**Impact of including growth, carcass and feed efficiency traits in the breeding goal for combined milk and beef production systems**

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**Supplementary Material S2**

*Sensitivity of results to economic production conditions and used model parameters*

The sensitivity of the results to changes in the production environment was studied to determine whether the economic benefits resulted from the inclusion of new traits are applicable in the different possible future economic conditions. The current removal of subsidies paid per liter of milk in the subsidy region in southern Finland, a Russian embargo on dairy products and possible more market orientated milk production resulted from the EU milk quota abolition in 2015 are likely to decline the producer price for milk. According to our results (sensitivity scenario 5, Table 1) lower revenues from milk production resulting from these changes would shift the selection pressure and response from milk production traits only slightly towards RFI traits and LW favoring smaller animals.

An increased feed price studied in sensitivity scenario 6 moved the selection pressure and response slightly from production traits to RFI traits and LW. It is likely that in the near future different regulations considering livestock production and consumption of products of animal origin will be implemented such as environmental taxes on animal products or subsidies favoring more environmental efficient animal production. This would lead to an increase in the economic values of traits that have been connected with the mitigation of GHG emissions in milk and beef production e.g. through taxes or subsidies related to the feed price. Therefore, even though the economic benefits of including RFI in the breeding goal for dairy cattle were relatively small in this study, the economic importance and motivation to improve these traits will likely increase in the future if economic values taking into account environmental aspects are introduced.

In our study, the combined milk and beef production system where surplus animals were used for beef production was considered. However, in many specialized dairy production systems where no fattened animals, beef production does not have a direct economic value (e.g. surplus calves are slaughtered soon after birth). Therefore, when considering the aim to shift the specialized system more towards combined milk and beef production, the effect of including new traits in the breeding goal was assessed excluding the correlated responses in new breeding goal traits from the profit of the breeding program in the reference or other scenarios. Otherwise, the scenarios were similar to those presented for the combined milk and beef production system. In these calculations, the inclusion of growth together with carcass traits resulted in the highest increase in the discounted profit of the breeding program (13.6%) in sensitivity scenario 1a. When also LW was included (sensitivity scenario 1b) an increase in the discounted profit was obtained but it was 5.8 percentage points lower than in sensitivity scenario 1a. Consideringfeed efficiency related traits, the inclusion of LW alone had moderate (4.1%) and RFI traits relatively small (1.5%) economic impacts on the profit of the breeding program. Therefore, the inclusion of LW in the selection index that excludes growth and carcass traits could be a more profitable option to improve feed efficiency in a specialized milk production system. However, if growth and carcass traits were included in the breeding goal, the inclusion of LW would not be beneficial because it substantially reduces the benefits resulted from breeding for beef traits.

A critical assumption in this study, due to unknown genetic correlations between RFI traits and other breeding goal traits in FAy, was that these correlations were set to zero. However, an unfavorable genetic correlation between RFI and fertility, although not statistically significant, has been reported in a few published studies carried out in dairy cattle (Vallimont *et al*., 2013; Gonzalez-Recio *et al*., 2014). Therefore, the sensitivity of selection response to the possible antagonistic relationship between RFI and fertility applying a moderate unfavorable genetic correlation (-0.3) was studied under scenario 4. In this sensitivity analysis (sensitivity scenario 7), the monetary genetic response in fertility traits slightly decreased (1 €/cow for the investment period) and, in contrast, in RFI traits increased (15 €/cow for the investment period). An undesired genetic change in fertility traits was obtained even when the genetic correlation between fertility and RFI traits was set to zero.Consequently, when RFI and fertility traits were unfavorably correlated, the antagonistic genetic response in fertility traits resulted in the higher desired genetic gain in RFI traits i.e. declining genetic merit for fertility traits led to increased genetic response in RFI traits. Gonzalez-Recio *et al*. (2014) found also that the inclusion of RFI would result in more feed efficient animals only with a negligible decline in the selection response in fertility in Holstein cows when fertility and RFI traits were an unfavorable correlated (-0.13).

Due to the uncertainties in correlations between growth traits, the sensitivity of the results to the correlations between growth traits (ADG\_R, ADG\_F) and LW was studied under scenario 4. When applying 20% lower genetic correlations between traits (sensitivity scenario 8) the discounted profit of the breeding program increased only by 1.2%. However, a small positive economic response obtained in LW (4 €/cow for the investment period) indicates that if the genetic correlations between LW and other growth traits were weaker genetic improvement in these traits would be possible to achieve simultaneously. Groen and Vos (1995) estimated very strong (>0.9) genetic correlation between average daily gain in calves and live weight of heifers after the first calving. However, a genetic correlation around 0.5 between carcass weight in Danish dairy cows and in fattened calves estimated by Closter *et al*. (2015) indicates that the genetic background of these traits partly differs. A likely explanation for these differences in genetic correlations among previous studies is that genetic correlations between growth traits are highly dependent on the trait definitions. Therefore, these genetic correlations should be estimated for traits considered for the inclusion in the breeding goal in the population studied to determine more carefully the benefits of selecting for growth traits together with LW.

Due to unprofitable beef production, the economic values of stillbirth and birth weight used in this study favored a decrease in the number of fattened animals i.e. each increase in the number of fattened animals would increase the economic loss. However, from the perspectives of animal welfare and ethical views the use of a selection index that leads to undesired genetic chances in these traits and other functional traits should be avoided. Therefore, considering the biological goal to avoid undesired changes in stillbirth and birth weight, we investigated sensitivity scenario 9 carried out under scenario 4 where the economic values of these traits were set to zero in the selection index. However, their correlated economic responses were accounted for in the profit. In this scenario, the slight desired annual genetic change in birth weight (towards the objective of lower birth weight) and the genetic change close to zero in stillbirth were obtained. In addition, the effect of the subjective modification of the breeding goal on the profit was only marginal (-0.1%). In general, even though the maximal profit is not usually achieved when avoiding deterioration of functional traits, improving health and fertility traits has traditionally been an important breeding goal in the Nordic countries.

*Additional reference*

Closter AM, Norberg E, Pedersen J and Kargo M 2015. Possibility to improve genetic evaluation for carcass traits using data from dairy cows. Book of Abstracts of the 66th Annual Meeting of the European Association for Animal Production No 21. pp. 228. Wageningen Academic Publishers, Wageningen, the Netherlands.

**Table 1** *Total annual monetary genetic gain per cow (AMGG), discounted profit per cow for the investment period (DP), and discounted monetary genetic gain for the sets of traits per cow for the investment period (DMGG) in the different sensitivity scenarios*

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Scenario1,2 | AMGG, € (%3) | DP, € (%3) | DMGG, € | | | | | |
| Production | Functional | LW | Growth | Carcass | RFI |
| Reference | 63.0 (100.0) | 332.3 (100.0) | 372.5 | -30.2 | 0.0 | 0.1 | 0.0 | 0.0 |
| Sce.1a | 68.1 (+8.2) | 377.5 (+13.6) | 357.7 | -30.3 | 0.0 | 56.9 | 3.3 | 0.0 |
| Sce.1b | 66.6 (+5.7) | 358.1 (+7.8) | 371.6 | -30.1 | -1.1 | 25.5 | 2.3 | 0.0 |
| Sce.2a | 65.5 (+4.0) | 346.0 (+4.1) | 349.7 | -28.6 | 35.5 | -0.6 | 0.0 | 0.0 |
| Sce.2b | 65.5 (+4.0) | 347.3 (+4.5) | 364.2 | -30.7 | 17.7 | 6.1 | 0.0 | 0.0 |
| Sce.3a | 63.7 (+1.1) | 337.4 (+1.5) | 366.5 | -29.7 | 0.0 | 0.1 | 0.0 | 10.9 |
| Sce.3b | 66.1 (+5.0) | 350.9 (+5.6) | 344.4 | -28.1 | 35.0 | -0.6 | 0.0 | 10.5 |
| Sce.4 | 67.2 (+6.7) | 362.8 (+9.2) | 366.5 | -29.7 | -1.1 | 25.2 | 2.3 | 10.1 |
| Sce.5 | 52.1 (-22.4) | 279.8 (-22.9) | 278.1 | -32.7 | 2.5 | 26.1 | 3.2 | 12.9 |
| Sce.6 | 65.1 (-3.2) | 351.2 (-3.2) | 340.6 | -28.0 | 3.5 | 26.9 | 2.3 | 16.4 |
| Sce.7 | 68.8 (+2.4) | 372.2 (+2.6) | 365.1 | -30.8 | -0.7 | 21.8 | 2.4 | 24.9 |
| Sce.8 | 67.7 (+0.7) | 367.3 (+1.2) | 360.6 | -30.8 | 4.0 | 31.7 | 2.1 | 10.0 |
| Sce.9 | 67.2 (-0.0) | 362.4 (-0.1) | 365.8 | -29.0 | -0.4 | 24.0 | 2.3 | 10.1 |

1Additional breeding goal traits in different sensitivity scenarios: Sce.1. a) Average daily gain of animals in the rearing and fattening periods and carcass traits b) with mature live weight (LW); Sce.2. a) LW b) with average daily gain of calves in the rearing period; Sce.3. a) Residual feed intake (RFI) traits b) with LW; Sce.4. LW, growth, carcass, and RFI traits.

2Sce.5. The economic values derived with the declined milk price; Sce.6. The economic values derived with the increased feed price; Sce.7. The unfavourable correlation (-0.3) between fertility and RFI traits was applied; Sce.8. The genetic correlations between growth traits and LW were reduced by 20%; Sce.9. The economic values for stillbirth and birth weight were set to zero.

3Scenarios Sce.1 to 4 compared with the reference scenario; scenarios Sce.5 to 9 compared with Sce. 4.