due to the deteriorated farm profitability.

Definition of the genetic parameters involved the estimation of genetic correlations among the traits of interest, genetic standard deviations of breeding objectives, and reliability of the estimated breeding values of the selection criteria traits. A performance testing database obtained from the Czech Pig Breeders Association (CPBA) was used to estimate the genetic parameters in accordance with the methodology developed by Wolf et al. (1999), Krupa and Wolf (2013) and Krupa et al. (2016a). The genetic relationship matrix contained 144706 and 92439 animals of CLW and CL, respectively.

Three constructions of the reproductive index were evaluated to consider the traits proportion:

1. based on the current index structure (i.e. 30 : 30 : 30 : 10);
2. optimised to reach the highest response and reliability of selection;
3. adjusted to compromise both the desired selection response and reliability along with the current index structure (mentioned in the construction No 2 and 1, respectively).

In total, six index variants were carried out for the given dam breed, taking into account three index construction (1, 2 and 3) and two alternatives of the trait EWs (A and B) in the studied index constructions as described above. For instance, variant 2B represented the traits proportion optimised to reach the most reliable selection and the highest response in breeding objectives (construction No 2), along with applying the declined EWs of traits (B) of the given breed. Expected selection response in the breeding goal traits and construction of indices were based on the general principles of the selection index theory utilised in the matrix program of the SAS environment (SAS Institute Inc., 2013) provided by Přibyl et al. (2004). Finally, animals of dam breeds currently included into the routine estimation of breeding values (28 520 CLW and 15 088 CL) were ranked according to the studied index variants to calculate Spearman's correlation coefficients (SAS Institute Inc., 2013).

3 Results and discussion

3.1 Genetic parameters

Current genetic correlations among the traits of interest, genetic standard deviations of the breeding objective traits, and the reliability of breeding values estimated for the reproductive selection criteria of the CLW and CL breed are presented in Table 2. In comparison to the inputs that have been applied in the current index construction (presented by Krupová et al., 2017a for the entire dam pig breed population), the genetic correlations among the litter size traits remained higher (e.g., 0.693 between the TNB and NBA in CLW breed; Table 2). Correlations between the litter size traits and the FI are still low and unfavourably positive (e.g., 0.058 between the NBA and FI in CL breed; Table 2), indicating that a direct selection on FI is needed to improve the reproduction ability of sows further.

Table 2 Genetic and economic parameters of dam pig breeds

Breed	Trait	Unit	EW (€/unit/sow/year)		GSD	Trait correlation			
			A	B		TNB	NBA	NW	FI
CLW	TNB	piglets per litter	–	–	–	1.000	0.693	0.503	0.005
	NBA		14.25	6.74	0.652	–	1.000	0.424	0.117
	NW		–	–	–	–	–	1.000	0.032
	FI	day	-2.11	-1.41	1.079	–	–	–	1.000
	reliability of breeding values					0.516	0.504	0.476	0.215
CL	TNB	piglets per litter	–	–	–	1.000	0.857	0.578	0.119
	NBA		37.22	18.61	0.567	–	1.000	0.566	0.058
	NW		–	–	–	–	–	1.000	0.031
	FI	day	-4.88	-3.25	0.694	–	–	–	1.000
	reliability of breeding values					0.509	0.473	0.466	0.134

EW – economic weight of the breeding goal trait calculated in two alternatives: A) under the stable setting of the production system, B) reduced due to the deteriorated farm profitability. TNB – total number of piglets born, NBA – number of piglets born alive, NW – number of piglets weaned (all expressed per litter), and FI – farrowing interval of sows (in days). CLW – Czech Large White; CL – Czech Landrace breed. Source: own calculation

Reliability of breeding values estimated for the traits included in the reproduction index has been slightly increased over the last period by 7% and currently varied from 0.134 (FI in CL breed) to 0.516 (TNB in CLW breed; Table 2). The greater improvement of the accuracy was calculated for the litter size traits. For instance, the reliability of breeding values estimated for NW enlarged by more than 30%, from 0.350 in 2017 (Krupová et al., 2017a) to the value of 0.476 (CLW) and 0.466 (CL; Table 2) calculated currently. Such functional traits usually show a relatively high proportion of residual variance on the overall genetic variance, low heritability (0.06 to 0.14), and thus susceptibility to environmental factors (Kasprzyk, 2007; Krupa et al., 2016a). Therefore, a consistent improvement of the local farm conditions and herd management in the preceding period could be expected.

On the other side, the genetic standard deviations of the breeding objective traits were reduced by 20% on average. As the parameter expressing the trait variability in the population, it could show a smaller potential for the selection progress. However, slightly higher reliability of the breeding values estimation permits to select animals more precisely. In this context it is supposed, that reliability of the breeding values estimation could be further improved due to ongoing genotyping of the reference population in the CzePig breeding program (thought the Project no. QK1910217).

3.2 Economic parameters

Economic importance (EWs) of the breeding goal traits of the CLW and CL breed in both of the evaluated alternatives are presented in Table 2. Under the stable setting of the production system (alternative A), the average EWs of traits were 20.82 € per piglet born alive (NBA) and -2.90 € per day of FI; both expressed per sow and year of the local dam breeds. When deteriorated farm profitability (alternative B) was considered in the study, the trait EWs were declined by 43% on average.

Generally, production and economic parameters of the studied population recorded for a certain period (lasting, e.g., the recent two years) are usually implemented in the bio-economic models (e.g., by Hermesch et al., 2014 and Wolfová et al., 2019). The main aim is to avoid the year-on-year variation and the seasonal fluctuation naturally occurring in agriculture. As already mentioned above, the economic conditions of the swine sector have been gradually influenced by several undesirable factors covering African Swine Fever (Marczin, 2021) and disproportion between the price of main outputs (slaughter pigs) and inputs (compound feeds; displayed in Figure 2 and 3). Despite the favourable genetic trends in most of the production and reproduction parameters achieved in the local pig population (presented in Figure 1) is questionable if it is sufficient to damp the objectionable conditions appearing in the pig sector recently. The first signals of the slaughter pig price increase at the time of manuscript submission (in spring 2022) particularly contribute to improving the recent development (SZIF, 2022).

Declined economic importance of the litter size (NBA) and that of FI resulted from the overall deterioration of the farm economy and thus declined benefits from the changed trait level. It is consistent with the former founding that EWs (mainly those belonging to the functional traits) are depreciated and underestimated when the farm (or some animal category) is operated at a loss (Krupová et al., 2017a). Likewise, Hermesch et al. (2014) founded the EW of functional traits (e.g. the survival rate of piglets) sensitive to input and output prices (i.e. those of weaned piglets and finished pigs, respectively). Declined EW of functional traits (for perinatal survival and survival to weaning) was also calculated by Quinton et al. (2006) for Canadian farms with lover litter size and thus with the expected decrease in profitability. The EW of survival traits in farm with eight piglets per litter was on average 50% in comparison to farm with doubled litter size.

Moreover, a slight reduction of EWs (by 15%) was found in Czech conditions when comparing the current trait economic importance (presented in alternative A) with those calculated five years ago (Krupová et al., 2017a). It could point out that the tendency of depreciated farm profitability might persist in the local population with lower or greater intensity for a longer time. Sensitivity analysis carried out by Houška et al. (2004) in commercial pig herds also showed that the trait economic importance can be modified over time due to changed production and economic parameters. Similarly, Marczin (2021) found a slight reduction of the market prices of pigs in the last period that indicate the deteriorated profitability in Hungarian swine sector. Moreover, the latter author pointed, that in such a globalised segment the crisis situations and low degree of sector integration are of higher (mostly negative) impact on small sized markets (like the Hungarian is) in comparison to the larger and better organised pig-keeping countries (represented e.g. by Germany). Having regard to the foregoing and to the fact that breeding process (selection) should be oriented to effective production in the future, the predictability of the upcoming production and economic circumstances seems to be currently much more problematic than before (determined by, e.g. Marczin, 2021 in context of the emergence of African Swine Fever). Therefore, the sensitivity analysis of EWs provided in our study aims to cope with the uncertainty appearing in the pig sector and to ensure the appropriate weighting of the breeding goal traits because it is defined as fundamental for the proper index construction and thus estimation of genetic gain (Wolfová et al., 2001).

3.3 Selection gain

Expected genetic and economical selection response in the breeding goal traits of the CLW and CL breed calculated for various index construction and the traits EWs are presented in Table 3. Under the stable economic circumstances and the current index construction (30 : 30 : 30 : 10 traits ratio; variant 1A), the favourable selection gain in litter size (+0.195 and 0.183 NBA) and a slight extension of FI (+0.002 and +0.011 days) are indicated for the CLW and CL dam breed, respectively. In comparison, the average genetic trend already achieved in the last years shows that both traits were improved (+0.209 NBA and -0.155 day of FI; Figure 1). It suggests that the real selection pressure on FI could be higher than specified in the index, and, secondly, it can result from a consistent improvement of farm management (as mentioned above). Impact of the selection intensity on the real genetic gain could be well demonstrated e.g. on NBA where is Generally, the resulted selection gain in breeding objective trait could vary in high extension and can be demonstrated e.g. by literature values ranging from 0.170 NBA per Landrace sow recorded in the intensive system (Kasprzyk 2007) to 0.02 NBA measured for the conserved populations managed extensively (Paixão et al., 2019).

Once the optimal index construction was calculated (variant 2A; Table 3), the resulted genetic gain would be favourable in both breeding goal traits of the CLW breed (i.e., +0.211 NBA and -0.022 FI). For the CL breed, the favourable genetic progress was calculated only for the litter size (e.g., 0.190 NBA) and genetic gain in FI was close to zero (+0.006 days). The adjusted index (variant 3A) would maintain the increase of litter size almost equal to the current index (0.195 and 0.182 NBA) along with achieving the favourable gain in FI (-0.006 and -0.002 days in CLW and CL, respectively).

Similar genetic progress in breeding objective traits was calculated under the deteriorated economic conditions presented in alternative B of each index construction (Table 3). The overall financial benefit from selection was almost half of those in stable economic conditions presented in alternatives A. The same was true even for the 2B index of the CLW breed, where the highest genetic gain in both traits achieved over all of the evaluated variants was not sufficient to compensate for the declined economic importance of traits.

3.4 Index structure and reliability

Structure of the studied index variants and the corresponding reliability of selection in dam pig breeds is presented in Table 3 and Figure 4, respectively. The current index can be optimised (variant 2A) in terms of the higher proportion of the NBA (on 47% in CLW and 42% in CL breed) to the detriment of the litter size at weaning (NW was reduced to one third in both dam breeds). The proportion of the FI should be optionally doubled to 24% (CLW) and 16% (CL), and the reliability of the animals' selection would be there the highest (60% on average) among the studied index variants. In

Table 3 Selection response and reliability of studied selection indices in dam pig breeds

Breed	Trait	Selection response[a]	Index variant[b]					
			current		optimal		adjusted	
			1A	1B	2A	2B	3A	3B
CLW	NBA	genetic	0.195	0.195	0.211	0.28	0.195	0.195
	FI		0.002	0.002	-0.022	-0.035	-0.006	-0.006
	–	economic	2.78	1.31	3.05	1.45	2.79	1.32
	reliability of selection		0.561	0.570	0.593	0.582	0.547	0.557
CL	NBA	genetic	0.183	0.183	0.190	0.189	0.182	0.182
	FI		0.011	0.011	0.006	0.003	-0.002	-0.002
	–	economic	6.78	3.38	7.03	3.51	6.77	3.39
	reliability of selection		0.593	0.599	0.609	0.599	0.556	0.528

Source: own calculation
[a] – Genetic response (gain) expressed in the unit of the appropriate breeding goal trait (in piglets born alive per litter (NBA), and in days of farrowing interval of sows (FI) of the Czech Large White (CLW) and Czech Landrace (CL) breed. Economic response expresses the sum of the genetic gain x EW of the breeding goal traits (presented in Table 2). [b] – Index variants: 1 – current index construction with the trait ratio 30 : 30 : 30 : 10; 2 – optimised to achieve the maximal selection response and reliability, 3 – adjusted to compromise both, the desired selection response and reliability, and the current index construction. EW of the breeding goal trait was calculated there in two alternatives: A – under the stable setting of the production system, B – reduced due to the deteriorated farm profitability

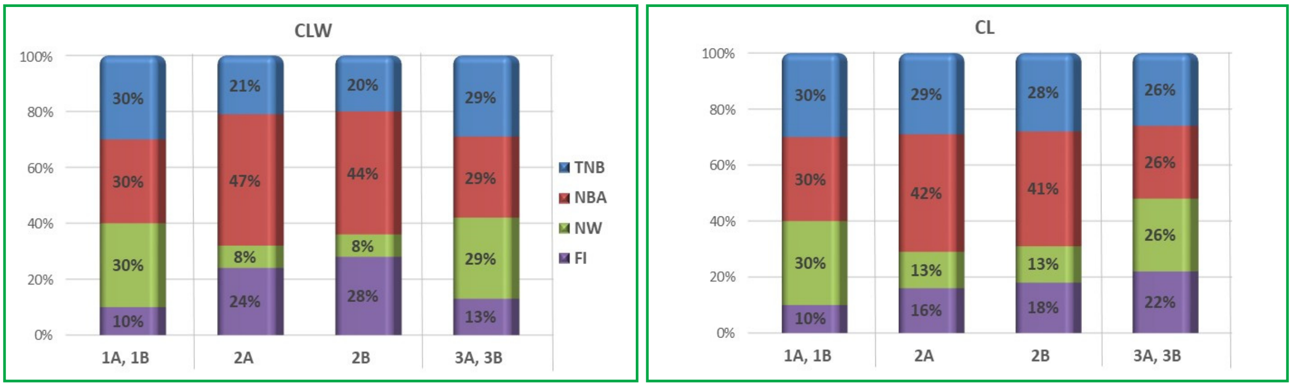

Figure 4 Structure of the studied index variants in dam pig breeds
CLW – Czech Large White; CL – Czech Landrace breed; 1 – current index; 2 – optimised index; 3 – adjusted index; A – "stable" economic weights; B – "declined" economic weights (for the index variant 1A and 1B the same traits proportion was applied; the same was true for the variant 3A and 3B); TNB – total number of piglets born, NBA – number of piglets born alive, NW – number of piglets weaned (all expressed per litter), and FI – farrowing interval of sows (in days); Source: own calculation

the context of the studied alternatives of EWs presented in the optimal index construction (i.e., 2A and 2B), the deteriorated economic conditions increased FI by 4 and 2 percentage points in CLW and CL breed, respectively.

Adjusted index (variant 3A and 3B) compromised both the current and optimal index construction and, next to the desired selection response in both traits (mentioned above), resulted in only a slight reduction of the selection reliability (-5 percentage points on average; Table 3). Favourable genetic response in FI (i.e., the shortening of FI) is based on strengthening the selection pressure on that trait at 13% and 22% in CLW and CL breeds, respectively. A slight increase of the FI proportion calculated under both EWs alternatives (for the stable and deteriorated conditions) indicates that such a revised index could ensure the adequate weighting of traits even in uncertain future conditions.

In the index currently applied in the selection praxes, the traits contribution (30 : 30 : 30 : 10; Krupová et al., 2017a) is based on the final decision of the local pig breeders included in the National pig breeding program. Similarly, the update of the index provided in our present study will be further discussed with the local breeders to compromise both the optimal contribution and their preferred manner. The Spearman's correlation between the current and evaluated index variants was relatively high, ranging from 0.958 for optimised index considering the deteriorated economic conditions (2B) to 0.999 for adjusted index variants (3A and 3B) in the CLW breed. Similarly, high correlations coefficients were calculated when ranking the animals of CL breed, i.e. from 0.971 (for adjusted index variants) to 0.988 (variant 2A). The statistical significance of the computed correlations was high (p <0.0001) in both breeds. Therefore, the eventual application of the adjusted index variants would result in only negligible changes in the ranking of animals, bringing the desired genetic response to both breeding objectives.

In accordance with the literature presented in the introduction section (e.g. Lundeheim et al., 2013), the range of selection candidates of the local dam pig population could be increased in the near future with the (functional) teat number. In this regard, the background for the routine estimation of breeding values has already been established (Krupa et al., 2016b), and EWs of the teats number have been calculated recently (Krupa et al., 2020). Improving this functional trait can advance the overall mothering ability, defined as one of the key breeding goals of dam pig breeds by Danbreed (2022), Topigs Norswin (2022), and also by CzePig program (represented by the annual number of piglets weaned per sow (PWpS; Table 1). Moreover, such welfare-related traits could improve the overall genetic response in both production and functional traits and increase overall economic benefit, as outlined in our study and Vargovic et al. (2021).

4 Conclusions

Selection under the current reproduction index of the Czech dam pig breeds resulted in an improvement in litter size and a slight increase in FI. Correlations between the litter size traits and the FI are still unfavourably positive, indicating that direct selection on FI is further needed to improve the reproduction ability of sow. Moreover, to ensure the desired selection response in both breeding objectives, the selection pressure on FI should be increased in both dam breeds. A slight increase of the FI proportion calculated in both studied economic conditions (under the stable and deteriorated EWs) indicates that such an index could ensure the adequate weighting of traits even in uncertain future conditions. Similarly, as it has already been provided in the current index construction, the final index structure will also harmonise the preferences of the local breeders as the primary users of the National pig breeding program.

Acknowledgments

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References

Baxter, E.M. et al. (2013). The welfare implications of large litter size in the domestic pig II: Management factors. *Animal Welfare*, 22, 219–238. https://doi.org/10.7120/09627286.22.2.219

Corredor, F.-A. et al. (2020). Genetic and genomic characterization of vulva size traits in Yorkshire and Landrace Gilts. *BMC Genetics*, 21, 28. https://doi.org/10.1186/s12863-020-0834-9

CPBA. (2022). *National breeding program*. Czech Pig Breeders Association. Retrieved February 21, 2022 from http://www.schpcm.cz/slechteni/slechteni.aspx In Czech.

Danbreed. (2022). *Breeding goal. Focus on maximum genetic and economic gain*. Danbreed. Retrieved March 25, 2022 from https://danbred.com/breeding-system/breeding-goal-of-the-future/

Hermesch, S. et al. (2014). Economic weights for performance and survival traits of growing pigs. *Journal of Animal Science*, 92, 5358–5366. https://doi.org/10.1017/S1751731118002513

Houška, L. et al. (2004). Economic weights for production and reproduction traits of pigs in the Czech Republic. *Livestock Production Science*, 85, 209–221. https://doi.org/10.1016/S0301-6226(03)00128-3

Kasprzyk, A. (2007). Estimates of genetic parameters and genetic gain for reproductive traits in the herd of Polish Landrace sows for the period of 25 years of the breeding work. *Archiv für Tierzucht*, 50, 116–124. https://aab.copernicus.org/articles/AAB-Sonderheft-2007-2.pdf

Krupa, E. et al. (2016a). Estimation of (co)variance components for age at first farrowing and farrowing interval in Czech large white. *Acta Agriculturae Slovenica*, (5),183–188. http://aas.bf.uni-lj.si/zootehnika/supl/5-2016/PDF/5-2016-183-188.pdf

Krupa, E. et al. (2016b). Estimation of genetic parameters for teat number and reproduction and production traits from different data sources for Czech dam breeds. *Livestock Science*, 19, 197–102. http://dx.doi.org/10.1016/j.livsci.2016.07.018

Krupa, E. et al. (2020). Estimation of economic weights for number of teats and sperm quality traits in pigs. *Journal of Animal Breeding and Genetics*, 137, 189–199. https://doi.org/10.1111/jbg.1243

Krupa, E., & Wolf J. (2013). Simultaneous estimation of genetic parameters for production and litter size traits in Czech Large White and Czech Landrace pigs. *Czech Journal of Animal Science*, 58, 429–436. https://doi.org/10.17221/6943-CJAS

Krupová, Z. et al. (2017a). Selection index for reproduction of Czech Large White and Czech Landrace breeds and the entire population of maternal pig breeds. *Research in Pig Breeding*, 11(1), 22–31. http://www.respigbreed.cz/2017/1/4.pdf

Krupová, Z. et al. (2017b). New breeding objectives for the Czech pig population. *Indian Journal of Animal Science*, 87(6), 778–781. https://epubs.icar.org.in/ejournal/index.php/IJAnS/article/view/71467

Lundeheim, N. et al. (2013). Genetic analysis of teat number and litter traits in pigs. *Acta Agriculturae Scandinavica*, *Section A*, 63,121–125. http://dx.doi.org/10.1080/09064702.2013.841749

Marczin, T. (2021). Economic effects of African swine fever at Hungarian and European level. *Journal of Agricultural Informatics*, 12(2), 18–27. https://doi.org/10.17700/jai.2021.12.2.605

Paixão, G. et al. (2019). Genetic parameters for reproductive, longevity and lifetime production traits in Bísaro pigs. *Livestock Science*, 225, 129–134. https://doi.org/10.1016/j.livsci.2019.05.010

Přibyl, J. et al. (2004). Selection index for bulls of Holstein cattle in the Czech Republic. *Czech Journal of Animal Science*, 49(6), 244–256. https://doi.org/10.17221/4307-CJAS

Quinton, V.M. et al. (2006). Economic weights for sow productivity traits in nucleus pig populations. *Livestock Science*, 99, 69–77. https://doi.org/10.1016/j.livprodsci.2005.06.002

SAS Institute Inc. (2013). SAS® 13.1 Statements: Reference. Cary, NC: SAS Institute Inc.

Sell-Kubiak, E. (2021). Selection for litter size and litter birthweight in Large White pigs: Maximum, mean and variability of reproduction traits. *Animal*, 15, 100352. https://doi.org/10.1016/j.animal.2021.100352

SZIF. (2022). *Market information system: Market reports, Price and information service.* SZIF. Retrieved February 21, 2022 from https://www.szif.cz/cs/trzni-informacni-system. In Czech.

Topigs Norswin. (2022). *Parent sows*. Topigs Norswin. Retrieved March 25, 2022 from https://topigsnorsvin.com/products/parent-sows/

Vargovic, L. et al. (2021). Economic benefit of additional recording for welfare traits in maternal breeding objectives for pigs. Proceedings of the Association for the *Advancement of Animal Breeding and Genetics*, 24, 406–409. http://www.aaabg.org/aaabghome/AAABG24papers/100Vargovic24406.pdf

Wallenbeck, A. et al. (2015). Preferences for pig breeding goals among organic and conventional farmers in Sweden. *Organic Agriculture*, 1–12. https://doi.org/10.1007/s13165-015-0125-3

Wolf, J. et al. (1999). Estimation of genetic parameters for litter traits in Czech pig populations using a multitrait animal model. *Czech Journal of Animal Science*, 44, 193–199.

Wolfová, M. et al. (2001). Impact of incorrect weighting of traits in the aggregate genotype of pigs on genetic gain. *Czech Journal of Animal Science*, 46(11), 474–480.

Wolfová, M. et al. (2017). Estimation of economic values for traits of pig breeds in different breeding systems: I. Model development. *Livestock Science*, 205, 79–87. https://doi.org/10.1016/j.livsci.2017.09.019

Wolfová, M. et al. (2019). Economic weights of maternal and direct traits of pigs calculated by applying gene flow methods. *Animal*, 13(6),1127–1136. https://doi.org/10.1017/S1751731118002513