Broiler Breeding for Sustainability and Welfare – are there Trade-Offs?

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Aviagen

Introduction

Recent years have seen a focus on the sustainability of livestock production in both scientific literature and political agendas worldwide. It is now common place to reiterate the global issues which are found almost inevitably in every introduction or discussion in papers and reports dealing with sustainability: population growth reaching over 9 Billion people by 2050, long-term increases in meat demand, scarcity of natural resources such as agricultural land and water, and concerns about environmental impact of livestock production (e.g., Foresight, 2011; Herrero and Thornton, 2013, Herrero et al, 2013, LEAP 2015, United Nations 2015, Bryden, 2016).

The OECD/FAO (2016) forecasts that by 2025 global meat production and consumption are to increase by 48 million tons. Poultry meat is expected to have a preponderant role on satisfying this increasing demand for meat products worldwide with a contribution of 44% to the total meat production growth. Low production costs and greater affordability when compared to other meats have contributed to making poultry the meat of choice for both producers and consumers in the developing world. A striking 73% of the increase in meat production is expected to come from developing countries. Moreover, poultry meat consumption increases are expected regardless of region and income levels, both in the developed and developing world and is equivalent to the additional growth of all other meats combined.

Several studies have consistently shown that poultry production systems have a lower environmental impact when compared to other meat livestock productions with values of CO_2 equivalents per unit of edible carcass ranging from around 20 to 60 for ruminants compared to 7 to 20 for pork and 3.7 to 5 for poultry (Williams et al., 2006, Leip et al, 2013, Herrero et al., 2013). Environmental impact calculations change depending on methodology used, production system assumptions and what pollutants are included in the total greenhouse gas emission calculation but it is clear that poultry has the lowest levels of pollutant emissions.

Comparisons among poultry production systems have shown that conventional systems have lower environmental impacts than organic or free range on the basis of global warming, eutrophication and acidification potential, abiotic resource and land use (Leinonen et al, 2012). These authors conclude that improving feed efficiency, including feed quantity, composition and nutrient content have a key role to play in reducing the environmental impact of broiler production even further. This agrees with the conclusion by Herrero et al (2013) that feed efficiency is a key driver of productivity, resource use and greenhouse gas emissions.

The realised genetic improvement in chicken biological efficiency is well documented. Comparisons between selected and unselected or heritage lines provide estimates of yearly improvements over the last 50 years of around 50g of bodyweight, feed conversion rate improvements of 15 to 25 g feed/kg or bodyweight, and around 0.2% increase in breast meat yield (Havenstein et al., 2003a, 2003b; Fleming et al., 2007; Mussini, 2012; Zuidhof et al., 2014). Long-term industry data which are a reflection of both management practices and genetics, have reported improvements of 25 to 30g live weight and 16 to 20g reduction in feed consumed per kg of live weight thus indicating sustained improvements feed efficiency (Laughlin, 2007; National Chicken Council, 2016).

Long-term rates of genetic improvement are predicted to stay at the above levels (Fancher, 2014). At the same time, there have been concerns over the sustainability of genetic improvement due to undesired consequences of genetic selection in terms of musculoskeletal disease and reproductive fitness and indeed any long-term limits to genetic selection (Dawkins and Layton, 2012; Hocking, 2014). On the other hand, both experimental and industry data have shown sustained improvements in leg health, liveability and product quality (Fleming et al, 2007; National Chicken Council, 2016).

In addition to sustained improvements in biological performance, the modern broiler has shown improvements in body composition. When compared to unselected genotypes, as a function of live weight, the modern broiler has greater leg strength (measured as tibia breaking force) and additional digestive capacity (e.g., greater small intestine surface area, larger pancreas and liver), with no evidence of negative impacts on cardiovascular function (Fancher, 2014). Thus the modern broiler is well equipped with the support system to handle higher feed intakes and express the genetic potential for higher growth and development (Fancher, 2014).

Neeteson et al (2013) showed that a route to sustainable genetics is the implementation of broad breeding goals including biological efficiency, environmental adaptability, reproductive fitness, welfare and product quality. A key component of a balanced breeding strategy is the estimation and handling of antagonistic genetic correlations between trait groups in the breeding goal, for example between biological performance and welfare or product quality. This is shown by Kapell et al. (2012a, 2012b) and Bailey et al (2015) in the context of leg health, contact dermatitis and breast myopathies, respectively.

While broiler production and demand is growing globally, there has been a growing interest for broiler products arising from alternative production systems with various schemes targeting thresholds for growth rates lower than 50 g/day and/or specific requirements regarding welfare attributes (e.g., 'Chicken of Tomorrow' and 'Beter Leven' in the Netherlands, 'Für mehr Tierschutz' in Germany, and 'RSPCA Assured' in the UK).

This paper explores the environmental sustainability of a range of broiler chicken genotypes with differing biological performance levels from the point of view of i. resource requirements and ii. environmental burdens. We will also address how any trade-offs between environmental sustainability and welfare or environmental adaptability can be dealt with through the management of antagonistic genetic correlations between traits in a broad breeding goal. Finally, we will discuss how current global market trends influence the evolution of breeding goals and the corresponding consequences from the sustainability of broiler breeding.

Genotype Portfolio

Table 1 shows the predicted field biological performance adjusted to 2.5kg target live weight for seven Aviagen broiler genotypes ranging from conventional to a range of slow grow types.

Table 1. Biological performance[1] of seven Aviagen genotypes to 2.5 kg bodyweight

Genotype	ADG	Days	FCRadj	Evis%	Breast%	Liveability %
Ross 308	65.0	38.5	1.62	73.2	22.6	96.5
Ross 708	62.0	40.3	1.63	74.1	23.9	97.0
Ranger Classic	49.0	51.0	1.83	71.9	21.4	97.5
Ranger Premium	50.0	50.0	1.83	72.5	22.2	97.5
Ranger Gold	46.5	53.8	1.90	71.5	20.0	97.8
Rowan Ranger	43.5	57.5	1.99	70.8	19.1	98.0
Rambler Ranger	33.5	74.6	2.15	70.3	18.1	98.5

ADG = Average Daily Gain; FCRadj = adjusted Feed Conversion Rate to 2,5 kg; Evis% = Eviscerated Yield; Breast%=Breast Yield %.

Ross 308 and 708 are well known and established commercial genotypes in the broiler industry worldwide while the remaining broiler types are a range of slower growing genotypes, part of Aviagen's Rowan Range (http://eu.aviagen.com/brands/rowan-range/) portfolio. The growth rates of five slow grow genotypes fall within the acceptability of current accreditation schemes in the EU like 'Kip van Morgen' and 'Beter Leven' in the Netherlands, and 'Deutsche Tierschutzbund' in Germany.

Table 1 shows the wide biological performance differences to reach 2.5kg between the fastest (Ross 308) to the slowest (Rambler Ranger) genotype: 31.5g per day for daily gain (ADG), 36.1 days to achieve the target weight and 0.53 kg feed per kg of live weight. Comparing with the highest yielding bird (Ross 708) the gap is 3.8% eviscerated and 5.8% breast yield. In contrast with the wide differences in biological performance, the liveability differences between the fastest and the slowest genotype is only 2%. This is achieved by the use of balanced breeding goals combining biological performance and liveability and welfare related traits as explained by Kapell et al (2012 a,b) and Neeteson et al (2013) and will be addressed in the next section.

Impact of Biological Efficiency on Resource Requirements

Biological efficiency has a direct impact on resource requirements and utilisation. Table 2 shows the yearly requirements of feed, agricultural land, water and housing required for an integration processing 1,000,000 birds per week.

Table 2. Yearly requirements for feed[1], water[2], agricultural land[3], and housing[4] for seven Aviagen genotypes for an integration processing 1,000,000 birds per week with a 2.5 kg target bodyweight.

Product	Feed (Tons)	Water (Tons)	Land (Has)	Houses
Ross 308	210,600	379,080	48,232	286
Ross 708	211,900	381,420	48,530	297
Ranger Classic	237,900	428,220	54,485	398
Ranger Premium	237,900	428,220	54,485	392
Ranger Gold	247,000	444,600	56,569	633
Rowan Ranger	258,700	465,660	59,248	670
Rambler Ranger	279,500	503,100	64,012	839

[1]Feed calculated as 1,000,000 birds/week*52weeks*2.5kg*FCR; [2]Water calculated as Feed*1.8; [3]Feed assumed to be 65% Cereal (of which 60% Maize and 40% Wheat) and 35% Soy. Yield were assumed to be: Maize 9 ton/ha; Wheat 4 ton/ha; Soy 2.9 ton/ha. [4] Housing was calculated as 1,000,000 birds/week*52/Liveability/25,000 birds per house*(stocking density ratio from Ross 308 base)/Cycles per year.

As expected, the results in Table 2 show an increased requirement of resources when moving from the standard to the slower growing genotypes. When going from Ross 308 to Rambler Ranger the requirement of feed, water and land increases by 32.7% which is in direct relationship with the increase in FCR in Table 1 from 1.62 to 2.15. The increase in housing requirement is three times greater as it includes both the differences in stocking density and number of yearly cycles which are a function of the number of days to achieve the target weight. The stocking density used was 42 kg/m^2 for Ross 308 and 708, 38 kg/m^2 for Rowan Classic and Rowan Premium (i.e. conforming with the 'Kip van Morgen' requirement), and 25 kg/m^2 for Ranger Gold, Rowan Ranger and Rambler Ranger (i.e., conforming with the Beter Leven and RSPCA Assured requirement).

While results in Table 2 focus on the physical requirements, these differences will inevitably have an economic impact affecting the profitability of the integration. Clearly, integrations using slow grow options will have to rely on capturing premium product prices which exceed the increased resource requirement and cost to remain profitable. In addition, a significant shift towards slow grow genotypes globally will likely mean an increased pressure on the ingredients market due to poorer FCR, with concomitant higher prices for corn, soya and wheat, hence further driving up the production cost of meat.

Impact of Biological Efficiency on Environmental Burdens

The environmental impact of the broiler genotypes in Table 1 was compared using a Life Cycle Assessment (LCA) tool developed by Cranfield and Newcastle University (Poultry LCA Model Version 1.0). A 'cradle to farm gate' LCA approach was followed accounting for all the inputs and outputs of a production system as described by Leinonen et al. (2012). The LCA predicts the amount of carbon dioxide (CO_2) equivalents per ton of edible carcass weight for the following environmental burdens (see Leinonen et al, 2012, 2015 for details):

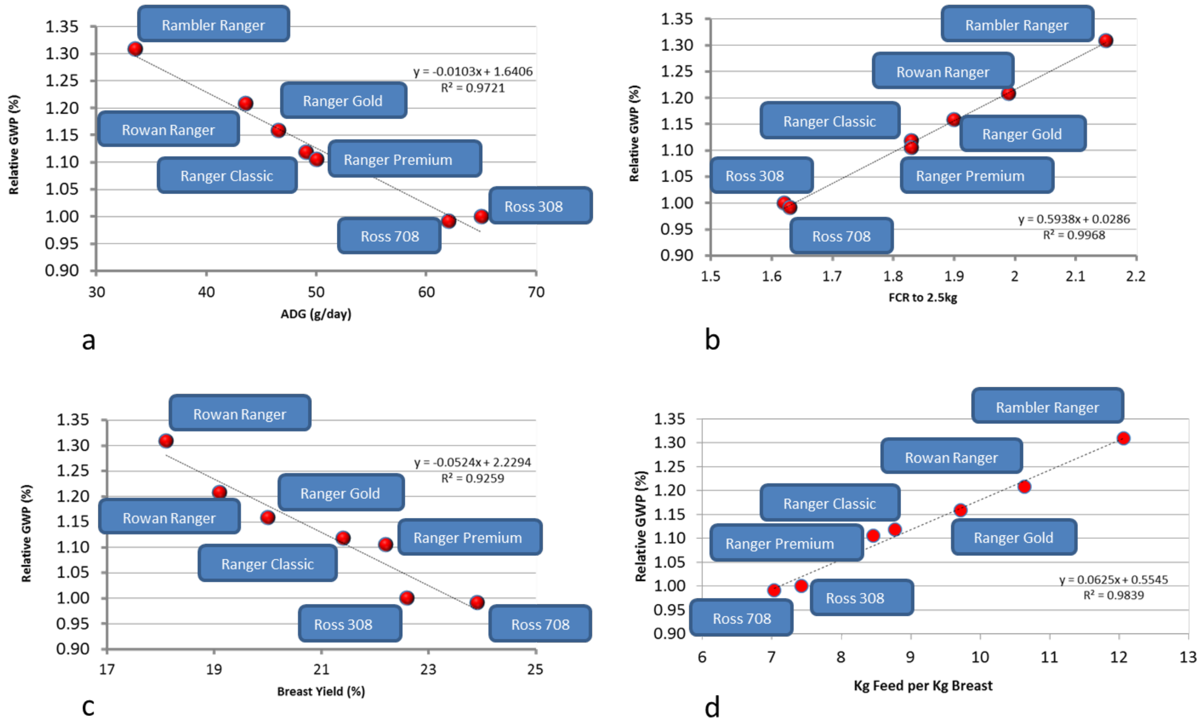
- **Global Warming Potential (GWP)**: A measure of the greenhouse emissions to the atmosphere calculated using a timescale of 100 yrs. Main contributors to GWP are CO_2 from fossil fuel and land use changes, and to a lesser extent Nitrous Oxide (N_2O) and methane (CH_4). GWP is quantified as CO_2 equivalents (1kg of CH_4 and 1kg of N_2O equivalent to 25 and 298 kg of CO_2, respectively).
- **Eutrophication Potential (EP)**: Main sources of EP are Nitrate (NO_3) and Phosphate (PO_4) leaching into the water and Ammonia (NH_3) emissions into the air. EP is quantified in terms of PO_4 equivalents (1 kg NO_3 and 1 kg or NH_3 are equivalent to 0.44 and 0.43 kg of PO_4, respectively.
- **Acidification Potential (AP):** Main source of AP in poultry are NH_3 emissions and Sulfur Dioxide (SO_2) from fossil fuel combustion. Although is alkaline, NH_3 contributes to acidification as it oxidises to nitric acid when released on the soil or into the atmosphere. AP is quantified in terms of SO_2 equivalents (1 kg NH_3 is equivalent to 2.3 kg of SO_2)
- **Primary Energy Use (PEU)**: Energy use includes diesel (e.g., feed production and transport), electricity (e.g., ventilation) and gas (e.g., heating). These are quantified in terms of primary energy needed for extraction and supply of fuels (e.g., coal, natural gas). PEU is quantified as MJ of primary energy which ranges from 1.1 MJ of natural gas per MJ of available process energy to 3.6 MJ of primary energy per MJ of electricity. A proportion of electricity is assumed to come from renewable sources (e.g., wind and hydro-power), 3.6% and 8% for UK and European Union, respectively.

The environmental burdens above were calculated on a per ton basis assuming a stocking density as mentioned above of 42 kg/m^2 for Ross 308 and 708, 38 kg/m^2 for Rowan Classic and Ranger Premium, and 25 kg/m^2 for Ranger Gold, Rowan Ranger and Rambler Ranger. A five stage feeding program was assumed (Starter: 0-11d; Grower 1: 12-21d; Grower 2: 22-32d; Finisher 1: 33-43d, and Finisher 2:44-depletion) with feed densities according to Aviagen Ross 308 broiler nutrition specifications (http://eu.aviagen.com/assets/Tech_Center/Ross_Broiler/Ross-308-Broiler-Nutrition-Specs-2014r17-EN.pdf). In other words, differences in FCR between genotypes arise from differences in feed amounts to reach the 2.5kg target weight at the corresponding age for their target daily gain, and not from differences in feed densities.

Inputs requirements for each broiler system (Electricity, Heating, Water and Bedding) were modelled based on Leinonen et al (2012) per bird values to 39d and adjusted to the corresponding age to reach 2.5kg. This means that input requirements increased linearly with bird age.

Biological efficiency is a main driver for the differences in environmental impact as shown in Figure 1 illustrating the relationship between GWP and ADG, Breast% and two indicators of biological efficiency, FCR and feed to breast ratio (FBR, kg Feed per kg of Breast derived from Table 1) adjusted to 2.5kg. As ADG and Breast % increases, GWP decreases in a linear fashion while the opposite is true for FCR and FBR. Clearly, the more biologically efficient genotypes have the lowest environmental impact in terms of pollutants emissions.

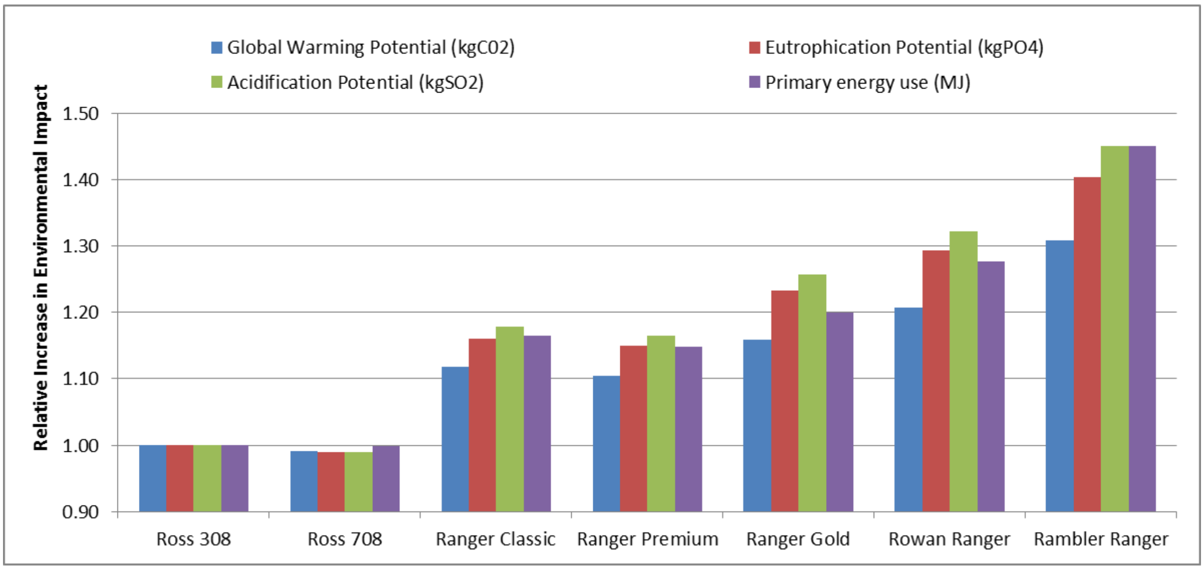
Figure 1. Relative Global Warming Potential (GWP) for seven Genotypes as a function of ADG (Average Daily Gain, g/day), FCR (Feed Conversion Rate, kg/kg), Breast Yield (%) and Feed to Breast rate (FBR, kg/kg), Ross 308 is based for comparison at 1.0



These results are consistent with the findings by Leinonen et al (2012) which showed that a free range and an organic production system had a predicted higher GWP of 16% and 28%, respectively over a standard production system. The same linear relationships between AP, EP and PEU and biological performance were also observed (results not shown).

Figure 2 shows the relative levels of GWP, AP, EP and PEU with Ross 308 taken as the base reference level (1.0) for the seven genotypes evaluated. Ross 308 and 708 had the lowest predicted environmental impact while the slow grow genotypes are predicted to increase environmental impact from around 10% to 30% for GWP and 12% to 45% for AP, EP and PEU.

Figure 2. Relative environmental impact of seven Aviagen genotypes to 2.5 kg bodyweight (Ross 308 is base for comparison at 1.0)



As mentioned previously for GWP these results agree with the findings by Leinonen et al (2012) who showed that a standard production system had lower EP, AP and PEU than a free range and an organic production system. In the study by Leinonen et al (2012) the organic production system had the highest environmental burdens with 40% higher EP, 96% higher AP and 59% higher PEU compared to the standard production system.

Leinonen et al (2012) also showed how biological efficiency, in terms of feed requirements and length of the production cycle, are linked to the environmental impact of different production systems inputs. The highest environmental impact on GWP and PEU was feed (including production, processing and transport) and water usage which contributed to about 70% of the GWP and 65% to 80% of the PEU depending on the production system. Farm gas and oil had the second highest impact in PEU ranging from 12-25% followed by farm electricity (ventilation, feeding and lighting). The use of gas, oil and electricity is generally lower in free-range and organic systems but the lower usage of these inputs does not compensate for the greater FCR and production cycle length.

In conclusion, the impact of genotypes with lower biological efficiency on resource utilisation and environmental burdens can range roughly between 30% to 40% higher when compared to conventional genotypes. On the other hand, more broadly, the suitability of a genotype to a production system or market segment will depend not only on biological performance but also on consumer preference, product price and other product attributes including the perceived balance between performance and welfare.

Managing the trade-offs between environmental sustainability and bird welfare.

Genetic improvement in broiler and breeder biological efficiency is predicted to contribute to lower environmental footprint. Leinonen et al (2016) predicted that selective breeding for broiler (feed efficiency, liveability and carcass yield) and breeder (chick output) performance can contribute to cumulative reductions in EU (12%), AP (10%) and GWP (9%) and PEU (4%) over a 15 years horizon.

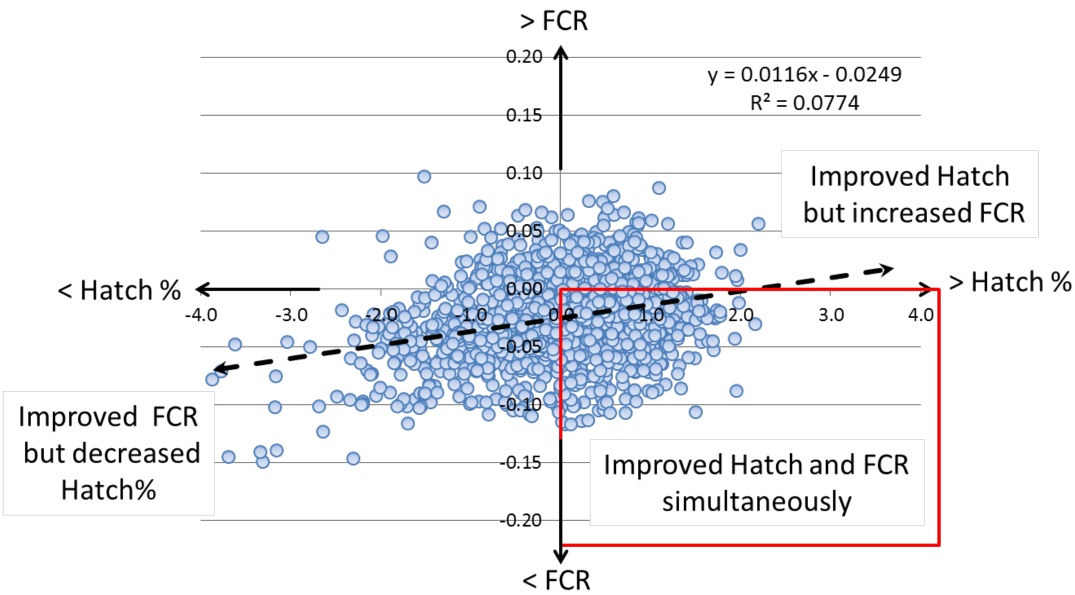
This result highlights the importance of maintaining sustainable long-term genetic trends for biological performance. At the same time, concerns have been raised with regards to potential undesired consequences of genetic selection for biological efficiency on welfare related traits (Dawkins and Layton, 2012; Hocking, 2014).

From a breeding point of view, the key parameter that controls the extent of the genetic antagonism between traits in a breeding goal is their genetic correlation (GC). In simple terms the GC measures the extent to which two traits are controlled by the same genes. A favourable GC means that the genes controlling both traits have the same effect on each trait while an unfavourable or antagonistic correlation means that the effect is the opposite in each trait. One well known trait antagonism in broiler breeding is the antagonistic relationship between broiler and breeder performance. This has led to one of the most popular paradigms in broiler breeding: "..if broiler performance is improving, it is very likely that breeder performance will suffer..".

The genetic antagonism between FCR and Hatch% is illustrated in Figure 3 which shows the estimated breeding values (EBVs) for 1385 birds as deviations from the population mean, with Hatch % on the horizontal axis and FCR on the vertical axis. In this dataset, the GC between Hatch% and FCR is 0.27 - which is typical for the antagonism between broiler and breeder performance traits. The dotted double arrowed trend line indicates that as we move further to the left we will find birds with better FCR (i.e., lower) but worse Hatch % while to the right we find birds with improved Hatch but poorer FCR (i.e., higher). In this example FCR would deteriorate at a rate of 0.012 (i.e., 12 g of feed per kg of live weight) per every percent increase in Hatch.

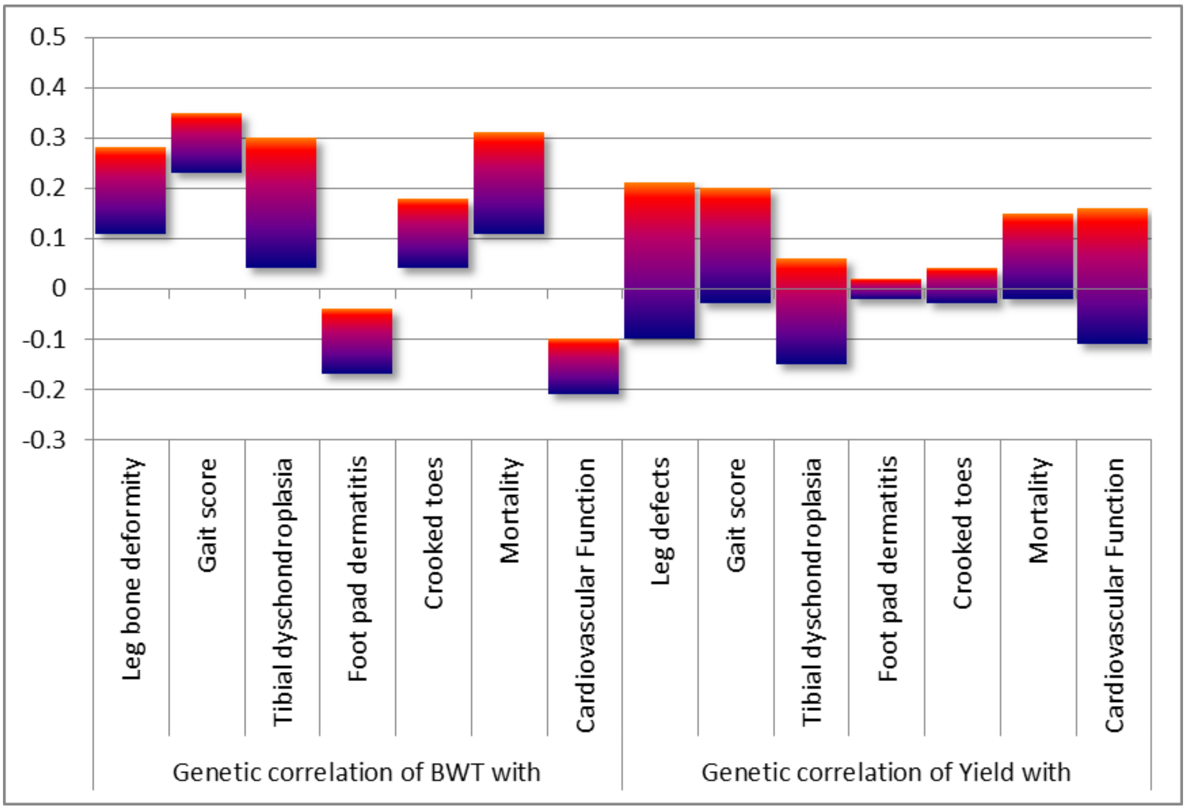
The way to deal with this antagonism is to have both traits in the breeding goal and select for birds which are good for both traits at the same time. This is illustrated by the red box which contains the quadrant with birds having EBVs that are better than the population average for both traits simultaneously.

Figure 3. Estimated Breeding Values (EBVs) for FCR (Feed Conversion Rate; vertical axis) and Hatch % (horizontal axis) as deviations from the population mean.



The same concept illustrated above applies to the genetic antagonism between biological performance and welfare related traits. Figure 4 shows the range of GC (across a number of elite broiler breeding lines) between Live Weight (LWT) and Breast Yield (BY, %) and a range of welfare related traits: with Leg bone Deformities (LD, %), Gait Score (GS), Tybial Dyschondroplasia (TD, %), Foot Pad Dermatitis (FPD, %), Crooked Toes (CT, %), Mortality (MOR, %) and Oxygen Saturation level in blood (OXI, %). Clearly, all the correlations are below 0.5 indicating that the extent of the antagonism is not extreme. A maximum GC of 0.35 between LWT and GS while in some cases the antagonism is low (e.g., when the bars are very close to 0) or there is no genetic antagonism at all, for instance between LWT and FPD or between BY% and TD, FPD, CT and in some cases with OXI.

Figure 4. Ranges of Genetic correlations between Live Weight (LWT) and Breast Yield (BY%) with Leg Bone Deformities (%), Gait Score, Tibial Dyschondroplasia (%), Foot Pad Dermatitis (%), Crooked Toes (%), Mortality (%) and Oxygen Saturation levels in blood (%).



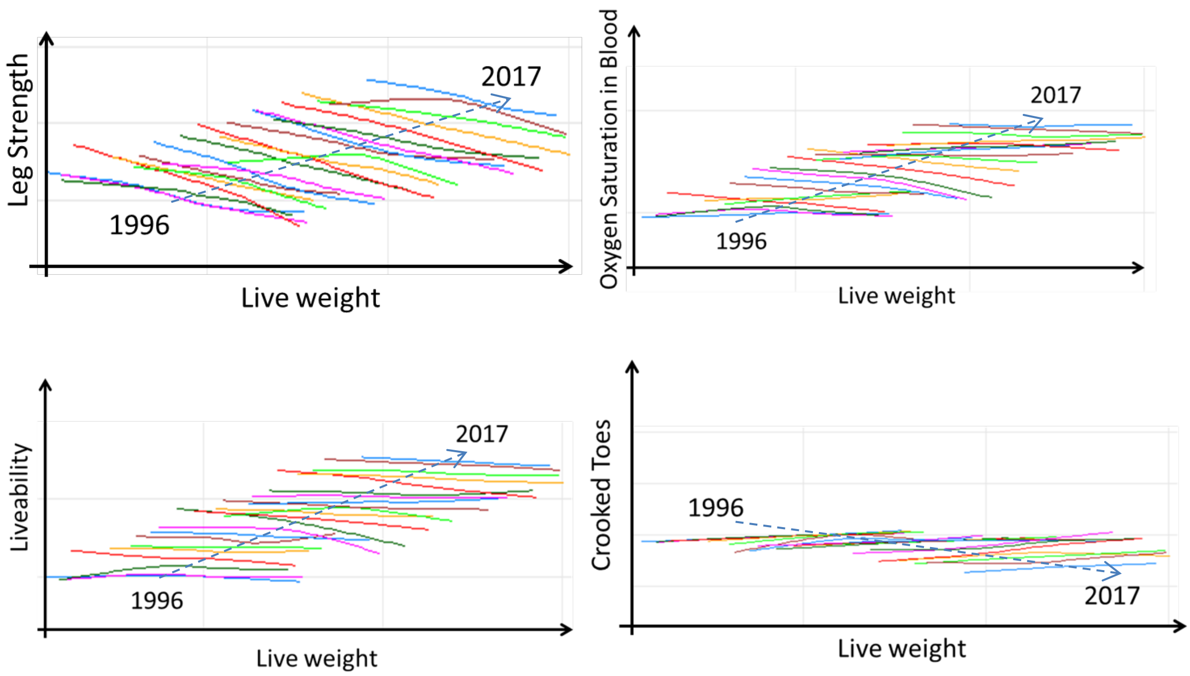
The above ranges of GC are of crucial importance because they indicate that there are ample opportunities to improve both biological performance and welfare related traits even in the presence of genetic antagonisms when both groups of traits are included in a broad and balanced breeding goal. This is what has been taking place over the last decades in the Aviagen breeding programme and will continue in the future.

Scientifically one can conclude that without selection for e.g., LWT the improvement in welfare traits can go somewhat faster albeit at the expense of economic and environmental gains. This translates potentially in a wider portfolio of genotypes that can fulfil varying societal demands, be it for environmental efficiency or slower growth with somewhat further improved welfare.

Neeteson et al (2013) illustrated how growth rate and leg strength can be improved simultaneously over the long term while the antagonistic genetic relationship between both traits holds within a year. Figure 5 extends the approach followed by Neeteson et al (2013) to, based on Aviagen breeding program data, describe the joint trajectory between LWT and

OXI, Liveability, LD and CT over 22 years from 1996 to 2017. Each coloured line shows the relationship between the traits EBVs for selection candidates hatched in a specific year. The broken arrow represents the joint direction of the average breeding value for each trait involved in the trade-off. The relationships between traits remains antagonistic within each year but there is a favourable trajectory for each trait because of simultaneous selection, that is, as BWT increases, cardiovascular function, liveability, leg strength increases while CT decreases. In addition, it can be seen that the worst EBVs for OXI, LIV, LD and CT in 2017 are far better than the maximum of the 1996 birds.

Figure 5. Long term relationships between Live Weight and Leg Strength (%), Livability (%), Oxygen Saturation in Blood and Crooked Toes (%). Each coloured line represents the relationship between breeding values for each trait within a year. The broken arrow represents the joint direction of the average breeding value for each trait involved in the trade off.



The above examples show the principle of multi-trait genetic selection in the presence of trait antagonism and demonstrates that when traits are included in a broad breeding goal and balanced selection is applied, the desired direction in each trait can be achieved.

The incorporation of novel recording and analytical approaches for predicting genetic values with higher accuracy is critical for both the genetic improvement of sustainability and welfare and the handling of trait trade-offs. Examples of this have been the use of transponder technology to record feed intake in large groups (Howie et al., 2011) to improve feed efficiency, and the use of X-ray technology to detect the sub-clinical incidence of Tibial Dyschondroplasia (Kapell et al, 2012b).

The recent introduction of Genomics information and 3D imaging technology in broiler breeding provide unprecedented opportunities to the management of the trade-offs between traits, particularly important in traits that are not expressed in the selection candidate, for instance, traits expressed by one sex only (e.g., egg production, fertility and hatchability) traits or processing and meat quality traits.

The above novel recording technologies coupled with the routine recording of both the performance traits (e.g., BWT, BY%, FCR) and the welfare related traits (e.g., leg health and contact dermatitis) and their inclusion in the breeding goal allow for the long term management of the trade off as illustrated by Kapell et al. (2012a, b). This agrees with Hill (2016) who concluded that continued genetic responses for production efficiency while minimising demand on resources without sacrificing animal health and welfare is feasible within a multi-trait selection set up including both fitness and production traits.

From a line improvement perspective, the focus on selection accuracy, novel recording technology and management of trade-offs applies to both conventional and slow grow genotypes as any product arising from these has to be both competitive and sustainable.

Future Breeding Goals and Genotype portfolio

Broiler breeding goals have expanded vastly in the last three decades, combining productivity and biological efficiency with liveability, robustness, adaptability and reproduction (Neeteson et al; 2013). This process of breeding goal expansion is not expected to stop but to continue even further. Below there is a list of key global drivers and their link with future breeding goals:

i. Broiler production will keep expanding globally, particularly in developing economies and in countries with surplus grains (OECD/FAO, 2016). Therefore, broiler genotypes will have to be able to express their genetic potential in a wide range of geographical and production environments and adapt to changes in feed composition, and gut and immune challenge. Biological efficiency (feed and water) and robustness will indeed be major drivers and will have to be expressed in a range of feed types and climates worldwide.

ii. Antibiotic free production, in particular the elimination of sub-therapeutic doses of growth promotion antimicrobials is gaining momentum both in Europe and USA. This clearly means that liveability and robustness through a better gut and immune function will be of key importance. Understanding the gut function in relation to nutrient absorption and as a physical barrier to bacterial challenge, and how gut bacterial communities impact both biological performance and immune response will be of paramount importance. In this scenario, there is a clear link between sustainability through biological performance and welfare through robustness and liveability.

iii. An evolution of consumer choice drivers. A study by Deloitte (Ringquist, et al. 2015) in the U.S. identified a shifting of consumer value drivers. While historically consumers made decisions based 'Traditional Drivers' (price, convenience and taste), a new set of 'Evolving Drivers' including Health and Wellness, Safety, Social Impact, Experience and Transparency are now influencing consumer purchase decisions. This study shows that about 50% of the purchase decisions were influenced by Evolving Drivers, and the corresponding broader purchase consideration arising from these new drivers was independent from region, age and income level. In addition, the consideration of Evolving Drivers in purchase decisions was important in both elaborated products (e.g., fresh prepared meals 66%) and non-elaborated products (e.g., meat, fish and poultry 49% and dairy 42%). Clearly some of the Evolving Drivers will be more related to retail aspects (e.g., safety), but social impact and health and wellness, have a direct link with breeding goals through sustainability, animal welfare and reduced usage of antimicrobials, respectively.

From a breeding perspective, the above means the following:

i. A continual expansion of breeding goals with the ability to change and adapt as a response to current and future changes in global trends. This, in plain words just means More Balanced Progress across More Traits!

ii. An expanded genotype portfolio to be able to address the whole spectrum of industry requirements, from covering the sheer scaling up of broiler meat production and demand globally in a sustainable way to providing options to emerging niche markets (e.g., free range and organic). Thus, the need for large genetic pools suitable to generate broiler products aligned with current and future market needs.

iii. Continued investment in R&D to elucidate the genetic basis of novel traits and emerging genetic correlations and trade-offs between new and existing traits in the breeding goal. This includes investing in novel recording and selection techniques for the improvement of genetic lines contributing to conventional and slow grow products.

In a growing and evolving marketplace, there will be room for both conventional and slower growing genotypes. While it is difficult to predict the relative representation of each type of product globally or regionally, clearly the focus from the primary breeder will be to offer genetic potential suited to all market segments while fulfilling sustainability requirements from economical, biological, welfare and environmental considerations.

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