NUFFIELD COUNCIL ON BIOETHICS

Review of literature and publicly available data on the longitudinal effect of balanced breeding strategies in context of historical health and welfare outcomes.

Prepared by Molly Gray

September 2021

Table of Contents

Summary

This review examines literature and publicly available data on the longitudinal effects of selective breeding programmes on historical farmed animal health and welfare issues. In addition, this review will explore modern breeding technologies and opportunities such as genome-editing tools that could be used within breeding programmes. This examination includes an overview of published data which examines any improvements balanced breeding strategies may or may not have achieved at addressing health and welfare problems in four farmed animals: broilers, pigs, cows and aquaculture.

The review indicates the following conclusions:

- Animal breeding programmes have the ability to improve the health and welfare of farmed animals but also negatively impact the animal.
- Breeding programs that only or predominantly focus on production traits will likely increase the prevalence of welfare problems found among farmed animals. Balanced breeding programmes are needed for farm animal species which encompasses both production, health and welfare, and sustainability traits. A greater emphasis on non-production traits in breeding programs is needed to see bigger and quicker improvements in the welfare and health of farmed animals.
- The intensity of selection and welfare consequences varies between livestock species. In some instances, health and welfare improvements have been achieved through breeding programmes, for example, addressing skeletal leg disorders in broiler chickens. However, more reliable peer-reviewed data is needed that reflects the subtle impacts of including health and welfare traits in breeding programmes over time, especially in pigs and chickens.
- Genetic progress using selective breeding is dependent on traits having a level of heritability, the generation interval of species and targeting multiple traits in a breeding program.
- The genetic era and the increasing discovery and development of novel genetic techniques have the potential to uncover the heritabilities of different welfare and health traits that could impact breeding decisions. Genetic tools will likely help in the understanding of complex traits, and targeted genome selection approaches that could address different phenotypes. The development of new measurement technologies could offer breeding companies the opportunity to more accurately monitor and record health and welfare traits in real-time, which could influence the accuracy of breeding programme data.
- Broadening breeding goals to include health and welfare traits can positively impact societal demand for higher-welfare meat production and positively affect the selection of productivity traits simultaneously.
- Gene-editing technology has the potential to offer a new opportunity within the breeding industry to address health and welfare issues observed in multiple farmed animals species, with a primary focus likely on disease resistance. A key example is the modification of the CD163 gene in pigs resulting in complete resistance to PRRS virus.
- Gene-edited stocks will have to be carefully studied and managed to ensure the genes being modified have the desired effect intended and does not create any other off-target effects before spreading through breeding populations.
- Genome-editing would need to be integrated into well-managed selective-breeding programs and depend entirely on the acceptability from the public and the regulatory landscape.
- Welfare surveillance and standardised welfare assessments have the potential to identify welfare issues as they arise, with the possibility to incorporate them into breeding programmes as quickly as possible instead of many years later.
- As illustrated by the Scandinavian countries, integrated centralised databases which collect data from abattoirs, health data from veterinary services and on-farm

surveillance from both the individual animal and the herd resulted in the successful recording, evaluation and selection for health and welfare traits. Establishing similar animal recording systems, especially in the dairy industry, would be of great benefit to UK farmers to help guide daily decisions and aids in the detection of change in health and productivity over time. Centralised systems also provide the opportunity to compare herds and are accessible data sources for breeding programmes.

Background

1 Farmed animals, in particular broiler (meat) chickens, pigs, cows and aquaculture have been selected by breeders for various traits since domestication. Since the 1970s-1980s, it has been well documented in the literature that selective breeding of farm animals for productivity traits can have adverse consequences for their health and welfare. Examples of health and welfare problems in farmed animals can be considered in relation to the impact of breeding techniques, with over 100 issues associated with livestock breeding programmes described by Rauw and colleagues in 1998.[1] The broiler chicken has some of the most documented welfare issues associated with commercial breeding methods where selection for increased growth rate is negatively related to leg and cardio-pulmonary problems.[2] However, the factors that influence welfare outcomes are multi-factorial, and the environment and management conditions can also influence the health and welfare of an animal. Traditional selective breeding methods and breeding technologies can both impair and improve different aspects of the health, welfare and productivity of farmed animals.

2 Although major breeding companies have acknowledged the issues with welfare and have been incorporating health, fitness, and welfare traits into their breeding programs for several decades; modern commercial strains of animals are still reported to have key welfare issues making it unclear how much of a difference selective balanced breeding is making on animal welfare over time.[3] Existing literature and studies looking into these improvements are mainly over a decade old or focus on free-range systems, which only make up a small amount of production systems, creating a need to understand if the modifications in selection programmes have had a positive outcome on the health and welfare of farmed animals over the last 40 years. Recent developments and availability in genomics have revolutionised terrestrial livestock breeding, and novel gene-editing tools (using CRISPR/Cas9) open up the potential for step changes in trait improvement to address both production barriers and health and welfare outcomes.

Aims of this review

3 This rapid review aims to consider a wide range of literature and data explaining and exploring if balanced breeding strategies are readdressing the health and welfare outcomes associated with the historical breeding of different farmed animals. This review will include a brief overview of the current regulations and initiatives relating to

[1] Rauw WM, Kanis E, Noordhuizen-Stassen EN and Grommers FJ (1998) Undesirable side effects of selection for high production efficiency in farm animals: a review *Livestock Production Science* **56**: 15-33

[2] Farm Animal Welfare Council (1998) *Report on the welfare of broiler breeders*, available at: https://www.gov.uk/government/publications/fawc-report-on-the-welfare-of-broiler-breeders

[3] Farm Animal Welfare Committee (2012) *Opinion on the welfare implications of breeding and breeding technologies in commercial livestock agriculture*, available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/324658/FAWC_opinion_on_the_welfare_implications_of_breeding_and_breeding_technologies_in_commercial_livestock_agriculture.pdf

animal breeding and animal welfare in the UK and EU, including any welfare protocols used to measure welfare outcomes in commercially farmed animals. It addresses three key questions:

- Have balanced breeding strategies improved the health and welfare outcomes associated with historical selective breeding of different farmed animals?

- Are selective breeding methods, which seek to improve animal health and welfare, addressing issues related to the animal itself or are they mitigating the adverse health effects of keeping animals in management conditions?

- To what extent does the regulatory environment affect trait selection in breeding programmes in the UK and EU and thus improve the health and welfare of farmed animals? What animal welfare protocols are used to assess welfare indicators of farmed animals?

4 Where possible, each of these questions will be applied to each of the farmed animals focusing on broiler chickens, pigs, cows, and aquaculture. The findings of this review will inform the Nuffield Council on Bioethics' project on Genome Editing in Farmed Animals, which will be published in 2021.

Review methods

Identifying of literature and publicly available data

5 Advice on relevant literature will be gathered from working group members, Council members and other academics working in the field of farming, breeding, genetics and animal welfare. Identifying any evidence-based academic/peer-reviewed literature available to address the key research questions. Information and data collection include the following main topics:

- Selective breeding of animals and its impact on the welfare of farmed animals (predominantly broiler chickens, pigs, cows but also addressing aquaculture);
- Improvements in animal health and welfare indicators through selective breeding;
- The relationship between incorporating health and welfare parameters in selective breeding programmes and the management conditions animals are kept in;
- The regulatory context in the UK and EU for selective breeding and welfare;
- If there are any baseline welfare standards/protocols.

6 Key words relating to animal breeding and welfare were identified and used to construct search terms that formed the basis of this review. Initially, the key terms searches used were: selective breeding, breeding, genetics, welfare, animal welfare and animal husbandry. More specific word searches were conducted with the key words listed above, each relating to a specific farmed animal search below:

Broiler* OR meat chicken* OR poultry* AND animal welfare* AND breeding*

Pig* OR piglet* OR sow* AND animal welfare* AND breeding*

Cow* OR dairy cow* OR cattle* AND animal welfare* AND breeding*

Fish* OR mariculture *OR aquaculture* AND animal welfare* AND breeding*

Specific species groups were targeted in the search, for example, 'Atlantic salmon' 'rainbow trout', and 'carp' in this instance.

7 The search terms were entered into Google (in order to gather grey literature) and into the following online databases: PubMed, Google Scholar, ScienceDirect and Scopus (https://pubmed.ncbi.nlm.nih.gov/; https://scholar.google.co.uk/; https://www.sciencedirect.com/; https://www.scopus.com/). The searches were limited to literature published after 2019 to the present day in English.

8 The first five pages of each set of results will be reviewed. Online searches will be supplemented by reviewing:

- Relevant material cited in articles identified as searching above.
- Other relevant material by authors of articles identified by searching as above.

Consultations with stakeholders

9 Information on any published literature and longitudinal data will also be sought by contacting balanced stakeholders involved in the breeding of animals. Stakeholders will be invited to meet with the NCOB executive working on the farmed animals project. The aim of meeting with breeders is to inquire if they can provide any recent evidence if breeding strategies are readdressing historical health and welfare problems. In other words we wanted to contact breeders to see to what extent they can provide current evidence which can address the research questions proposed.

10 We identified a list of stakeholders to contact including:

Commercial breeding companies

- Aviagen
- PIC
- Benchmark Genetics

Regulators of breeding practices

- The European Forum of Farm Animal Breeders (EFFAB)
- Department for Environment Food & Rural Affairs (DEFRA)
- The Agriculture and Horticulture Development Board (AHDB)
- Animal and Plant Health Agency (APHA)
- Association of the European Poultry Breeders (EPB)
- International Poultry Welfare Alliance (IPWA)
- European Live Poultry and Hatchery Association (ELPHA)

Other

- Professor Eileen Wall – Head of Research at Scotland's Rural College (SRUC)
- Dr Ingrid de Jong – Senior Researcher Poultry Welfare at the Wageningen Livestock Research
- Paul Tompkins – Dairy Farmer
- John Armour and Elizabeth Bauld – Agriculture Policy Division, Scottish Government
- John Royle – National Farmers' Union
- Rebecca Veale – National Pig Association
- Philip Hailhead – Norbreck Genetics
- Michael Lohuis - Semex

Broilers

11 This section examines if broiler breeding companies have incorporated welfare traits in their selective breeding programmes to improve broiler health and welfare over time.

Have balanced breeding strategies improved the health and welfare outcomes associated with the historical selective breeding of different broilers?

12 Since the 1950s, the primary trait selected for in the modern broiler has been growth rate, with evidence to suggest there has been a 400% increase in broiler growth rate between the years of 1950-2005.[4] More recently, genetic selection strategies have focused on high breast yield, liveability and feed use efficiency.[5] It has been well documented that selection for increased growth rate has been associated with multiple welfare problems, particularly skeletal leg and cardio-pulmonary problems. Other welfare issues related to the modern broiler include ascites, footpad dermatitis, hock burns, gut health problems and sudden death syndrome.[6] Improving animal welfare can be obtained by including welfare indicators in the breeding selection index; however, the priority to include welfare traits in genetic lines remains low.[7] In some instances, there is evidence to suggest breeding companies have addressed some of the issues associated with historical selective breeding. For example, the prevalence of leg disorders have been decreasing over the last 30 years, whilst other health conditions have primarily remained the same.

Skeletal leg health disorders

13 Since the 1980s, leg health disorders have been identified as a key welfare issue in broilers which has been beyond a doubt been associated with selection for increased growth weight. Leg health traits include deformities of the long bones, crooked toes and tibial dyschondroplasia (TD). In 2000, The Science Committee on Animal Health and Animal Welfare (SCAHAW) recommended that breeding companies improve the leg strength and walking ability caused by selection for increased growth rate and productivity.[8] A few studies have shown successful selection for improved leg health traits through genetic breeding programs over the last 30 years. A notable study carried out by Kappell et al., 2012 (*see Table 1*) examined the long-term changes to broiler leg health through the Aviagen UK breeding program between 1986-2010. The results show considerable decreases in the prevalence of leg disorders (long bone deformity, crooked

---

[4] Zuidhof MJ, Schneider BL, Carney VL, Korver DR and Robinson FE (2014) Growth, efficiency, and yield of commercial broilers from 1957, 1978, and 2005 *Poultry Science* **93**: 2970-82

[5] Renema RA, Rustad ME and Robinson FE (2007) Implications of changes to commercial broiler and broiler breeder body weight targets over the past 30 years *World's Poultry Science Journal* **63**: 457-72

[6] McKay JC, Barton NF, Koerhuis ANM and McAdam J (2000) The challenge of genetic change in the broiler chicken *BSAP Occasional Publication* **27**: 1-7

[7] RSPCA (2020). Eat. Sit. Suffer. Repeat. The life of a typical meat chicken. [Online] [Accessed 18-03-2020]

[8] Scientific Committee on Animal Health and Animal Welfare (SCAHAW) (2000) *The welfare of chickens kept for meat production (broilers)*, available at: https://ec.europa.eu/food/sites/food/files/safety/docs/sci-com_scah_out39_en.pdf

toes, tibial dyschondroplasia and hock burns) achieved by genetic selection and accurately scoring of leg defects over 25 years.[9]

14 Data provided from the commercial breeding company Aviagen indicates a decrease in birds with affected leg defects over a 25 year period (1986-2016) for the Ross 308 cross-breed (fast-growing strain). In particular, the data shows a reduction of TD in affected Ross 303 pedigree birds between 1992-2016.[10] This research used an X-ray device called the Lixiscope as the tool for TD selection. What is unclear from this report and data presented is the methodology used to score TD using the Lixiscope and which score constitutes being classified as having TD and thus included in the data. Furthermore, the report does not state if all broilers scored for TD were kept in the same management conditions making it difficult to understand how the uniformity of assessments where achieved. This highlights the problems of interpreting data that has not been peer-reviewed.

15 Based on the Aviagen breeding programme information, data was reported in 2017, which describes the trajectory between live body weight and welfare traits of broilers, including leg strength, over 21 years from 1996-2017. The figures presented in the report illustrate that within a year, the relationship between two traits, leg strength and growth rate, remain antagonistic but simultaneously improved over time due to simultaneous selection.[11] It is unsure from the data how many selection candidates are recorded in a specific year or from which strain of bird.

16 Nevertheless, a large study completed in 2020 at the University of Guelph claiming to be "the most comprehensive study of broiler chicken welfare worldwide" have found few indicators of leg bone issues, specifically TD and long bone deformities, among different commercial strains of broiler chickens. The summary of results, released ahead of being published in peer-reviewed journals, indicate the successful incorporation of these welfare traits into selection indices across strains.[12]

Cardio-pulmonary disorders

17 Genetic selection for an increased growth rate in broilers can cause higher levels of oxygen demand in parts of the body, creating pressure for the heart and lungs. This can increase the risk of broilers suffering from two types of heart conditions known as ascites and Sudden Death Syndrome (SDS).[13]

18 In 1991, Aviagen started using pulse oximetry, which measures the oxygen saturation level of the blood (OXI, %) in broilers and indicates the susceptibility to develop ascites and SDS. Data provided from Aviagen, measured by the Agriculture and AgriFood

---

[9] Kapell DNRG, Hill WG, Neeteson AM *et al.* (2012) Twenty-five years of selection for improved leg health in purebred broiler lines and underlying genetic parameters *Poultry Science* **91**: 3032-43

[10] Neeteson A-M, Swalander M, Ralph J, Koerhuis A. Decades of welfare and sustainability selection at Aviagen chickens and turkeys. Aviagen Brief. 2016. [cited 27 June 2019]. http://en.aviagen.com/assets/ Tech_Center/Broiler_Breeder_Tech_Articles/English/AviagenBrief-DecadesOfWelfare-2016-EN.pdf.

[11] Proceedings Poultry Beyong 2023 Conference (2017) *Broiler Breeding for Sustainability and Welfare – are there Trade-Offs?*

[12] https://globalanimalpartnership.org/wp-content/uploads/2020/09/Better_Chicken_Project_Summary_Report_Global_Animal_Partnership.pdf

[13] Scientific Committee on Animal Health and Animal Welfare (SCAHAW) (2000) *The welfare of chickens kept for meat production (broilers)*, available at: https://ec.europa.eu/food/sites/food/files/safety/docs/sci-com_scah_out39_en.pdf

Canada (AAFC), suggests a reduction in the level of ascites between 1995-2018. Within the chapter, it is summarised that "ascites levels as measured by AAFC have fallen correspondingly from about 36 per 10,000 birds slaughtered (1995) to about 8 (2008), and continue to stay low".[14] Whilst this indicates a reduction in the incidence of ascites within broilers over time, the data uses condemnation statistics (due to ascites) and does not include affected birds that die on farms or during transport making it unclear what percentage of all broilers in breeding programmes may suffer from ascites but may die before the time of slaughter. Moreover, broilers condemned for other conditions (e.g. cellulitis) but may have ascites are not included in the condemnation records as ascites.

19 Overall, there is little published information on the prevalence of ascites within broiler breeding programmes and no longitudinal data from breeding companies published in peer-reviewed journals which show the reduction in ascites in commercial broilers due to genetic selection. With recent papers still stating that ascites is a major issue within broilers, more studies are needed using on-site clinical diagnosis of broilers with ascites to measure the condition's prevalence in broiler breeding programmes over time.

Health and welfare outcomes of fast and slow-growing breeds of broilers

20 Conventional fast-growing breeds have been intensively selected for efficient growth, high breast meat yield and improved feed conversion rates. In the UK, 94% of broiler chickens are a faster-growing breed, weighing on average 2.2kg at the time of slaughter at 5-6 weeks of age.[15] The most extensively fast-growing breeds used worldwide are the European Ross 308 (Aviagen), Cobb 500 and Hubbard Flex. These faster-growing strains have resulted in many health and welfare issues, including preventing natural behaviours such as foraging, locomotion and mobility. As mentioned in the previous section, breeding companies have successfully incorporated some welfare indicators into the selection index in a few genetic lines; however, the priority given to health and welfare indicators still remains low. Therefore, more attention is being paid to the use of alternative strains of 'slow'-growing broiler chickens, which require a longer rearing period to reach the desired slaughter weight but have been associated with decrease welfare issues.

21 There has been relatively limited literature comparing the health and welfare outcomes of slow-growing and fast-growing broiler breeds kept under the same conditions until recently. A few recent studies have compared fast-growing and slow-growing strains reared in the same conditions (*see Table 1).* The studies consistently show fast-growing breeds have worse health and welfare outcomes (including more hock burns, lameness, and less time performing natural behaviours and more time sitting) than slower-growing broilers. The studies conclude a genotype associated with a lower growth rate is one of the major determining factors to improve broiler health and welfare.

22 A recent study of particular significance by Dixon (2020) compared the three most commonly used fast-growing strains from broiler breeding companies to a commercially used slower-growing broiler housed in the same indoor conditions. The study found slower-growing birds had improved welfare and behaviour measures, including lower mortality rates, lower gait, hock and cleanliness scores and increased activity levels compared to faster-growing birds. The study also found that despite fast-growing birds having better production rates, they had worse meat quality, affecting animal welfare

---

[14] Neeteson A-M, Avendaño S and Alfons K (2020) Poultry breeding for sustainability and welfare, in *The Economics of Farm Animal Welfare: Theory, Evidence and Policy*CABI)
[15] DEFRA (2021) *United Kingdom poultry and meat statistics - May 2021*, available at: https://www.gov.uk/government/collections/poultry-and-poultry-meat-statistics

due to muscular deterioration.[16] This study assessed the welfare by conducting welfare assessments (*see section on regulations for more information*) and compared breeds kept in the same conditions, which allow for scientific comparison. However, the study kept the birds in a high welfare environment (such as the litter being kept dry) and a low stocking density that might not represent the conditions found in a commercial environment. Therefore, it would be useful to replicate the study to fully quantify the health and welfare outcomes of fast-growing and slow-growing broiler breeds under commercial conditions.

23 As mentioned in the section above, a very recent study described as "the first multi-disciplinary research project of chicken welfare to include carefully chosen indicators such as behaviour, anatomy, production, and meat quality together into one research project" has published its findings on the funder's website, Global Animal Partnership (G.A.P). The study ran over two years and included over 7,000 broiler chickens from 16 different genetic strains. The study used tests of mobility and the presence of footpad lesions and hock burns to measure if the birds were experiencing pain or poor health. The researchers outfitted a sample of birds with wearable devices to measure the bird's inactivity levels over time. They found fast-growing birds were more inactive than slower-growing birds of the same age. Overall, conventional broiler chickens grew faster and more efficiently and had higher breast yields compared to slower-growing strains. However, increased growth rate reduced activity levels, mobility and interactions with environmental enrichments, and increased footpad lesions and hock burns.

24 This literature indicates many health and welfare issues are still prevalent in broilers, and these indicators are directly related to fast growth rate and increased muscle breast. Recent research has found fast-growing strains of broilers are associated with increased health and welfare issues compared to slower-growing broilers and showing less natural behaviours such as perching, locomotion, and foraging.

Are balanced breeding methods, including animal health and welfare traits, addressing issues related to the animal itself or mitigating the adverse health effects of keeping animals in poor management conditions?

25 Impacts of breeding on health and welfare cannot be viewed in isolation, with management conditions playing a role in broiler health and welfare. There is high variability in the environments in which broilers are raised in including: temperature, housing conditions, stocking densities, outdoor access, quality of water sources, etc.) and certain breeds of broilers will likely perform well in one type of environment and poorly in another. Recently, NGOs in Europe have targeted food companies requesting several requirements relating to the health and welfare of broiler chickens. Two of these requirements are "to implement a maximum stocking density of 30kg/m" and "adopt breeds that demonstrate higher welfare outcomes".[17] These recommendations raise questions about the impact management conditions within broiler production may have on the health and welfare of broilers and the ability to genetically select birds to adapt to an environment. Analysis of this question is divided into two sections: the first summarises the aetiology of certain health and welfare indicators in broilers and genetic adaptability through breeding programmes to environments (paragraphs 28-30); the second addresses the welfare outcomes of different strains of broilers and environmental interactions (paragraphs 31-36). Similarly, Cheng (2007) proposed the question:

[16] Dixon LM (2020) Slow and steady wins the race: the behaviour and welfare of commercial faster growing broiler breeds compared to a commercial slower growing breed *PLoS One* **15**: e0231006

[17] European Chicken Commitment (2021), available at: https://welfarecommitments.com/europeletter/

"Should we change housing to better accommodate the animal or change the animal to accommodate the housing?"[18]

Genotype vs environment

26 The aetiology of particular health and welfare issues seen in broilers varies. Some traits are closely linked to the bird's growth rate, such as skeletal leg disorders and others more caused by environmental stresses such as increased ambient temperatures. Some health and welfare issues are multi-factorial, involving both environmental conditions and genetic heritability.[19]

27 Contact dermatitis is a key welfare issue associated with broilers and presents as an inflammation of the skin, most commonly found on the feet of broilers (footpad dermatitis, FPD). Contact dermatitis is primarily attributed to poor management practices, with a wet litter environment being the main underlying contributing factor.[20] However, research has reported FPD has a moderate to low degree of genetic heritability and more recent studies reporting differences in the prevalence of FPD between the most commonly used broiler breeds. This indicates the possibility of selecting broilers based on their genetic predisposition for susceptibility to contact dermatitis without negatively impacting body weight.[21]

28 In 2010, the EFSA recommended that welfare issues with a moderate degree of heritability, for example, contact dermatitis, should be included in selection programmes in combination with improving good litter management to improve the welfare of broilers.[22] A study in 2006 found significant differences in FPD incidence between a slow-growing and fast-growing strain of broiler, with no FBD lesions found compared to 40%, respectively.[23] This is likely due to fast-growing birds spending more time sitting and in contact with the litter surface than slow-growing broilers. This indicates continued selection for growth rate will lead to an increased prevalence of FPD. Contact dermatitis is an example of a welfare issue where based on the traits heritability estimates may be achievable to be successfully included in selection indices, alongside improving litter management practices, to decrease its prevalence in commercial breeding programmes.

Welfare outcomes of slow-growing and fast-growing broilers in higher welfare systems

29 Currently, there is an increasing trend to move towards broiler production systems of 'higher welfare'. The definition of a higher welfare system varies within- and between

---

[18] Cheng H-W (2007) Animal welfare: should we change housing to better accommodate the animal or change the animal to accommodate the housing? *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources* **2**

[19] EFSA Panel on Animal Health and Welfare (2010) Scientific Opinion on the influence of genetic parameters on the welfare and the resistance to stress of commercial broilers *EFSA Journal* **8**: 1666

[20] Scientific Committee on Animal Health and Animal Welfare (SCAHAW) (2000) *The welfare of chickens kept for meat production (broilers)*, available at: https://ec.europa.eu/food/sites/food/files/safety/docs/sci-com_scah_out39_en.pdf

[21] Kjaer JB, Su G, Nielsen BL and Sørensen P (2006) Foot Pad Dermatitis and Hock Burn in Broiler Chickens and Degree of Inheritance *Poultry Science* **85**: 1342-8; and Martins B, Martins M, Mendes A, Fernandes B and Aguiar E (2016) Footpad dermatitis in broilers: differences between strains and gender *Brazilian Journal of Poultry Science* **18**: 461-6

[22] EFSA Panel on Animal Health and Welfare (2010) Scientific Opinion on the influence of genetic parameters on the welfare and the resistance to stress of commercial broilers *EFSA Journal* **8**: 1666

[23] Kjaer JB, Su G, Nielsen BL and Sørensen P (2006) Foot Pad Dermatitis and Hock Burn in Broiler Chickens and Degree of Inheritance *Poultry Science* **85**: 1342-8

countries with no standard animal welfare guidelines of the management conditions (*see paragraph 61*); this inconsistency is likely to impact the welfare outcomes of broilers. However, in general, higher welfare systems use a slower-growing breed of broiler, increased stocking density (38kg/m2), enrichments, and better litter. These facilities have been in use for a number of years in a small number of countries and make up a small share of the market.

30 While higher welfare systems do not necessarily guarantee an adequate level of welfare, a small set of studies have shown that using higher welfare systems can improve welfare outcomes compared to using fast-growing broilers in conventional systems. However, what is unclear from the differences observed in welfare indicators between the two systems results from the genotype of the bird (slow-growing or fast-growing) or the differences in an environment that the birds were reared in or if both factors contribute to increased welfare outcomes.

Welfare outcomes of slow-growing and fast-growing broilers in different commercial systems

31 Research comparing the different breeds of broilers and varying commercial husbandry conditions effect on welfare outcomes is largely over a decade old and does not reflect the most recent genetics of broilers. However, recent research by Rayner et al. (2020) evaluated the welfare outcomes of different breeds of broilers (different growth rates) in four commercially different conditions (different stocking densities). This was the first on-farm large-scale study that used positive measures of welfare (bales occupied and positive behavioural observations) and more traditional negative welfare assessments, such as hock burn and gait scores. The study showed there are some welfare benefits of using a lower stocking density environment, especially when using a slower-growing broiler. However, the biggest improvement in welfare outcomes came from using a slow-growing bird compared to the fast-growing bird, concluding that growth rate is still one of the most important factors to improving broiler chicken welfare. Whilst this study had notable benefits of using a commercial environment, the study was performed on one farm, and it would be of benefit to replicate the study at multiple commercial facilities.

32 The study also shows the benefit of using behavioural observations as a measure of health and welfare. Historically, welfare assessments involve observing or quantifiably measuring indicators such as physiological responses. Recently, attention has focused on using behavioural assessments to determine welfare in farm animals. Behavioural monitoring can be achieved by recording animals spending time performing a certain activity or by assessing external factors of behaviours such as skin lesions to quantify aggression in pigs (*see paragraph 44-45*). If an animal has a strong reaction or avoids an object or event, this can provide information on its emotive state and hence it's welfare. Using behaviours as a measure of welfare has notable strengths such as the ability to differentiate animals who behaviour 'normally' or undergo stress. However, a major limitation to using behavioural assessments is the increased workload and lack of effective technology to measure behavioural traits. A key question to consider with behavioural assessments is defining the terms 'abnormal' or 'normal' behaviour including understanding the naturalness, particularly when considering behavioural differences between wild and domestic animals. This presents a challenge in the assessment of welfare based on behaviour from the perspective of affective states.

Summary

33 Health and welfare issues in broilers are directly linked to the intense genetic selection for increased growth and production. In an attempt to address these historic breeding welfare issues, breeding companies have incorporated certain welfare traits into their breeding programmes. There is some evidence in literature and data provided from

relevant companies which shows improved leg health in broilers over a 25 year period and some evidence to suggest the incidence of ascites has reduced. However, the largely the data comes from sources which are yet to be peer-reviewed.

34 When considering the second question if selective breeding methods address issues with the animal itself or mitigate the health impacts of poor management conditions; the ability to detect the heritability of health conditions and subsequently measure welfare indicators using new technologies in broilers, breeding companies currently focus on balanced breeding methods to address health and welfare issues. Recommendations continue to be made to use balanced breeding methods to adapt the birds to the management environment, for example, e.g. contact dermatitis. Incorporating traits into a breeding population has challenges such as difficulties in measuring trait outcomes, low heritability's of traits and uncertain economic prospects. New technologies are now on the horizon such as improved measurements of welfare indicators, whole genome sequencing and targeted genetic modification to improve welfare of broilers.

35 However, it is beyond a doubt that selection for growth rate is the determining factor for health and welfare outcomes in broiler chickens, and with the growth rate of broilers predicted to increase in the future, with current trends predicting a 2kg broiler by 2075.[24] Although slight improvement is seen by adapting the commercial environments broiler are reared in, recent research indicates using slower-growing genotypes in breeding programmes will offer long-term solutions and see bigger improvements to health and welfare of broilers.

Pigs

36 This section examines if breeding companies have incorporated welfare traits in their selective breeding programmes to improve pig health and welfare over time.

Have balanced breeding strategies improved the health and welfare outcomes associated with the historical selective breeding of pigs?

37 Following the domestication of the wild boar roughly 10,000 years ago, rapid growth rate, lean meat quality, backfat reduction, decrease feed conversion and recently increased litter size are the key traits that have been selected for in pig lines over the last century.[25] The global pig industry has been hugely effective at increasing the productivity of pigs; for example, the annual improvement in pig growth rate is currently five g/pig/day.[26] As selective breeding for production traits intensified this caused a significant impact on the health and welfare of pigs, such as high prolificacy in reproductive females resulting in detrimental welfare issues such as piglet mortality. Many piglets are born alive and then die within the nursing period shortly after birth due to several different causes such as hypothermia, starvation, health issues or being crushed, resulting in a decreased welfare. Diseases such as Porcine Reproductive and Respiratory Syndrome (PRRS), present an enormous economic and health and welfare challenge for the pig industry, due to the clinical outcomes of the disease causing reproductive failure in sows'. Aggression in pigs is also reported as a significant welfare problem as it can result in skin lesions that can become infected causing intense pain for affected swine. In 2011, the national pig levy board, the Agricultural and Horticultural

---

[24] Pollock (1999) A geneticist's perspective from within a broiler primary breeder company *Poultry Science* **78**: 414-8

[25] Rauw WM, Kanis E, Noordhuizen-Stassen EN and Grommers FJ (1998) Undesirable side effects of selection for high production efficiency in farm animals: a review *Livestock Production Science* **56**: 15-33

[26] Hermesch S, Li L, Doeschl-Wilson A and Gilbert H (2015) Selection for productivity and robustness traits in pigs *Animal Production Science* **55**: 1437-47

Development Board (AHDB) Pork launched a new strategy for the pig industry (the BPEX 20:20 Pig Health and Welfare Strategy) which identified the most important health and welfare issues in the pig industry to address. These included tail biting, tail docking, lameness and piglet mortality. This scheme has since ended and the Pig Health Scheme has been launched by the AHDB which helps farmers monitor the current health status in a herd.[27] There is evidence in pigs that improving the welfare of the animal will simultaneously improve the productivity in breeding goals, highlighting the importance of including health and welfare traits within breeding programmes. This section will discuss a few of the key welfare issues related to the intensive breeding of pigs over time and any efforts being made by breeding companies to address these problems.

Litter size and piglet mortality

38 At the end of the last century, selection for increased litter size to achieve lean progeny achieved its aims; in the UK there was a 21% increase in the weight of pig meat produced by each sow per year over a five period to 2014.[28] In Denmark, selection for litter size (total number born) was introduced in 1992 and from 1996, the average litter size increased by 0.3 piglets per year.[29] However, the selection of the modern-type pig has been associated with negative welfare behaviours and piglet welfare.[30] It has been demonstrated that increased genetic selection for large litter sizes at birth has led to increased piglet mortality due to a reduced birth weight around the time of farrowing. Whilst it is widely debated whether death itself can be considered a welfare issue. Many agree that the events that lead to death can present welfare issues as this can be associated with pain and suffering. Piglet mortality is a risk factor for decreased welfare as it is likely to be associated with piglet starvation, increase long-term health problems and health issues for the sow.[31] Stillbirths are a serious issue for pig farmers as they have the potential to compromise the economic, social and sustainable production of breeding companies. Selective breeding programmes have been modifying the selection indices to reduce piglet mortality by focusing on lowering litter sizes at birth and improving the neonatal period of sows; however, piglet mortality remains a serious problem, averaging between 16-20% per litter.[32]

39 Over the last 30 years, efforts have been made to improve the management conditions to address welfare issues associated with large litter sizes; however, in recent years, attention has shifted to explore the underlying genetic mechanisms of this trait to include them in selection programmes. Data provided by the AHDB Pork's Interpig reports indicate fluctuations in the percentage of pre-weaning piglet mortality between 2006 to 2014; however, no downward trend is observed.[33] In particular, in Denmark, the direction indicated a reduction in piglet mortality, but an increase in pig litter size was observed. This trend coincided with changes made to the Danish pig breeding programmes. In 2004, increasing piglet survival traits (changing from 'total number born' to 'live piglets

---

[27] AHDB (2021) *Pig health scheme*, available at: https://ahdb.org.uk/pig-health-scheme
[28] AHDB (2015) *The BPEX Yearbook 2014–2015. Key Industry Statistics, Pig Performance Data and Details of Knowledge Transfer, Research and Development Activity*, available at: http://pork.ahdb.org.uk/media/73777/bpex-yearbook-2015.pdf
BPEX Year Book 2014–2015, Agriculture and Horticulture Development Board, Kenilworth, UK (2015)
[29] Rutherford KMD, Baxter EM, D'Eath RB *et al.* (2013) The welfare implications of large litter size in the domestic pig I: biological factors *Animal Welfare* **22**: 199-218
[30] Canario L, Bidanel J-P and Rydhmer L (2014) Genetic trends in maternal and neonatal behaviors and their association with perinatal survival in French Large White swine *Frontiers in Genetics* **5**
[31] Rutherford K, Baxter E, D'eath R *et al.* (2013) The welfare implications of large litter size in the domestic pig I: biological factors *Animal Welfare* **22**: 199-218
[32] Baxter EM and Edwards SA (2018) Chapter 3 - Piglet mortality and morbidity: Inevitable or unacceptable?, in *Advances in Pig Welfare*, Špinka M (Editor) (Woodhead Publishing)
[33] Ibid

at day five after giving birth') has been incorporated in the Danish genetic selection breeding programmes.[34] One study collected data on the total number born, mortality and litter size at day five after farrowing from 2004 to 2010 and included two different breeds of sows (Landrace and Yorkshire) kept in commercial conditions. The results found including survival traits in selective breeding programmes resulted in an increase in the total number of piglets born but a reduction in mortality at birth and five days after farrowing in these herds.[35] Similar trends have been shown from breeding programmes in The Netherlands.[36] Genetic trends have been released for the Norwegian breeding organisation Topigs Norsvin, which since 2001 has incorporated selection for piglet survival by introducing breeding values for mothering abilities of the sow, piglet vitality and piglet weighing protocol (piglets individually weighed at birth and 21 days of age). Since breeding for higher piglet survival Topigs has seen a reduction in piglet mortality however an increase in litter size has continued.[37]

40 A piglets birth weight is an important trait that can impact piglet mortality and quality, with a reduced birth weight increasing the risk of death. There is evidence that suggests as the total number of piglets are born per sow increases the birth weight of piglets reduce which can lead to increased risk of mortality.[38] Stabilising the uniformity of birth weight rates of piglets has also been recognised as an important breeding trait to improve piglet survival as the variability of having larger piglets and runts can create intense competition for the mother's teats which can result in the weaker siblings not receiving the nutrition they need and dying from starvation. Data provided from pig breeding company PIC (the swine division of Genus plc) show the genetic trends for the total number of piglets born and birth weight (kg) from 2006 – 2019. The data indicates a reduction in the birth weight of piglets from 2006 – 2013, then a sudden increase in the birth weight after 2013 whilst simultaneously increasing the total number of piglets born. This was achieved by the introduction of the Relationship-Based Genomic Selection (RBGS) into PIC's genetic program in 2013 which measured the actual genomic-based relationship between animals instead of the assumed pedigree-based relationship. PIC combined this new selection method with selection for individual piglet birth weight. This resulted in more piglets that are viable and therefore increasing the producer's productivity.[39] However, it is not clear how much uniformity of birth weight as a trait is included as a breeding goal index.

41 More recently, research has focused attention on incorporating other determinant traits of piglet mortality in section indices, for example, increased sow maternal behaviour, improvement of udder conformation and colostrum and improved placental efficiency.[40]

---

[34] Su G, Lund M and Sorensen D (2007) Selection for litter size at day five to improve litter size at weaning and piglet survival rate *Journal of Animal Science* **85**: 1385-92

[35] Nielsen B, Su G, Lund M and Madsen P (2013) Selection for increased number of piglets at d 5 after farrowing has increased litter size and reduced piglet mortality *Journal of Animal Science* **91**: 2575-82

[36] Merks JW, Mathur PK and Knol EF (2012) New phenotypes for new breeding goals in pigs *Animal* **6**: 535-43

[37] Topigs Norsvin (2020) *TOPIGS research: flushing sows gives higher piglet birth weight*, available at: https://topigsnorsvin.com/tn-content/uploads/2020/01/5_1006-TOPIGS-insider-Summer-2010.pdf

[38] Bergstrom J, Potter ML, Tokach M *et al.* (2009) Effects of piglet birth weight and litter size on the preweaning growth performance of pigs on a commercial farm *Kansas Agricultural Experiment Station Research Reports* **0**

[39] PIC (2019) *The PIC UK-Newsletter*, available at: https://gb.pic.com/wp-content/uploads/sites/9/2019/04/PICmatters_UK_NSI_Genetic_Improvement_in_the_pig_industry_2020-11.pdf

[40] Baxter EM, Jarvis S, Sherwood L *et al.* (2011) Genetic and environmental effects on piglet survival and maternal behaviour of the farrowing sow *Applied Animal Behaviour Science* **130**: 28-41; and

Lactation efficiency is another trait associated with piglet survival and is measured as the energy efficiency of sows during lactation. However, the heritability of lactation efficiency has been reported as being low (0.12), making it unlikely to be included in breeding goals due to the limited effect on piglet survival.[41] Selection for maternal behaviour has been demonstrated to be possible and can have a large impact on the health and survival of piglets; however, large litter sizes require an increased maternal commitment from the sow, which can subsequently be compromised.[42] Although research has shown the potential for genetic improvement of maternal behaviours, defining maternal behaviour can be difficult. This might explain the lack of research and data which shows if breeding companies have started incorporating these traits into their selection indices. Several new maternal genetic traits such as udder conformation and uterus quality have been shown to have moderate heritability and suggested to be a target for genetic improvement; however, it is unclear the current weighting of this trait in selection indices.[43]

42 Although research indicates breeding programmes successful incorporation of survival traits in selection criteria to improve piglet mortality by measuring mortality or survival, there is a lack of data that measures the impact of introducing survival traits in selection programmes on specific health and welfare outcomes, such as complex health problems of the sow, rates of piglet starvation or trauma. Studies have shown the increased pressure of bearing large litters may produce specific health and welfare concerns for the sow, in particular, leg disorders and a nutritional deficiency during lactation. As demonstrated through data provided from PIC and Topigs, the birth weight of piglets is simultaneously increasing with the total number of born however this raises the concern of increased risk of leg weakness for the sow due to the increased weight.[44] A further concern is the increased risk of nutritional deficiency due to larger litter sizes needing more feed intake but this increases at a lesser extent than milk production, therefore increasing the proficiency of the sow is likely to increase the risk of nutritional deficiency during lactation, generating a welfare issue.[45] This is likely to have economic consequences due to reproductive performance being challenged. It can be postulated that improving piglet mortality will improve the welfare of the offspring; however, evaluating the welfare outcomes that incorporating survival traits has in breeding strategies opens up the possibility of identifying specific methods to improve the health and welfare of pigs and thus the productivity.

Aggression and skin lesions

43 Aggression in pigs, commonly observed following regrouping, has been identified as a common welfare concern and is known to affect growth.[46] Agonistic behaviour occurs when unfamiliar pigs try to set a hierarchy when mixing, this can lead to intense fights

---

Balzani A, Cordell HJ and Edwards SA (2016) Relationship of sow udder morphology with piglet suckling behavior and teat access *Theriogenology* **86**: 1913-20

[41] Bergsma R, Kanis E, Verstegen MW and Knol EF (2008) Genetic parameters and predicted selection results for maternal traits related to lactation efficiency in sows *J Anim Sci* **86**: 1067-80

[42] Baxter EM, Jarvis S, Sherwood L *et al.* (2011) Genetic and environmental effects on piglet survival and maternal behaviour of the farrowing sow *Applied Animal Behaviour Science* **130**: 28-41

[43] Balzani A, Cordell H, Sutcliffe E and Edwards S (2016) Heritability of udder morphology and colostrum quality traits in swine *Journal of Animal Science* **94**: 3636-44

[44] Prunier A, Heinonen M and Quesnel H (2010) High physiological demands in intensively raised pigs: impact on health and welfare *Animal* **4**: 886-98.

[45] Eissen JJ, Kanis E and Kemp B (2000) Sow factors affecting voluntary feed intake during lactation *Livestock Production Science* **64**: 147-65.

[46] Meese GB, and Ewbank R (1973) The establishment and nature of the dominance hierarchy in the domesticated pig *Animal Behaviour* **21**: 326-34; and Stookey JM, and Gonyou HW (1994) The effects of regrouping on behavioral and production parameters in finishing swine *J Anim Sci* **72**: 2804-11.

can result in large skin lesions; the number of skin lesions that pigs can receive due to fighting can range from 1 to 140.[47] Skin lesions can often become infected when the animal's immune system is low, resulting in reduced welfare. Aggressive behaviour when mixing pigs can also impact the productivity of the meat, including a reduction in meat quality, weight gain and carcass grading by using a greater proportion of energy for activity rather than food conversion.[48]

44 Aggression and susceptibility of skin lesions in pigs have been shown to have a genetic component. A fighting and bullying behaviour phenotype has a low-moderate heritability in pigs (between 0.17 and 0.43). Additionally, the susceptibility to skin lesions has a similar heritability between 0.21 and 0.26).[49] Single Nucleotide Polymorphisms (SNPs) in a number of different genes are involved in the mediation of the hypothalamic-pituitary-adrenal axis, which controls aggressiveness.[50] Therefore, the number of skin lesions observed on pigs can be a useful measure of genetic propensity towards aggression and welfare. However, the different locations of lesions on a pigs body result from different types of aggression, resulting in multiple aggressiveness traits with the potential to be incorporated in breeding programmes. One study has suggested to improve the welfare of pigs without compromising production traits; breeders could use a multi-trait index to reduce anterior skin lesions and aggression in pig groups.[51]

45 Selection on social effects could reduce aggression under stable management conditions and hence improve animal health and welfare. It is important to understand how selecting against aggression will affect other behaviours and productivity. More research is needed to address how selection against aggressiveness could impact welfare by understanding how the aggressive state in pigs can be an indicator of their emotions.

Porcine Reproductive and Respiratory Syndrome resistance

46 PRRS was first described in the US in 1980s and characterised in the UK in the 1990s.[52] The virus mechanism works by attaching to the CD163 receptor to enter cells and release the viral genetic information. PRRS is widely considered to be one of the most economically important viral diseases in pigs worldwide.[53] As well as economic importance, PRRS presents several health and welfare issues for pigs. Pregnant sows affected by PRRS are likely to experience reproductive failure, usually resulting in aborting or giving birth to stillborn piglets.[54] Any piglets which survive are usually a lower

---

[47] Turner SP, Farnworth MJ, White IM *et al.* (2006) The accumulation of skin lesions and their use as a predictor of individual aggressiveness in pigs *Applied Animal Behaviour Science* **96**: 245-59

[48] Tan S, Shackleton D and Beames R (1991) The effect of mixing unfamiliar individuals on the growth and production of finishing pigs *Animal Science* **52**: 201-6.

[49] Turner S, Roehe R, D'eath R *et al.* (2009) Genetic validation of postmixing skin injuries in pigs as an indicator of aggressiveness and the relationship with injuries under more stable social conditions *Journal of Animal Science* **87**: 3076-82.

[50] Fernandez X, Meunier-Salaün M-C and Mormede P (1994) Agonistic behavior, plasma stress hormones, and metabolites in response to dyadic encounters in domestic pigs: interrelationships and effect of dominance status *Physiology & Behavior* **56**: 841-7.

[51] Turner S, Roehe R, D'eath R *et al.* (2009) Genetic validation of postmixing skin injuries in pigs as an indicator of aggressiveness and the relationship with injuries under more stable social conditions *Journal of Animal Science* **87**: 3076-82.

[52] Balka G, Podgórska K, Brar MS *et al.* (2018) Genetic diversity of PRRSV 1 in Central Eastern Europe in 1994–2014: origin and evolution of the virus in the region *Scientific Reports* **8**: 7811

[53] Dietze K, Pinto J, Wainwright S, Hamilton C and Khomenko S (2011) Porcine reproductive and respiratory syndrome (PRRS) *Rome: FAO's Emergency Prevention System* **1**: 1-8

[54] Lunney JK, Benfield DA and Rowland RRR (2010) Porcine reproductive and respiratory syndrome virus: An update on an emerging and re-emerging viral disease of swine *Virus Research* **154**: 1-6

birth weight and experience respiratory disease in the weeks after being born, with up to 80% of piglets with PRRS die after birth. The virus is known to persist for long periods of time in pigs, with high levels of viral RNA found in lymphoid tissues in affected piglets 132 days after birth.[55] PRRS has now become the most prevalent disease among pigs in the world and despite 20 vaccines being commercially available, due to being a highly mutagenic RNA virus, vaccines have not been able to effectively control the virus.[56]

47 Large-scale PRRS virus challenge studies, carried out by the PRRS Host Genetics Consortium (PHGC) have demonstrated considerable genetic variation in resistance of growing piglets to PRRSV infection which is based on viral load.[57] Using these datasets, evidence from GWAS studies in pigs have identified a key region on pig chromosome four with a major QTL (SSC4) that explained 10 to 20% of the genetic variance for traits associated with resistance and resilience to PRRS.[58] Further studies have found the SSC4 region has been significantly associated with increased tolerance to PRRS, with pigs that are more genetically resistant also being more tolerant to the disease.[59] These studies indicate that selective breeding for this region, and natural resistance to the disease, could reduce the effects of PRRS in growing pigs, and could gradually improve resistance and tolerance simultaneously in pigs. An example of where this has been applied is the Topigs Norvin breeding programme which in 2018 incorporated breeding values for increased natural resistance to PRRS into the selection index.[60] However, genetic selection for natural resistance to the disease has so far not been successful, which is likely to be due to the genetic diversity of the virus and there being no natural mutation in the CD163 which results in a completely resistant PRRS virus phenotype.[61] A recent study, funded by Genus PLC, the BBSRC and the EU Horizon 2020 project SMARTER, reported selective breeding for resistance and tolerance to PRRS virus during infectious conditions were more than three times more profitable than breeding based on production traits in disease-free conditions, demonstrating the high economic value of PRRS resilience traits.[62]

48 Recent advances have been using novel genomic technology to manipulate the CD163 receptor in pigs to achieve complete resistance (or tolerance). Two types of genome editing to achieve this have been identified in the literature. The first study shows evidence that using precise CRISPR/Cas9 technology it is possible to remove the

---

[55] Benfield D, Nelson J, Rossow K *et al.* (2000) Diagnosis of persistent or prolonged porcine reproductive and respiratory syndrome virus infections *Veterinary research* **31**: 71-

[56] Lunney JK, Benfield DA and Rowland RRR (2010) Porcine reproductive and respiratory syndrome virus: An update on an emerging and re-emerging viral disease of swine *Virus Research* **154**: 1-6

[57] Hess AS, Islam Z, Hess MK *et al.* (2016) Comparison of host genetic factors influencing pig response to infection with two North American isolates of porcine reproductive and respiratory syndrome virus *Genetics Selection Evolution* **48**: 43 ; Boddicker NJ, Garrick DJ, Rowland RR *et al.* (2014) Validation and further characterization of a major quantitative trait locus associated with host response to experimental infection with porcine reproductive and respiratory syndrome virus *Anim Genet* **45**: 48-58

[58] Boddicker NJ, Bjorkquist A, Rowland RR *et al.* (2014) Genome-wide association and genomic prediction for host response to porcine reproductive and respiratory syndrome virus infection *Genet Sel Evol* **46**: 18

[59] Lough G, Hess A, Hess M *et al.* (2018) Harnessing longitudinal information to identify genetic variation in tolerance of pigs to Porcine Reproductive and Respiratory Syndrome virus infection *Genetics, selection, evolution : GSE* **50**: 50-

[60] Topigs Norsvin (2020) *The vigorous pig*, available at: https://topigsnorsvin.com/tn-content/uploads/2020/08/CSR_2019v2_LR.pdf

[61] Ruan J, Xu J, Chen-Tsai RY and Li K (2017) Genome editing in livestock: Are we ready for a revolution in animal breeding industry? *Transgenic Research* **26**: 715-26

[62] Knap PW and Doeschl-Wilson A (2020) Why breed disease-resilient livestock, and how? *Genetics Selection Evolution* **52**: 60

CD163 receptor resulting in pigs that show protection from PRRS.[63] Other methods of genome editing to produce resistance to PRRS involves only removing part of the receptor to remove its capacity to facilitate PRRSV invasion.[64] The use of genome editing technology in animal breeding has the potential to be a powerful tool, with PRRS resistance pigs being a prominent example due to being able to alter the properties of the CD163 gene (through complete knock-out or part deletion) which result in pigs that are completely resistant to PRRS virus without losing the original physiological functionality of the protein structure.

49 A research team at the Roslin Institute at the University of Edinburgh, have successfully used genome editing to produce pigs which are fully resistant to the PRRS virus. They achieved this by using the CRISPR/Cas9 system to remove a small section of the CD163 gene which is responsible for producing the binding target of PRRS virus on the macrophages. This prevents the virus from binding and invading the cells. The pigs with the PRRS resistant gene were found to be completely resistant to the virus and otherwise healthy and normal.[65] The success of the project has led to the a collaboration with the pig breeding company Genus PIC to create an elite stock of PRRSV-resistant gene edited animals and hope to regulate the breeding stock with the FDA in the US. A similar collaboration has also begun with a Chinese breeding company.[66] This technology has the potential to eliminate the disease in pigs at a quicker pace than selecting for disease resistant pigs through traditional breeding methods.

Summary

50 Over the last 30 years, intensive selection for production and growth traits has resulted in detrimental welfare issues such as piglet mortality. There has also been an increase prevalence in devasting diseases such as PRRS. There is evidence to suggest improving animal health and welfare can directly contribute to breeding economic and sustainability goals, making it desirable to focus on such traits. In some countries such as Denmark, traits for piglet survival have been included in selection indices which now show promising results of increasing piglet mortality. Other breeding programmes have manged to achieve an increase in total piglets born per sow whilst simultaneously increasing the birth weight of piglets. Despite it being debated if stillborn piglets present health and welfare issues, a larger litter size still presents negative welfare outcomes for the sow. When selecting for certain traits, possible consequences of other traits should be taken into account to avoid detrimental effects, especially related to health and welfare. A specific example of this is the selection for traits associated with piglet survival such as increased birth weight, whilst this might improve piglet mortality and thus welfare, an increase in birth weight and litter size can have detrimental health and welfare outcomes for the sow such as leg disorders.

51 There is a lack of data that shows if other welfare-relevant issues which counter the impact of selection for productivity have been addressed in breeding programmes, despite being recognised as genetic targets such as maternal behaviours. One reason for this might be the lack of research into the genetic mechanisms underlying traits. A lack of data collected and accessed also slows the progress to address future needs in the pig production sector, one project which aims to address this is PIGWEB, a five year

---

[63] Whitworth KM, Rowland RRR, Ewen CL *et al.* (2016) Gene-edited pigs are protected from porcine reproductive and respiratory syndrome virus *Nature Biotechnology* **34**: 20-2
[64] Burkard C, Lillico SG, Reid E *et al.* (2017) Precision engineering for PRRSV resistance in pigs: Macrophages from genome edited pigs lacking CD163 SRCR5 domain are fully resistant to both PRRSV genotypes while maintaining biological function *PLOS Pathogens* **13**: e1006206
[65] Ibid
[66] The University of Edinburgh (2019) *Pigs that can resist a fatal virus*, available at: https://www.ed.ac.uk/roslin/community-engagement/ag100/current-projects/prrs

project funded by the EU's Horizon 2020 research and innovation program with the aim to strengthen the pig research community and cooperation between research and industrial and societal stakeholders.[67]

52 Recent attention in the pig industry has now focused on using genome editing to address disease resistance in pigs, with the first line of PRRS resistant pigs currently being developed. A further example of using genome editing to target disease resistance in pigs was achieved in 2016 where research successfully introduced the alleles from a warthog which are associated with African Swine Fever into pigs using ZFNS.[68] This method of addressing diseases such as African Swine Fever is impossible to achieve through traditional methods of breeding, which presents the possible role of genome editing technology where traditional breeding methods may not be able to achieve this.

Box 1. Reaching the biological limits of farmed animals

The rapid genetic progress through selection of specific traits, including fitness and production traits, has seen dramatic changes in the performance of farmed animals. This can be illustrated by looking at the production changes in breeding programmes in the Scandinavian countries where the slaughter weight of broiler chickens in the Netherlands increased from 1250 g to 1900g from the period of 1965 to 1996, and similar trends being observed for the growth rate in pigs and increased milk production in dairy cattle around the world. This poses the question if these trends will continue at the same speed and the future consequences on health and welfare. When considering the future of genetically selected farmed animals, indicators can be taken from selection experiments with studies being carried out experimentally to understand the underlying biological limits in the underlying biology of farmed animals.[69] There is evidence in the literature which suggests that the growth rate in broiler chickens will soon reach a maximum biological threshold that might be overcome with traditional forms of breeding. A recent study has shown the physical limits to increased growth rate in broiler chickens are likely to be reached much earlier than originally predicted by the poultry industry.[70] Similarly, controlled selection experiments over 12 generation in pigs have identified no current biological limits, which equals 25 years in pig breeding. However, biological limits are often more pronounced in selection experiments than in on farm breeding programmes due to more traits being included in breeding indices than selection experiments. The Farm Animal Breeding and Reproduction European Technology Platform (FABRE TP) in 2006 produced a vision for 2025 of how livestock breeding may develop in the medium term, within this goal it promoted 'breeding of farm animals that is biologically and economically sustainable'.[71] Ultimately, the future of breeding industries depends on farmed animals being able to continue to perform successfully with limited negative outcomes and fewer management resources applied. As genetic potential of animals continues to progress management requirements will also need to be adjusted to meet these demands and could be received

---

[67]PIGWEB (2021) *An infrastructure for experimental research for sustainable pig production*, available at: https://www.pigweb.eu/

[68] Lillico SG, Proudfoot C, King TJ *et al.* (2016) Mammalian interspecies substitution of immune modulatory alleles by genome editing *Scientific Reports* **6**: 1-5

[69] Bakken M, Vangen O and Rauw W (1998) Biological limits to selection and animal welfare

[70] Pollock (1999) A geneticist's perspective from within a broiler primary breeder company *Poultry Science* **78**: 414-8

[71] FABRE TP (2006) *Sustainable farm animal breeding and reproduction*, available at: http://www.fabretp.eu/uploads/2/3/1/3/23133976/vision_fabretp.pdf

by consumer concern about the welfare of farmed animals and the meat quality. Currently, the biological limits of livestock in selection programmes where the traits either plateau or the productivity or fitness of an animal deteriorates beyond an acceptable level has yet to conclude a definitive answer.

Cows

53 This section examines if beef and dairy breeding companies have incorporated welfare traits in their selective breeding programmes to improve the health and welfare of cattle over time.

Have balanced breeding strategies improved the health and welfare outcomes associated with the historical selective breeding of cattle?

54 From the 1930s to the 1970s, a range of traits has been genetically selected to meet the demands of society and the beef and dairy industry. Economic benefit has historically driven the specific traits selected for in beef cattle, which are largely split between indices for maternal fitness, e.g. milking/maternal ability and carcass traits such as meat yield and quality. In the dairy industry, responses from consumer preferences lead to a shift in selection indices, which included selection for increased milk yield and include milk quantity.[72] However, selection for high production efficiency has been associated with poor health and welfare consequences for cattle. For beef cattle, an increased selection for meat yield has led to extreme muscular hypertrophy which is associated with welfare issues such as an increased risk of dystocia and reduced calf survival.[73] Genetically selecting for increased milk production in dairy cattle has been negatively associated with health and welfare issues, such as the increased prevalence of mastitis, lameness and decreased fertility and longevity. The numerous health and welfare issues associated with the increased pressure on productivity in the beef and dairy industry has led to many breeding companies and programmes to broaden their breeding goals to incorporate specific health, welfare and fitness traits alongside productivity. The Scandinavian countries were the first to formally recognise these welfare issues and develop a novel breeding scheme that placed a high weight on health and fitness traits in their selection indices, which many other countries swiftly adopted (*see box 2*). According to the Agriculture and Horticulture Development Board (AHDB), formally known as DairyCo, a UK non-profit levy-board funded by farmers and organisations, reports that cow health, welfare and longevity have been a focus of the national breeding strategy for more than 10 years and the current UK national breeding goals Profitable Lifetime Index (£PLI). Currently, the £PLI weights 'fitness' traits overproduction traits in a ratio of roughly 32:68.[74] This section reviews the key welfare issues associated with selective breeding in the beef and dairy industry, and any efforts to address these over time.

Beef

---

[72] VanRaden P (2004) Invited review: Selection on net merit to improve lifetime profit *Journal of Dairy Science* **87**: 3125-31

[73] Conington J, Gibbons J, Haskell M and Bünger L (2010) The use of breeding to improve animal welfare. In Proc. 9th World Congress on Genetics Applied to Livestock Production, Leipzig, Germany. German Society for Animal Science, Leipzig, Germany.

[74] AHDB (2021) *UK dairy breeding objectives*, available at: https://ahdb.org.uk/uk-dairy-breeding-objectives

Double muscling and dystocia

55 During the end of the last century, breeding companies have selected beef cattle for higher meat yield, lean meat and increased muscle weight. Often defined as muscle hypertrophy, double-muscled cows have the potential to produce very lean meat. Double muscling (DM) was first identified in the Belgian Blue Cattle but is also prevalent in other breeds such as Piedmontese.[75] In 1977, researchers identified the DM phenotype has a strong genetic cause by mutating the myostatin gene (GDF-*8*). Depending on the breed of cow, many different mutations on the myostatin gene can cause the DM phenotype for example one study reported at least five different variations of DM mutation including nt821 which most commonly affects the Belgian blue breed.[76] This naturally occurring mutation causes inactivation of the myostatin gene, causing increased skeletal muscle mass.[77] Double-muscling has led to many documented problems in cows, with the most common being obstructed labour (dystocia) in female beef cattle. Female cattle with a DM phenotype can struggle to give birth naturally and often require assisted births by a skilled veterinarian and emergency caesareans. During both natural births where there is no intention to perform a caesarean and assisted deliveries, considerable pain for the animal can occur, causing a reduction in the cow's welfare.

56 Research has shown that homozygous cattle for DM have little or no chance of calving without assistance, whereas cattle that are heterozygous for DM are larger than the wild type cattle and require less assisted births.[78] One study found DM animals have up to 20% more calving problems than non-DM bovine breeds, however, cattle with only one copy of the mutant gene still had increased muscularity but without the calving difficulties.[79] The need for assisted calving increases the cost for breeding companies and farmers, and without a skilled veterinarian can lead to further health complications for the cattle. This can make the production of DM phenotype not as cost-effective for breeding companies.

57 Prior to the characterisation of the myostatin mutation, DM would be identified by physical characteristics, such as the presence of intermuscular grooves. However, now myostatin is almost always identified through affordable, quick genetic marker testing, providing advantageous data to breeding programmes. Testing for the mutation in a bovine breeding stock can help select the bulls to breed from and avoid the bulls which carry the mutation. Thus, producing calves with only one copy of the gene.[80] Due to the antagonistic relationship between muscle hypertrophy and reproductive issues, breeding companies have further implemented recording programmes of Estimated Breeding Values (EBV) for cattle, especially in UK-reared beef cattle. Using EBVs can help breeders select traits to enhance in future generations, including genotyping using

---

[75] Fiems LO (2012) Double muscling in cattle: genes, husbandry, carcasses and meat *Animals* **2**: 472-506

[76] Dunner S, Charlier C, Farnir F *et al.* (1997) Towards interbreed IBD fine mapping of the mh locus: double-muscling in the Asturiana de los Valles breed involves the same locus as in the Belgian Blue cattle breed *Mamm Genome* **8**: 430-5

[77] Grobet L, Martin LJ, Poncelet D *et al.* (1997) A deletion in the bovine myostatin gene causes the double-muscled phenotype in cattle *Nat Genet* **17**: 71-4

[78] Bellinge RHS, Liberles DA, Iaschi SPA, O'Brien PA and Tay GK (2005) Myostatin and its implications on animal breeding: a review *Animal Genetics* **36**: 1-6

[79] Casas E, Keele JW, Fahrenkrug SC *et al.* (1999) Quantitative analysis of birth, weaning, and yearling weights and calving difficulty in Piedmontese crossbreds segregating an inactive myostatin allele *Journal of Animal Science* **77**: 1686-92

[80] Karim L, Coppieters W, Grobet L, Valentini A and Georges M (2000) Convenient genotyping of six myostatin mutations causing double-muscling in cattle using a multiplex oligonucleotide ligation assay *Anim Genet* **31**: 396-9

primers for mutations in the myostatin gene to identify cows that are carriers, affected or normal for the DM gene. This can allow for mating pairings to be managed to produce heterozygous offspring.

58 The recent affordability and accessibility to test for Myostatin have resulted in breeders in the UK adopting new initiatives to test and publish results of the mutation in their herds. For example, in 2015, the Limousin Society began publishing individual cow myostatin test results as a commitment to improving the breeding programme for Limousin cattle.[81] Particular attention has been placed in Beef Shorthorn breeding programmes and all South Devon pedigree registered bulls are tested to determine their myostatin status. However, most of the breeding companies state testing for myostatin genotype should be used information that breeders can use in conjunction with EBVs.

Dairy cattle

59 The current breeding goals in the UK include milk, fat and protein yields and lifespan which are combined into profitable lifetime index (£PLI). Data from National Milk Records in the UK show an increase in average yields of dairy cows of about 200 kg per year from 1996 to 2002 with 50% of the progress in milk yield attributed to genetics, a similar trend was observed in the US where between 1957 and 2007 the average milk production increased by 5,997 kg, with 3,390 kg of this increase due to genetics.[82] Milk quality and composition (protein and fat contents) also became a trait to regularly selected in cattle. The rapid increase of milk yields observed (including the high energy output and long lactation periods) results in several health and welfare consequences. The relationship between milk performance and health in dairy cattle has been associated with an unfavourable genetic correlation, particularly between milk yield and mastitis (0.26 – 0.65) and lameness (0.24 – 0.48).[83] In the 1997 report, the United Kingdom's Farm Animal Welfare Council (FAWC) recommended the following to dairy breeding programmes:

"Achievement of good welfare should be of paramount importance in breeding programmes. Breeding companies should devote their efforts primarily to selection for health traits so as to reduce current levels of lameness, mastitis and infertility; selection for higher milk yield should follow only once these health issues have been addressed ".[84]

Lameness

60 Lameness is a significant issue for the dairy industry in many countries as it causes huge economic loss and reduced animal welfare. Lameness is described as a clinical presentation that is recognised by impaired locomotion and movement, typically associated with painful lesions on a hind limb, with more than 90% of lesions found in the foot.[85] The most prominent lesions associated with lameness are sole ulcers, digital dermatitis, foul-in-the-foot and white line disease. Lameness is associated with a

[81] Limousin (2015) *Myostatin (double muscling) in British Limousin cattle*, available at: https://limousin.co.uk/wp-content/uploads/2015/06/Limousin-Fact-Sheet-3-Myostatin-FINAL.pdf
[82] Pryce JE and Veerkamp RF (2001) The incorporation of fertility indices in genetic improvement programmes *BSAP Occasional Publication* **26**: 237-49 ; VanRaden PM, Sanders AH, Tooker ME *et al.* (2004) Development of a national genetic evaluation for cow fertility *J Dairy Sci* **87**: 2285-92
[83] Ingvartsen KL, Dewhurst RJ and Friggens NC (2003) On the relationship between lactational performance and health: is it yield or metabolic imbalance that cause production diseases in dairy cattle? A position paper *Livestock Production Science* **83**: 277-308
[84] Farm Animal Welfare Committee (1997) *Report on the welfare of dairy cattle,* available at:
[85] Archer S, Bell N and Huxley J (2010) Lameness in UK dairy cows: a review of the current status *In Practice* **32**: 492-504

decrease in milk yield, production and prolonged calving intervals and is a key reason for culling.[86] Clinical lameness costs the UK dairy herd on average £7,499.30 per year, translating to 0.97 pence per litre.[87] As well as the financial impact, lameness is a major welfare issue as it causes considerable pain and suffering for the animal. Traditional forms of lameness such as sole ulcers and foul-in-the-foot have improved over time, this is largely due to better hoof management such as the growing use of licenced foot trimmers and recent efforts in the dairy industry to reduce lameness. In 2019, a UK study revealed the mean herd prevalence of lameness was estimated at 30.1 per cent, which compared to a previous UK prevalence study conducted in 2010 which reported a mean prevalence of 36.8 per cent, indicates a reduction in lameness prevalence.[88]

61 The aetiology of lameness in dairy cows is complex and multifactorial, with older cows often being more susceptible. Many studies have explored the factors which contribute to lameness, and suggest that both genetic and management factors play a role in the development of the disease. Previous studies have identified a wide array of on-farm risk factors associated with the condition including larger herd sizes, an increase in the length of housing period and long standing times. Lameness can also be improved by the farm infrastructure and management conditions such as through cubicle design improvements, implementing straw yards, construction of suitable cow tracks, and hoof paring. Some types of lameness caused by digital dermatitis can also be effectively treated by topical antibiotics and footbaths. Recent evidence has shown that cattle with a low body condition score (BSC) is associated with an increased risk of lameness in dairy cows and the ability to recover from the disease.[89] The AHDB provide several methods to identify and score lameness in UK dairy cattle, such as providing photographs to identify the cause of the lameness and mobility scoring to effectively score how many cows are lame in a herd at any one time by assessing the cow's gait. The dairy mobility score being the most widely accepted lameness scoring system used in the UK.[90]

62 Several projects and initiatives have been developed to help farmers reduce the prevalence of lameness in their herds in many countries. Between 2002 and 2006, a multidisciplinary project called The EU Lamecow project investigated the risk factors in husbandry systems, biomechanics, and the underlying biological mechanisms of lameness. The aim of the project was to produce a set of guidelines for husbandry systems and training packages to help reduce lameness in the dairy industry. In addition, in 2011 the AHDB launched the Healthy Feet Program which aimed to help British dairy farmers to decrease the prevalence of lameness within their herds. Following the introduction of this program, one study reported a reduction of lameness events by one fifth demonstrating an effective intervention to tackle lameness.[91] Given the efforts placed on lameness management and research in recent years, the prevalence of

[86] Huxley JN (2013) Impact of lameness and claw lesions in cows on health and production *Livestock Science* **156**: 64-70
[87] Willshire J and Bell N (2009) An economic review of cattle lameness *Cattle Practice* **17**: 136-41
[88] Randall LV, Thomas HJ, Remnant JG, Bollard NJ and Huxley JN (2019) Lameness prevalence in a random sample of UK dairy herds *Veterinary Record* **184**: 350 ; Barker Z, Leach K, Whay H, Bell N and Main D (2010) Assessment of lameness prevalence and associated risk factors in dairy herds in England and Wales *Journal of Dairy Science* **93**: 932-41
[89] Randall LV, Green MJ, Chagunda MG *et al.* (2015) Low body condition predisposes cattle to lameness: An 8-year study of one dairy herd *J Dairy Sci* **98**: 3766-77 ; Lim PY, Huxley JN, Willshire JA *et al.* (2015) Unravelling the temporal association between lameness and body condition score in dairy cattle using a multistate modelling approach *Prev Vet Med* **118**: 370-7
[90] AHDB (2021) *Lameness in dairy cows*, available at: https://ahdb.org.uk/knowledge-library/lameness-in-dairy-cows
[91] Brown A, Pearston F, Mrode R, Kaseja K and Winters M (2016) Lameness evaluations for the UK dairy industry *Interbull Bulletin*

lameness would be expected to be decreasing rapidly, however, a recent study published indicated only a small decrease in the prevalence of lameness in the UK from 36.8% in 2010 to 31.8% in 2018.[92] Attention is now being focused on the underlying genetic variation for lameness-associated traits, which may have the potential to improve the selection strategies by using genetic markers. Previous studies have demonstrated the heritability estimates range from 0.06 to 0.52 for lameness-associated traits, in particular foot lesions.[93] The largest study conducted taking a genomic approach to address the traits associated with lameness grouped the lameness-associated lesions into two categories: infectious and non-infectious using SNP data to identify several genomic regions with candidate genes linked to the immune system, morphogenesis and cell proliferation.[94]

63 Due to the small but sufficient level of heritability associated with foot lesions and other indicator lameness traits, many breeding programmes in multiple countries now include lameness in their breeding indices. In the UK, lameness is now available as a breeding value with the opportunity to be included in a breeding index to address welfare issues. Incorporated into the UK national breeding indexes since 2018, the lameness advantage (LA) trait is calculated using the information on actual lameness incidents which come directly from on-farm lameness records via the Cattle Information Service (CIS) and National Milk Records (NMR). This information is combined with existing data for locomotion and feet and legs, including bone quality and digital dermatitis records from breed society type classification services as recorded at the National Bovine Data Centre (NBDC). As described on the AHDB website, lameness advantage (LA) traits "are expressed as a percentage and range from -5% (bad) to +5% (excellent). Every 1% change in a bull's LA predicts a change of 1% of daughters becoming lame per lactation. For example, a bull with a +5% LA is expected to have 5% fewer cases of lameness in his daughters per lactation than a bull with an LA of zero".[95] The LA trait is available for all breeds of bull evaluated in the UK and genomically evaluated Holsteins. Due to a rising demand from farmers to understand which bulls specifically transmit improved resistance to digital dermatitis, in 2020 the AHDB offered digital dermatitis as a separate index for dairy cows which similar to the LA trait, a positive value are favourable meaning for every per cent increase in an animal's index, means there will be a corresponding one per cent decrease in their daughter's digital dermatitis cases.[96]

64 Despite lameness being recognised as a significant issue for the dairy industry for many years, overall the prevalence of lameness has reduced very minimally over the last 20 years. This is likely due to the low heritability of traits associated with lameness, and a lack of accurate data recording of lameness. In addition, it has been noted that lameness

[92] Griffiths BE, Grove White D and Oikonomou G (2018) A Cross-Sectional Study Into the Prevalence of Dairy Cattle Lameness and Associated Herd-Level Risk Factors in England and Wales *Frontiers in Veterinary Science* **5**

[93] Boettcher PJ, Dekkers JC, Warnick LD and Wells SJ (1998) Genetic analysis of clinical lameness in dairy cattle *J Dairy Sci* **81**: 1148-56;Zwald NR, Weigel KA, Chang YM, Welper RD and Clay JS (2004) Genetic Selection for Health Traits Using Producer-Recorded Data. I. Incidence Rates, Heritability Estimates, and Sire Breeding Values *Journal of Dairy Science* **87**: 4287-94; Koenig S, Sharifi AR, Wentrot H *et al.* (2005) Genetic Parameters of Claw and Foot Disorders Estimated with Logistic Models *Journal of Dairy Science* **88**: 3316-25 ; Schöpke K, Gomez A, Dunbar KA, Swalve HH and Döpfer D (2015) Investigating the genetic background of bovine digital dermatitis using improved definitions of clinical status *Journal of Dairy Science* **98**: 8164-74

[94] Malchiodi F, Schenkel F, Christen A, Kelton D and Miglior F (2018) Genome-wide association study and functional analysis of infectious and horn type hoof lesions in Canadian Holstein cattle. In World Congress on Genetics Applied to Livestock Production.

[95] AHDB (2021) *Health, welfare and fertility PTAs*, available at: https://ahdb.org.uk/knowledge-library/health-welfare-fertility-ptas

[96] Ibid

improvement has also been hindered by the perceptions and attitudes of farmers on their farms, with one study reporting that farmers often placed lower importance on lameness management compared to other health issues, with time, labour and finance being reported as the key barriers to improvement.[97] In addition, a recent study which found an association with BCS and lameness occurrence suggested the regular monitoring and maintenance of BSC on farms could be a key tool for reducing the prevalence of lameness.[98] Despite efforts to improve the prevalence of lameness among dairy cattle through management practices, the recent focus on the underlying genetic factors of lameness has the potential to further reduce the incidence of lameness through genetic selection. Recent studies indicate that genetically selecting for indicator traits of lameness, such as hoof health and type traits, can indirectly impact other lameness traits and increase the genetic gains achievable for lameness.[99] Having only recently been included in the UK national breeding indexes for dairy cattle, the recent trends of lameness are currently not available with only future predictions made that the incidence of lameness will reduce over time, with the AHDB predicting to see daughters of bulls bred using the Lameness Advantage index having a 1.4% reduction in lameness cases per lactation.[100]

65 A further potential strategy for combating lameness within the dairy industry is through a more radical approach of incentives/penalties, as a method to encourage the improvement of lameness in dairy herds. This can be illustrated through legislation used in Holland, where milk produced by severely lame cows was prevented from entering the market (linked to European parliament regulation EC 853/2004 from the Farm Animal Welfare Council FAWC). Subsequently, Holland has one of the lowest prevalence of lameness in the world, and such a strategy may have played an important role in achieving lameness control.[101]

Mastitis

66 In dairy cows, the selection for increased milk yield has been associated with multiple welfare issues, with mastitis being a major issue. Mastitis is the inflammation of the mammary glands most commonly caused by a large number of bacterial infections, in particular *Staphylococcus aureus,* and is one of the most frequent diseases among found among dairy cattle. Mastitis can be categorised as either clinical mastitis (CM), when the cow presents with abnormal milk secretion for one or more quarters, or subclinical mastitis which is defined as an inflammation of the udder usually diagnosed by the elevated somatic cell score (SCC). An increase in SCC is mainly due to an elevated level of white blood cells due to an infection in the udder and is widely used as a phenotypic indicator of mastitis in breeding programmes around the world. Despite improved veterinary care and management, the incidence of mastitis has been increasing over the last 30 years, most likely a result of intensive milk production and the antagonistic relationship between milk production and mastitis. The incidence of

[97] Whay H, Main D, Green L and Webster A (2002) Farmer perception of lameness prevalence. In proceedings of the 12th International Symposium on Lameness in Ruminants, pp. 9-13.
[98] Lim PY, Huxley JN, Willshire JA *et al.* (2015) Unravelling the temporal association between lameness and body condition score in dairy cattle using a multistate modelling approach *Prev Vet Med* **118**: 370-7
[99] Ring SC, Twomey AJ, Byrne N *et al.* (2018) Genetic selection for hoof health traits and cow mobility scores can accelerate the rate of genetic gain in producer-scored lameness in dairy cows *Journal of Dairy Science* **101**: 10034-47
[100] AHDB (2019) *Taking steps to improve lameness*, available at: https://ahdb.org.uk/news/taking-steps-to-improve-lameness
[101] Farm Animal Welfare Council (2009) *Opinion on the welfare of the dairy cow*, available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/325044/FAWC_opinion_on_dairy_cow_welfare.pdf

mastitis creates huge economic loss in the farming industry, this is largely a result of direct loss of milk production, veterinarian costs, expensive treatments and reduced reproductive performance (extended calving intervals).[102] As well as the high economic loss associated with mastitis, the disease is associated with a high level of pain for cows and is associated with sickness behaviours (e.g. reduced feed intake and lethargy), therefore creating a health and welfare issue for cattle.

67 The heritable genetic variation in the incidence of mastitis was demonstrated in 1950s, demonstrating the possibility of genetic selection for improved mastitis resistance in dairy cattle. Recent studies have reported the heritability for CM is estimated at ranging from 0.001 to 0.06.[103] Studies have also shown it can be effective to indirectly selection for mastitis resistance using SCC and genetic evaluations, which have been implemented in most countries over the last 25 years. The heritability of CM has a strong genetic correlation (ranging from 0.59 to 0.85) for SCC, creating the possibility to include SCC in breeding goals to reduce mastitis incidence. Now most countries have evaluation systems that ranks bulls and cows based on their genetic evaluations for SCC. In addition to using SCC as the predicator trait for the selection of mastitis resistance, other morphological traits are also correlated with mastitis, for example recent studies have reported dairy cattle with a high milking speed are genetically more susceptible to have CM.[104]

68 More recently, health and disease data recording has become an important tool to accelerate genetic progress for mastitis resistance. This can be illustrated by the mastitis control plan which was developed by the AHDB in the UK, and is voluntary for farmers to enrol. This control plan was further used to develop the QuarterPRO, a new initiative that aims to provide continual improvement in mastitis control and udder health by using milk recording data (SCC and CM cases) into a tool which helps predict patterns of mastitis on farms.

69 Up to the mid-1990s, the majority of breeding goals in the dairy industry focused on production traits (protein and milk yield), milk composition (fat content) and morphological traits (udder conformation), however due to an increase in phenotyping the Scandinavian countries were the first to expand their breeding goals to include mastitis resistance (*see box 2*). Subsequently, due to the unfavourable relationship between mastitis and fertility, most European breeding companies swiftly included other non-production traits into their breeding objectives particularly mastitis resistance. Mastitis resistance is now included alongside production traits in many breeding programmes around the world, and individual specific indexes have been developed to also address mastitis through genetic selection. A review of the recently defined breeding objectives reported that mastitis resistance accounts for 10 to 30% of the total weight of all traits combined.[105] In the Canadian dairy industry a mastitis index was developed which includes 11 associated-traits including SCC in the first lactation and

---

[102] Esslemont D and Kossaibati M (2002) Mastitis: How to Get Out of the Dark Ages *The Veterinary Journal* **164**: 85-6

[103]Heringstad B, Klemetsdal G and Ruane J (2000) Selection for mastitis resistance in dairy cattle: A review with focus on the situation in the Nordic countries *Livestock Production Science* **64**: 95-106

[104] Pérez-Cabal MA and Charfeddine N (2013) Genetic relationship between clinical mastitis and several traits of interest in Spanish Holstein dairy cattle *Interbull Bulletin* **47**: 77-81

[105] Pedersen J., Sander Nielsen U., Aamand G.P., Economic values in the Danish Total Merit Index, Interbull, Bulletin 29 (2002) 150–154 Pedersen J, Nielsen US and Aamand GP (2002) Economic values in the Danish total merit index *Interbull Bulletin*: 150-4 ; Colleau JJ and Le Bihan-Duval E (1995) A Simulation Study of Selection Methods to Improve Mastitis Resistance of Dairy Cows *Journal of Dairy Science* **78**: 659-71

upper depth.[106] In 2014, the Lifetime Profit Index (LPI) was expanded in the UK to include the Mastitis Resistance index. However, the weight for mastitis resistance within a breeding index varies between countries and breeds for example in the Austrian index the udder health indices (made up of 70% SCS and 30% CM) for the Fleckvieh breed composes 10% of the economic weight. Whereas, in the French Holsteins and Norwegian Reds, the udder health index weights for 18% of the Total Merit Index. In 2017, Great Britain included a direct measure of CM in their evaluation for mastitis (Interbull). The inclusion of mastitis resistance in selection objectives has been shown to be an effective method to reduce the incidence of CM as illustrated in Norway where in 1994 was the incidence of CM was 0.44 cows treated per cowyear which then decreased to 0.23 in 2002.[107]

70 Latest research is focusing on increasing the accuracy of selection for mastitis resistance by better modelling for SCC and CM, combining these traits in an index along with other predicator traits such as udder health and milking ease. Ongoing research is focusing on detecting QTLs that are associated with variations in mastitis resistance, to integrate in marker-assisted selection as a tool in mastitis resistance in dairy cattle. Recent research is aiming to develop biotechnologies as an alternative method to address mastitis, such as the creation of transgenic cows from genetic engineering for enhancing resistance to mastitis. One study reported successfully producing transgenic cows which resisted *Staphylococcus aureus* via secretion of small amounts of lysostaphin in their milk.[108] A more recent study reported successfully creating cows which produce milk which had the ability to kill *S. aureus* by inserting a human lysozyme gene to B-casein locus using zinc-finger nucleases.[109] These studies demonstrate the feasibility of using genetic engineering to introduce beneficial genes into cattle which could benefit not only the profitability in the dairy industry but potentially the welfare of cows.

Temperament traits

71 There is a growing interest in behavioural traits associated with animal welfare, this includes temperament traits such as handling, fearfulness and aggression in beef cattle and milking temperament in dairy cattle. Measuring behavioural traits has the potential to provide valuable information as it can impact how the animal responds to husbandry conditions, handling (including milking) and transport. In some cases, a poor temperament may lead to injury, emotional and physical distress, resulting in lower welfare. In some studies, the handling temperament has been linked to the growth rate, feeding efficiency and meat quality of beef cattle demonstrating the economic value of an increased docile temperament. Heritability of maternal temperature has been estimated, and in some cases, the QTL has been identified. Studies have shown an association between a less excitable temperament and increased growth rate, with similar results found in phenotypes with high flight speed and measures of feed efficiency.[110]

---

[106] Jamrozik J, Koeck A, Miglior F *et al.* (2013) Genetic and genomic evaluation of mastitis resistance in Canada *Interbull Bull* **47**: 43-51

[107] Østerås O and Sølverød L (2009) Norwegian mastitis control programme *Irish Veterinary Journal* **62**: S26

[108] Wall RJ, Powell AM, Paape MJ *et al.* (2005) Genetically enhanced cows resist intramammary Staphylococcus aureus infection *Nature Biotechnology* **23**: 445-51

[109] Liu X, Wang Y, Tian Y *et al.* (2014) Generation of mastitis resistance in cows by targeting human lysozyme gene to β-casein locus using zinc-finger nucleases *Proc Biol Sci* **281**: 20133368

[110] Cafe L, Robinson DL, Ferguson D *et al.* (2011) Cattle temperament: persistence of assessments and associations with productivity, efficiency, carcass and meat quality traits *Journal of Animal Science* **89**: 1452-65

72 A large number of studies have estimated the heritabilities for the three major temperament traits in beef cattle, demonstrating a wide range of heritabilities from low to moderate. This indicates genetic development can be made through the selective breeding of these traits in a breeding stock. Despite the large number of studies demonstrating the heritability of these temperament traits, variance in estimates for temperament traits exists. This could largely be due to the difference in measuring protocols and recording methods, however variance in heritability is also demonstrated between different beef cattle breeds for example the *Bos indicus* breeds tend to have higher heritabilities for temperament traits than for the *Bos taurus* breeds.

73 Milking temperament, includes the response to being milked and handling procedures. Currently, farmers or milking staff score the cattle on different level of response to being milked (typically ranging form 1-5 or 1-9 representing poor to good milking temperament). This temperament data is recorded by milk recording companies in the UK such as Interbull. Research has shown a range of heritabilities for milking temperament traits in dairy cattle, estimated to be a mean of 0.19.[111]

74 Despite research indicating a favourable relationship between temperament and productivity in cattle, the incorporation of temperament traits in selection programmes remain low. Many temperament traits have been identified to have moderate heritabilities, and a key challenge identified has been the ability to define and find measures which accurately represent the behaviours. Some key assessments which have been established are the chute test, flight speed/time, and docility score. However despite this, temperament traits are often not including in breeding indices. Although the positive correlation between handling temperament and growth and meat quality suggest including temperament traits in a selection index would be beneficial for both profit and welfare, when analysing EBVs, in some countries milking temperaments and docility scores for

[111] Haskell MJ, Simm G and Turner SP (2014) Genetic selection for temperament traits in dairy and beef cattle *Frontiers in Genetics* **5**

Box 2. The inclusion of health and fitness traits in Scandinavian dairy cattle breeding programmes

The process of transition in the Scandinavian countries from a selective breeding programme focusing predominantly on production traits to a broader breeding programme which included health and fitness traits for the dairy cattle industry began as early as the 1960s. This first achieved by the dairy farmers cooperative organisational structure which allowed the creation of integrated databases including milk-recording and artificial insemination (AI) services. The integration of the two databases meant automatic pedigree control and registers were established for all recorded cows. A few years later, health data from veterinary services was also incorporated into the databases. This system was largely adopted and funded by the farmers, but was supported by representatives of the veterinary organisations and scientists. The centralised databases meant it was possible to analyse trends in traits of dairy cattle, draw conclusions from past experiences and predict future outcomes. This opened up the possibility to establish total merit indexes (TMI) which include health and welfare traits alongside traditional production traits, allowing a complete re-evaluation of breeding objectives. Considerable emphasis was given to non-production traits as it was to production traits, to improve health and welfare alongside genetic improvement for production.[112] The key points on the successful recording, evaluation and selection for health and welfare traits in Scandinavian countries are summarised below:

- Reproduction, health and welfare traits in general show low heritabilities, however due to the large scale field datasets established in all Scandinavian countries large genetic variation has been confirmed in genetic analyses. Dairy cattle breeding in the Nordic countries include functional traits of low heritability which is based on progeny testing of young bulls with large daughter groups.
- The Norwegian Dairy Herd Recording System (NDHRS) is the centralised system used in Norway to record production parameters such as milk yield, carcass quality at slaughter, calving information, alongside disease and treatment data recording.[113]
- First started in Norway in 1978, estimated breeding values for mastitis was first calculated. Swiftly followed by Sweden, Finland and Denmark who also included mastitis resistance into the Denmark selection indexes. Research showed that using a selection index where mastitis resistance is given double the weight relative to yield, production increased by 964 kg and number of mastitis treatments/100 cows decreased 5.5. In Norway, data indicates the incidence of clinical mastitis increased from 0.15 cows treated per cowyear in 1975 to 0.44 in 1994, however then decreased to 0.23 in 2002. This showed including mastitis resistance in a selection objectives was effective.[114]
- In 2002, Danish cattle breeders revised their total merit index for sires and cows to include two new groups of traits 'other diseases' and 'functional longevity'. Within the 'other diseases' category this encompasses udder health and frequency of mastitis.

---

[112] Philipsson J and Lindhé B (2003) Experiences of including reproduction and health traits in Scandinavian dairy cattle breeding programmes *Livestock Production Science* **83**: 99-112

[113] Espetvedt MN, Reksen O, Rintakoski S and Østerås O (2013) Data quality in the Norwegian dairy herd recording system: Agreement between the national database and disease recording on farm *Journal of Dairy Science* **96**: 2271-82

[114] Osterås O and Sølverød L (2009) Norwegian mastitis control programme *Irish Veterinary Journal* **62 Suppl 4**: S26-S33

- Fertility and reproduction traits were included in the breeding goals, and subsequent data has shown an increase in calving interval of 12.5 months in 1987 to nearly 13.5 months in 2003 for the Swedish Holstein breed, indicating an improvement in fertility.
- Inclusion of health and welfare traits into TMIs has successfully lead to the improved incidence of health and welfare issues in dairy cattle, despite the strong increase production still observed.
- Scandinavian countries incorporating hoof trimming data at a national level use much tighter quality control than currently in the UK.
- The original model created in Scandinavian for producing balanced breeding objectives, which include health and welfare traits as well as production traits, has been used an example and is now widely adopted in many other countries outside Scandinavia.

The example of the breeding programmes in Scandinavian countries illustrate it is possible to successfully address welfare issue by including health and welfare traits in selective breeding without reducing profitability.[115]

British and European breeds are available as stand-alone EBVs, but the trait is not currently included in selection breeding programmes.[116]

Surveillance of dairy cow welfare

75 The UK is one of the few countries in the EU which does not have a centralised system to record health and welfare indicators in cattle. Norway and Canada are examples of countries which have such schemes. In the UK, mainly two private companies, the Cattle Information Service (CIS) and National Milk Records (NMR), collect almost all the dairy industry data, with other smaller companies such as QMMS also offering milk recording services. However, there is no common analysis or frequent publication of the results from these companies. This method of recording dairy industry data has been described as 'a serious handicap, putting the UK at a distinct disadvantage and limiting welfare improvements on dairy farms' by the FAWC in the 2009 report on the opinion of welfare in dairy cows. They subsequently recommended the British dairy industry develop a national database which contains information about cow health and welfare, including production traits. It was further recommended that more public surveillance of cow

[115] Philipsson J and Lindhé B (2003) Experiences of including reproduction and health traits in Scandinavian dairy cattle breeding programmes *Livestock Production Science* **83**: 99-112
[116] Haskell MJ, Simm G and Turner SP (2014) Genetic selection for temperament traits in dairy and beef cattle *Frontiers in Genetics* **5**

welfare is carried out so that progress can be monitored.[117] Since this recommendation, there has been no development of a centralised system.

Summary

76 This section describes several of the key welfare issues which have been exacerbated by the rapid increase in selective breeding for production in the beef and dairy industry. When selection focuses on production traits for example selecting for rapid increase in milk yield per cow, this has detrimental effects on the health and welfare of dairy cattle. Due to the unfavourable trend between milk production and welfare indicators, an effective way to prevent the decline and potentially improve the welfare of dairy cattle would be to adopt a selection index in which welfare-traits are included. Whilst this has been observed in many countries for non-production traits such as mastitis resistance and recently lameness, they still make up a small weight of the total indices. Currently in the UK, lifespan, health and fertility now have a relative weighting of about 45% in breeding indices despite not being addressed till late in the 1990s. Breeding values now exist for lifespan, mastitis, lameness and fertility (calving interval and non-return rate) and research is now focusing on including dystocia. However, it is estimated the maximum progress per generation is around 1-2% for each trait, therefore improvements in health and welfare will take some time to show in a herd. Efforts to improve welfare of dairy cattle are often met with fears this will be uneconomical or reduce production, however this is not always the case as shown in the example of expanding the PLI to include mastitis resistance and reduce calving intervals could increase economic response to selection by up to 80%, compared to selecting for milk production alone.

77 The inclusion of non-production traits in genetic indices alongside production traits such as milk production and growth-rate is largely to address the accumulation of welfare issues created through intensive selective breeding, this is mainly a result of the antagonistic genetic relationships between increased performance of production and health and welfare traits. This is largely, in part, because the traits in breeding indices are weighted by their relative financial contribution to overall profitability, rather than their contribution to welfare, and because non-production traits are often less heritable than production traits. Therefore, a greater emphasis needs to be placed on non-production traits in breeding programs to see bigger improvements in the welfare and health of cows.

78 More research is needed on specific welfare-related traits and their heritabilities, tools to collect on-farm data on the welfare-traits, and use this information for future breeding programs of dairy and beef cows. The absence of a centralised system which collects data for the dairy industry, limits the ability to make rapid strides in addressing health and welfare issues seen within the industry and regular surveillance would be beneficial to monitor progress. A multi-trait selection programme in which health and welfare traits are appropriately weighted against production traits and included in the breeding objectives has the potential to improve the health and welfare for cows. The Scandinavian countries are a good example to illustrate how non-production traits can be included in genetic indices to improve welfare, and have been including health and welfare traits in their breeding indices for the last 20 years and should be used as an example model for future cattle breeding programmes.

---

[117] Farm Animal Welfare Council (2009) *Opinion on the welfare of the dairy cow*, available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/325044/FAWC_opinion_on_dairy_cow_welfare.pdf

Aquaculture

79 This section examines if aquaculture breeding companies have incorporated welfare traits in their selective breeding programmes to improve the health and welfare of fish over time.

Have balanced breeding strategies improved the health and welfare outcomes associated with the historical selective breeding of different aquaculture?

80 Aquaculture is currently the fastest growing sector in world production of animal-derived food with an average worldwide growth rate of 6-8% a year.[118] The British farmed salmon industry is concentrated in Scotland, one of the world's largest producers. The first experiments to improve disease resistance in fish through selection began in the 1920s, however it was not until the early 1970s when the first breeding program using Atlantic salmon and rainbow trout in Norway began.[119] Since the emergence of breeding programs for the Atlantic salmon and rainbow trout, mass selection for growth rate and appearance has been the key trait selected for, with the genetic gain in body weight being very high at around 12.7% per generation. High heritabilities for desirable production traits in fish, such as growth rate, feed consumption and protein/energy retention, and the shorter generation time (1-4 years) when bred in captivity, explains the increased genetic gain achieved through aquaculture breeding programs over recent years.[120] With this high genetic gain numerous publications have reported doubling the growth rate of targeted populations over five to six generations in Atlantic salmon and Nile tilapia.[121] As growth rate quickly increased, attention turned to including other traits of economic importance in selective breeding programs. This can be demonstrated through AquaGen's breeding goals which initially only targeted growth rate during the initial period of 1975-80, and later expanded this index to include a further 22 traits in the Atlantic salmon and 12 traits in rainbow trout, such as growth rate, robustness, age at sexual maturation, flesh pigmentation and resistance to several diseases, which often have a medium to high heritability.[122]

81 Intensively farmed fish can experience a range of health and welfare issues including increased susceptibility to infectious disease, such as infectious pancreatic necrosis (IPN) and Infectious Salmon Anaemia (ISA), sea lice infestations, skeletal deformities, cataracts and deafness. However, it is largely recognised that the emergence of diseases and sea lice populations in aquaculture are also closely linked with the husbandry and environmental conditions which the fish are reared in. In 2008 the European Food Safety Authority (EFSA) pointed out that “the intensification of fish farming has inevitably resulted in the emergence of disease problems, in particular of diseases of infectious origin although over recent years a number of issues relating to health and disease have been successfully addressed through better husbandry and the introduction of vaccines”.[123] This section will focus on a few of the key health and welfare

---

118 Compassion in world farming (2009) *The welfare of farmed fish*, available at: https://www.ciwf.org.uk/media/3818654/farmed-fish-briefing.pdf

119 Boudry P, Allal F, Aslam ML *et al.* (2021) Current status and potential of genomic selection to improve selective breeding in the main aquaculture species of International Council for the Exploration of the Sea (ICES) member countries *Aquaculture Reports* **20**: 100700

120 Thodesen J, Grisdale-Helland B, Helland SJ and Gjerde B (1999) Feed intake, growth and feed utilization of offspring from wild and selected Atlantic salmon (Salmo salar) *Aquaculture* **180**: 237-46

121 Ibid

122 AquaGen (2013) *Broad selective breeding goals*, available at: https://aquagen.no/en/2013/06/13/broad-selective-breeding-goals/

123 Scientific Report of the Panel on Animal Health and Welfare on a request from the European Commission on animal welfare aspects of husbandry systems for farmed Atlantic salmon. The EFSA Journal (2008) 736, 1-122

issued associated with the commercial fish farming industry, and explore the current breeding methods used to address these issues.

Disease resistance

82 In the 2008, the EFSA highlighted that the "intensification of fish farming has inevitably resulted in the emergence of disease problems, in particular of diseases of infectious origin". Intensive farming of fish kept in open-ocean management conditions, increases the risk of infectious disease due to the reduced ability to control disease through biosecurity. Wild species can often transmit diseases to farmed fish in surrounding waters.[124] In 2012, The World Organisation for Animal Health listed the most commercially important farmed fish diseases including Viral haemorrhagic septicaemia (VHS), infectious hematopoietic necrosis (IHN), spring viremia of carp (SVC), pancreas disease (PD) , IPN, and ISA. However, it has been noted that the diseases in farmed fish are not caused by primary conditions but are generally closely linked with poor husbandry conditions which the fish are being kept in.[125] Rearing large number of fish in crowded conditions can not only facilitate the transmission of infectious diseases, but may experience higher levels of stress making them more susceptible to a wide range of disease and have a reduced ability to fight infectious diseases.[126] Evidence has shown fish who contract an infectious disease can increase the risk of impaired growth due to infection and high rate of mortality.

83 The incidence of several diseases have been substantially reduced due to the development of effective vaccines and medicines. One publication reports there are currently 36 vaccinations commercially available to prevent against bacterial and viral diseases in fish. However, despite the important role vaccinations play to control the spread of disease in the commercial fishing industry, the use of vaccines is often hindered by the lack of efficacy, cost and the difficulty in obtaining regulatory approval for the use of certain vaccines. As a result of this, attention is now focusing on selective breeding as a major method to control disease in farmed aquaculture populations, by producing a stock with improved resistance to certain infectious diseases. Studies exploring the genetic basis of disease resistance in fish, have revealed a high level of heritability for these traits, concluding the feasibility of incorporating disease resistance traits in a selection index to help control diseases found among fish.[127] Today major breeding companies include disease resistance alongside other desired traits such as growth-rate in the breeding goals, for example breeding programmes in Norway have included disease resistance to bacterial and viral infections since 1993.[128] Since disease resistance has a relatively high heritability, disease testing can be applied to relatives of the selection candidates in a breeding scheme, in particular found in salmon and tilapia breeding programmes.[129]

---

[124] Lafferty KD, Harvell CD, Conrad JM *et al.* (2015) Infectious Diseases Affect Marine Fisheries and Aquaculture Economics *Annual Review of Marine Science* **7**: 471-96

[125] European Food Safety Authority (2008) *Animal welfare aspects of husbandry systems for farmed trout - scientific opinion of the panel on animal health and welfare*, available at: https://www.efsa.europa.eu/en/efsajournal/pub/796

[126] Håstein T (2004) Animal welfare issues relating to aquaculture. In Global conference on animal welfare: an OIE initiative. European Communities, Paris, France, (Citeseer), pp. 212-21.

[127] Yáñez JM, Houston RD and Newman S (2014) Genetics and genomics of disease resistance in salmonid species *Frontiers in Genetics* **5**

[128] Gjøen H and Bentsen H (1997) Past, present, and future of genetic improvement in salmon aquaculture *Ices Journal of Marine Science - ICES J MAR SCI* **54**: 1009-14

[129] Yáñez JM, Houston RD and Newman S (2014) Genetics and genomics of disease resistance in salmonid species *Frontiers in Genetics* **5** ; LaFrentz BR, Lozano CA, Shoemaker CA *et al.* (2016)

84 Selective breeding aquaculture programs use simple approaches such as mass selection which can enable rapid genetic progress for resistance traits. It has been reported that mass selection programs have produced greater than 60% increase in Oyster Herpes Virus survival compared with controls after four generations of selection, similar results have been shown for Taura Syndrome Virus in Panaeid shrimps.[130] Despite the progress made by mass selection, the method is not often applied to advanced selective breeding programs due to a risk of inbreeding depression. As a result, the majority of breeding schemes use family selection to obtain data on disease resistance, recording the survival rates of disease-challenged siblings of breeding candidates, since due to vertical transmission of the disease testing the breeding candidates is not possible.

85 Recent advances in biotechnology and molecular techniques, have helped identify molecular markers involved in genetic variants which influence a range of phenotypic traits in aquatic species which can be applied to selective breeding programmes, including disease resistance. Recently, a major single QTL was identified which explained 80-100% of the genetic variance of resistance against the IPN virus in Atlantic salmon, which has now been widely adopted in the aquaculture industry to successfully control the disease.[131] This has led to a 75% decrease in the number of IPN outbreaks in the salmon industry.[132] In addition, studies have reported a high heritability for PD resistance among the Atlantic salmon (estimated between 0.26-0.34).[133] A recent study confirmed that PD has a high heritability, and showed that the majority of the PF resistance is influenced by two significant QTL.[134] The emergence of new research shows the possibility of implementing disease resistance traits into a breeding program to improve the prevalence of disease outbreaks, especially using marker-assisted selection based on QTL regions.

86 Despite notable progress being made in selective breeding indices within the aquaculture industry, there is a still a lack of understanding of the genetic functional basis of many traits important in the farmed fish, particular the understanding of mutations underlying genotype-phenotype associations, making it difficult to apply genomic tools in the aquaculture sector. As a result of this, several large projects have been developed to address this lack of knowledge and build a new phase pf research. A large, collaborative EU-funded project called 'FISHBOOST' was developed in 2014, with the aim to improving selective breeding in six finfish species, to increase the efficiency and profitability of European Aquaculture. A mixture of low and high-tech technological advances will be developed to help improve the selective breeding

---

Controlled challenge experiment demonstrates substantial additive genetic variation in resistance of Nile tilapia (Oreochromis niloticus) to Streptococcus iniae *Aquaculture* **458**: 134-9

[130] Dégremont L, Nourry M and Maurouard E (2015) Mass selection for survival and resistance to OsHV-1 infection in Crassostrea gigas spat in field conditions: response to selection after four generations *Aquaculture* **446**: 111-21

[131] Houston RD, Haley CS, Hamilton A *et al.* (2008) Major quantitative trait loci affect resistance to infectious pancreatic necrosis in Atlantic salmon (Salmo salar) *Genetics* **178**: 1109-15 ; Moen T, Baranski M, Sonesson AK and Kjøglum S (2009) Confirmation and fine-mapping of a major QTL for resistance to infectious pancreatic necrosis in Atlantic salmon (Salmo salar): population-level associations between markers and trait *BMC Genomics* **10**: 368

[132] Moen T, Torgersen J, Santi N *et al.* (2015) Epithelial cadherin determines resistance to infectious pancreatic necrosis virus in Atlantic salmon *Genetics* **200**: 1313-26

[133] Gonen S, Baranski M, Thorland I *et al.* (2015) Mapping and validation of a major QTL affecting resistance to pancreas disease (salmonid alphavirus) in Atlantic salmon (Salmo salar) *Heredity* **115**: 405-14

[134] Hillestad B, Makvandi-Nejad S, Krasnov A and Moghadam HK (2020) Identification of genetic loci associated with higher resistance to pancreas disease (PD) in Atlantic salmon (Salmo salar L.) *BMC Genomics* **21**: 388

programmes. Show promising results. In addition, another European project called 'AQUA-FAANG', running from 2019-2023, is aiming to deliver a better understanding of genome function and genotype-to-phenotype prediction in the six most farmed fish in Europe. The project is aiming to generate genome-wide functional annotation maps, with a particular focus on improving resistance to diseases.

87 In 2018, 87% of salmon ova laid down to hatch were imported from outside the UK. These ova were largely genetically improved eggs from large consolidated pedigree-based selective breeding programmes, imported from companies such as AquaGen and Mowi (based in Norway). Breeding practices in the salmon industry varies from phenotypic selection to complex genomic technologies against key diseases. Resistance to disease and robustness is closely linked with profitability and good welfare.

Sea lice resistance

88 Ectoparasitic copepods, commonly known as sea lice, is the most harmful parasite for the Atlantic salmon fishing industry worldwide and currently one of the biggest pathogenic threats to the UK salmon industry.[135] Infection of Atlantic salmon by the salmon louse *Lepeophtheirus salmonis* in the Northern Hemisphere *and Caligus rogercresseyi* in the Southern Hemisphere.[136] Fish infested with sea lice can display skin lesions, an osmotic imbalance, reduced growth rate and greater susceptibility to bacterial and viral infections through the suppression of the immune response by the damage to the skin of the fish.[137] Sea lice not only put a significant negative impact on the health and welfare of salmon, but also creates an increased economic burden due to the cost of expensive treatments, lice prevention methods and loss of fish. Currently, methods used to control sea lice include feed supplements, "lice-zapping" lasers, cleaning fish and different husbandry designs. Expensive and chemically harsh drugs are also frequently used to control sea lice prevalence, however these treatments can cause potential environmental issues and the emergence of drug-resistant lice.[138] Recent methods to control sea lice are the recent shift to mechanical and thermal delousing, commonly being used in the Norwegian salmon industry. With this method gaining traction in other countries due to being highly effective, there are worries about the method's effect on the stress and welfare of the fish, with increased post-treatment mortality rates compared to traditional chemical treatments.[139]

89 Given the notable issues associated with sea lice infestations, especially in salmon aquaculture, host resistance to sea lice is becoming a key trait of interest to target through selective breeding. Intensive research has taken place to understand the underlying molecular mechanisms and parasite-fish interactions, to develop breeding methods to reduce the prevalence of sea lice. Studies have investigated the genetic variation for resistance to sea lice in Atlantic salmon populations. The studies revealed a heritable component (ranging from 0.12 to 0.32 and a range of 0.13 to 0.33) when

[135] Iversen A, Hermansen Ø, Andreassen O *et al.* (2015) Kostnadsdrivere i lakseoppdrett

[136] Hemmingsen W, Mackenzie K, Sagerup K *et al.* (2020) Caligus elongatus and other sea lice of the genus Caligus as parasites of farmed salmonids: A review *Aquaculture* **522**: 735160

[137] Jonsdottir H, Bron J, Wootten R and Turnbull J (1992) The histopathology associated with the pre-adult and adult stages of Lepeophtheirus salmonis on the Atlantic salmon, Salmo salar L *Journal of Fish Diseases* **15**: 521-7

[138] Frazer LN, Morton A and Krkosek M (2012) Critical thresholds in sea lice epidemics: evidence, sensitivity and subcritical estimation *Proceedings Biological sciences* **279**: 1950-8

[139] Overton K, Dempster T, Oppedal F *et al.* (2019) Salmon lice treatments and salmon mortality in Norwegian aquaculture: a review *Reviews in Aquaculture* **11**: 1398-417

resistance was defined as the number of parasites fixed in all the fins.[140] A further study reported a heritability value 0.09 for sea lice resistance in a rainbow trout breeding population.[141] Recent research has identified genomic regions which are associate with the immune system which could be involved in mediating sea lice resistance in the Atlantic salmon and rainbow trout.[142] QTLs have been detected North American and Chilean populations of Atlantic salmon which explain 6% and 13% of the genetic variation in sea louse resistance.[143] These findings indicate it is possible to control lice in fish, particularly salmon, breeding populations by utilising selective breeding due to the host resistance having a significant genetic component. This has been suggested in the literature.[144]

90 Two major fishing breeding companies in Norway (AquaGen and SalmoBreed) are now offering salmon lines which have been selected for sea lice resistance using marker-based selection or genomic selection. As a result of using genomic selection within salmon breeding programmes, there has been an increase in accuracy of selection for sea louse resistance by up to 22% and after focusing on genomic selection for sea lice resistance after two generation this resulted in 40-45% reduced sea louse infestation compared to unselected fish.[145] Given the accuracy of genomic prediction, it is likely that selective breeding for host resistance to sea lice will become an important part of sea live control and become more widely used in salmon breeding programmes.[146]

91 To date, gene-editing technique CRISPR/Cas9 has been successfully applied to different aquaculture species for different production traits for example reproduction and growth.[147] Further possible approaches for tackling sea lice resistance in Atlantic salmon include genetic editing to modify protein mechanisms or regulate the expression of genes affecting resistance.[148] Recent work has also explored the possibility of the hybridisation of Atlantic salmon with more louse-resistant salmonoid species, however so far research has found no difference in the sea-lice infection level between the hybrids and sea-lice resistant fish.[149]

---

[140] Correa K, Lhorente JP, Bassini L *et al.* (2017) Genome wide association study for resistance to Caligus rogercresseyi in Atlantic salmon (Salmo salar L.) using a 50K SNP genotyping array *Aquaculture* **472**: 61-5

[141] Bassini L, Neira Roa R, Yáñez López J *et al.* (2017) Genetic parameters for resistance to Caligus rogercresseyi, Piscirickettsia salmonis and body weight in rainbow trout (Oncorhynchus mykiss)

[142] Cáceres P, Barría A, Christensen KA *et al.* (2021) Genome-scale comparative analysis for host resistance against sea lice between Atlantic salmon and rainbow trout *Scientific Reports* **11**: 13231

[143]Rochus CM, Holborn MK, Ang KP *et al.* (2018) Genome-wide association analysis of salmon lice (Lepeophtheirus salmonis) resistance in a North American Atlantic salmon population *Aquaculture Research* **49**: 1329-38; Robledo D, Gutiérrez AP, Barría A *et al.* (2019) Discovery and Functional Annotation of Quantitative Trait Loci Affecting Resistance to Sea Lice in Atlantic Salmon *Frontiers in Genetics* **10**: 56-

[144] Gharbi K, Matthews L, Bron J *et al.* (2015) The control of sea lice in Atlantic salmon by selective breeding *Journal of the Royal Society, Interface / the Royal Society* **12**

[145] Ødeg✓ard et al. 2018

[146] Tsai et al., 2016

[147] Kishimoto K, Washio Y, Yoshiura Y *et al.* (2018) Production of a breed of red sea bream Pagrus major with an increase of skeletal muscle mass and reduced body length by genome editing with CRISPR/Cas9 *Aquaculture* **495**: 415-27 ; Li M, Yang H, Zhao J *et al.* (2014) Efficient and heritable gene targeting in tilapia by CRISPR/Cas9 *Genetics* **197**: 591-9

[148] Gratacap RL, Wargelius A, Edvardsen RB and Houston RD (2019) Potential of Genome Editing to Improve Aquaculture Breeding and Production *Trends in Genetics* **35**: 672-84

[149] Fleming M, Hansen T, Skulstad OF *et al.* (2014) Hybrid salmonids: ploidy effect on skeletal meristic characteristics and sea lice infection susceptibility *Journal of Applied Ichthyology* **30**: 746-52

Skeletal deformities, cardiovascular abnormalities, deafness and cataracts

92 A number of health problems have emerged since the increased selection for growth-rate in aquaculture over the past several decades, including various types of skeletal deformities, soft tissue malformations and cataracts. Skeletal deformities are a recurrent issue in farmed fish, in particular among Atlantic salmon and include malformations in the spine, head, jaw and softness of the skeleton. The type and level of deformities can often impact the fish's body shape and lead to economic loss due to a deformity affecting the product quality or being removed at slaughter due to not being able to be processed by machines. Other issues associated with skeletal deformities are the negative relationship with other production traits such as a reduced growth rate associated with vertebral deformities.[150] In addition to economic and production issues, skeletal deformities also create a severe problem for animal welfare. The aetiology of skeletal deformities is complex with different factors affecting the abnormal growth and development of the spine including factors relating to the environmental conditions, elevated temperatures and feed composition being a few.[151] A recent study found in the NZ Chinook salmon the predominant causative factor of abnormal curvature development is environmental, with many of the fish in the study occurring after doubling the bodyweight suggesting growth may be a contributing factor to abnormal spinal development. However, this period of growth in the fish was overlapped by elevated temperatures in the water and since high temperatures are used in aquaculture to increase the growth rate, the extent to which each factor solely or in combination plays a role in skeletal deformities still warrants further research.[152]

93 Cardiovascular issues including malformations of the heart have been associated with increased growth rate in Atlantic salmon in recent years. Documented malformations of soft tissues among salmon include ventricular hypoplasia (underdevelopment of chambers that pump blood out of the heart), deficient septum transversum and invertus of the heart. In addition to these anomalies, differences in heart shape between wild and farmed fish have been observed, with wild type fish such as smolt having an angular pyramid-shaped heart whereas the domesticated salmon phenotypically has a more rounded heart. This subsequently means the salmon has reduced output and function compared with the heart of wild salmon.[153] Moreover, studies have shown farmed salmon have higher levels of fat deposition in the ventricle, 44% compared to 9% in wild smolt.[154] Normal heart and cardiac function are crucial for fish to optimise oxygen supplies which contribute to growth rates and feed conversion in aquaculture, and a disruption of these functions can lead to an increased risk of myocardial dysfunction and death in farmed fish, causing health and welfare concerns. A focus on production traits such as growth rate in selective breeding programs in aquaculture combined with rearing strategies such as over-feeding and reduced level of activity is thought to be the leading

---

[150] Fjelldal PG, Hansen T, Breck O *et al.* (2012) Vertebral deformities in farmed Atlantic salmon (Salmo salar L.) – etiology and pathology *Journal of Applied Ichthyology* **28**: 433-40

[151] Sullivan M, Reid SW, Ternent H *et al.* (2007) The aetiology of spinal deformity in Atlantic salmon, Salmo salar L.: influence of different commercial diets on the incidence and severity of the preclinical condition in salmon parr under two contrasting husbandry regimes *J Fish Dis* **30**: 759-67

[152] Lovett BA, Firth EC, Tuck ID *et al.* (2020) Radiographic characterisation of spinal curvature development in farmed New Zealand Chinook salmon Oncorhynchus tshawytscha throughout seawater production *Scientific Reports* **10**: 20039

[153] Poppe TT, Johansen R, Gunnes G, Torud B. Heart morphology in wild and farmed Atlantic salmon Salmo salar and rainbow trout Oncorhynchus mykiss. Dis Aquat Org. 2003;57:103–8.

[154] Kristensen T, Urke HA, Poppe T and Takle H (2012) Atrial natriuretic peptide levels and heart morphology in migrating Atlantic salmon (Salmo salar) smolts from 4 rivers with different environmental conditions *Aquaculture* **362**: 172-6

factors contributing to the cardiovascular changes observed in fish.[155] Recent studies have also indicated high levels of stress observed in fish farm environment contributes towards the anomalies in heart morphology observed due to the persistently high levels of stress-hormone cortisol inducing cardiac issues among fish.[156] A key study recently conducted demonstrates the high prevalence and severity of cardiovascular disease in farmed rainbow trout throughout a range of aquaculture systems and concluded that continued selection for an increased growth rate for fish in aquaculture (including via both selective breeding programs and rearing environments such as increased temperatures), correlates with cardiac deformities and particularly a high prevalence of coronary arteriosclerosis. The researchers concluded it would be of benefit for further research to be conducted into the specific effects of selective breeding programs and/or management conditions on the development of cardiovascular diseases in farmed fish, in order to help develop potential methods or techniques to reduce the prevalence of this issue in the future.[157]

94 In addition to skeletal and cardiovascular abnormalities, rapid growth rate has been shown to cause abnormal vaterite otoliths formation (an essential component of the sensory organ that enable teleost fish to hear) in fish, leading to severe hearing loss potentially impacting the welfare of the fish. A recent study indicated that fast-growing fish are three times more likely to have vateritic otoliths than slow-growing fish providing strong evidence that a fast growth rate is likely to be the underlying cause.[158] Further research has identified a strong association between rapid growth rate and the increased incidence of cataracts among fish.[159] Deafness and cataracts could potentially have negative impacts on the welfare of the fish such as the inability to exert natural behaviour and communicate using sound (which is particularly important for the Nile tilapia which communities through sound) and reduced eyesight. This research could potentially have strong implications for the aquaculture industry as well as influence breeding programmes, by reducing the growth rate to prevent abnormalities such as cataracts and deafness.

95 Selective breeding programmes. In addition, the EFSA has pointed out the lack of data reporting on the negative health and welfare issues associated with selective breeding on body functions (cardiac, respiratory, reproduction and sensory) and disease susceptibility, highlighting the importance of accurate data recording of health and welfare issues to help develop effective methods or techniques to reduce or prevent these possible consequences from occurring.

Summary

96 Due to the fishing industry still being in its infancy, with commercially bred stocks being only a few generations of the wild species, there remains a high level of genetic variation in aquaculture species. Although genetic gains have been made through well-managed

---

[155] Poppe TT, Johansen R, Gunnes G and Tørud B (2003) Heart morphology in wild and farmed Atlantic salmon Salmo salar and rainbow trout Oncorhynchus mykiss *Diseases of aquatic organisms* **57**: 103-8

[156] Johansen IB, Sandblom E, Skov PV *et al.* (2017) Bigger is not better: cortisol-induced cardiac growth and dysfunction in salmonids *Journal of Experimental Biology* **220**: 2545-53

[157] McKay JC, Barton NF, Koerhuis ANM and McAdam J (2000) The challenge of genetic change in the broiler chicken *BSAP Occasional Publication* **27**: 1-7, Brijs J, Hjelmstedt P, Berg C *et al.* (2020) Prevalence and severity of cardiac abnormalities and arteriosclerosis in farmed rainbow trout (Oncorhynchus mykiss) *Aquaculture* **526**: 735417

[158] Reimer T, Dempster T, Warren-Myers F, Jensen AJ and Swearer SE (2016) High prevalence of vaterite in sagittal otoliths causes hearing impairment in farmed fish *Scientific Reports* **6**: 25249

[159] Ersdal C., Midtlyng P.J. & Jarp J., 2001. An epidemiological study of cataracts in seawater farmed Atlantic salmon (Salmo salar). Dis Aquat Org. 45: 229-236

selective breeding programmes for fish, overall the development of aquaculture breeding programs has been slow compared to plants and terrestrial farm animals, with less than 10% of the world aquaculture production being based on selectively improved stock.[160] This is likely due to the high fertility rates and mass spawning events which can lead to large genetic variability and a depression of fitness. Despite this statistic likely being higher in developed countries, generally, the aquaculture sector is lagging behind the breeding sector for livestock, especially when it comes to genetic technology. Despite this, the selective breeding for genetic improvement of production traits has coincided with a number of health and welfare issues including the susceptibility to infectious disease, skeletal and cardiovascular abnormalities, deafness and cataracts. Many of these issues being negatively associated with the intense selection for growth rate in fish.

97 Despite a plethora of research exploring QTL and heritabilities of traits of interest in aquaculture species, only a small number of large-effect QTL have been detected such as the major QTL explaining variation to the resistance of IPN virus. Most of the variation in disease resistance observed and other relevant traits are underpinned by polygenic genetic mechanisms. As a result of this, addressing disease resistance in aquaculture still largely relies on family-based selective breeding programs supplemented by genomic selection where disease resistance is the major focus.[161] Since the first successful demonstration of effective gene-editing in Atlantic salmon, CRISPR-Cas9 has been applied in various finfish and molluscs primarily as a proof of principle. Whilst genome editing tools has the significant potential to offer opportunities to accelerate genetic gains in production traits, it is likely disease resistance will be another primary focus for genome editing in the aquaculture industry.[162] This is mainly due to practical reasons as research and applications have access to thousands of externally fertilized embryos. There is a potential for this sector to grow through production using selective breeding and potentially using genome editing technologies, whilst simultaneously considering the health and welfare of the fish.

98 In 2012, the FAWC recommended breeding companies including fish should incorporate a broad range of breeding values in their programmes.[163] Aquaculture breeding programmes have the opportunity to take advantage of the genetic potential observed among fish and to build on production traits to create balanced breeding programs which include traits such as disease resistance which will inevitably improve the health and welfare of the fish as highlighted in a recent landmark report by the Food and Agriculture Organisation of the United Nations.[164] Despite there being an increase in research and development looking at the genetic basis of different non-production traits, there is still a lag in the amount of data published to understand the mutations which underly phenotypic traits, this results in different levels of breeding tools being adopted for different species such as the Atlantic salmon industry employing the highest level of

---

[160] Gjedrem T, Robinson N and Rye M (2012) The importance of selective breeding in aquaculture to meet future demands for animal protein: A review *Aquaculture* **350-353**: 117-29

[161] Houston RD (2017) Future directions in breeding for disease resistance in aquaculture species *Revista Brasileira de Zootecnia* **46**: 545-51

[162] Houston RD, Bean TP, Macqueen DJ *et al.* (2020) Harnessing genomics to fast-track genetic improvement in aquaculture *Nature Reviews Genetics* **21**: 389-409

[163] Farm Animal Welfare Committee (2012) *Opinion on the welfare implications of breeding and breeding technologies in commercial livestock agriculture*, available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/324658/FAWC_opinion_on_the_welfare_implications_of_breeding_and_breeding_technologies_in_commercial_livestock_agriculture.pdf

[164] Food and Agriculture Organisation of the United Nations (2019) *The state of the world's aquatic genetic resources for food and agriculture*, available at: http://www.fao.org/3/CA5256EN/CA5256EN.pdf

biotechnology such as the routine use of multiple trait selection in breeding programs. Initiatives and projects for example FISHBOOST, aim to better understand the underlying biological mechanisms of different traits in fish species and develop novel technologies to progress current aquaculture breeding programs. The outputs of these initiatives will likely allow the integration of the latest breeding technologies into the fishing industry. This may increase the number of domestic selection programmes, and reduce the negative impacts of importing stock such as the G x E interactions.

To what extent does the regulatory environment affect trait selection in balanced breeding programmes in the UK and EU and thus improve the health and welfare of farmed animals? What are animal welfare protocols used to assess welfare indicators of farmed animals?

99 Analysis of this question is split into two sections: the first summarises the current legal regulations governing genetic selection for balanced breeding; the second addresses recent initiatives started by organisations and consumers driving changes within the breeding sector.

Regulations

100 Many countries regulate animal welfare through legislation, in 2020 the EU Commission adopted the Farm to Fork Strategy which contains an action to launch an evaluation of the EU legislation on the welfare of farmed animals. A part of this strategy is to evaluate if the EU legislation on the welfare of farmed animals remains fit for purpose in the light of recent scientific and technological developments. Currently the EU law on animal breeding is set out in the EU Directive 98/58/EC (transposed into the Welfare of Farmed Animals (England) Regulations 2007 in England with similar legislation in Scotland and Wales) and annual inspections are carried out. Primary legislation which relates to breeding technologies and animal breeding in the UK comprise the Animal Welfare Act 2006 and the Animal Health and Welfare (Scotland) Act 2006; the Veterinary Surgeons Act 1966; and the Animals (Scientific Procedures) Act 1986.[165] Additionally, the European Forum of Farm Animal Breeders (EFFAB) has developed a 'Code of Good Practice for Farm Animals Breeding and Reproduction Organisations' (code-EFABAR) which sets out a set of practical codes of conduct including best animal health and welfare.[166] Questions concerning EU legislation on selective breeding of farmed animals include: How effectively is the EU breeding legislation enforced? Has there been a time when it's been used to restrict breeding of certain animals/lines? Effective advice and possibly legislative control is needed to define breeding goals and the realistic balance of traits to address health and issues problems identified in farmed animals.

101 There is an increase in novel techniques entering the EU breeding market and there is also concern of the current genetic breeding techniques used in the EU. This potential issue is well illustrated by the lack of regulations in the UK that state how many embryos can be implanted into a sheep or cattle or how many times this can be done in the same animal. Many of these new technologies come from overseas and therefore are not initially covered by the EU regulations. As a result, technologies have the potential of being used in breeding programs without evaluation of the impact of welfare. This

[165] Farm Animal Welfare Committee (2012) *Opinion on the welfare implications of breeding and breeding technologies in commercial livestock agriculture*, available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/324658/FAWC_opinion_on_the_welfare_implications_of_breeding_and_breeding_technologies_in_commercial_livestock_agriculture.pdf
[166] European Forum of Farm Animal Breeders (2020), available at: https://www.effab.info/code-efabar.html

typically can occur by being introduced by veterinary surgeons as a part of the veterinary practice and then become established in farmed practices in absence of the impact they may have on welfare. An example of when this has occurred is using the juvenile in vitro embryo transfer (JIVET) technique. Currently used in Australia, the JIVET is technique which stimulates follicle growth in juvenile animals (calves at 8-10 weeks and sheep and goats at 6-8 weeks old).[167] This mechanism has the potential to increase progeny and reduce the time between pregnancies and births. Whilst this presents a number of welfare issues this technique is currently being used in Australia and illustrates the possibility of similar techniques to be used in EU commercial agriculture.

Initiatives

102 Animal health and welfare within breeding is a society-sensitive sector, with growing public concerns of the issue of animal welfare within the EU, demonstrated in various surveys and reflected by increasing farm animal welfare legislation and policy initiatives.[168] Currently, there is a growing trend in European countries to move towards higher welfare broiler production systems. An example of when this has been illustrated is the successful transition to higher welfare broiler farming in the Netherlands. Analysis of how this was achieved, revealed that there were five important factors playing a role in this change:

1) the availability of a cost-efficient alternative to conventionally produced meat;

2) a basic willingness to change within the entire value chain (including consumers);

3) initiating and triggering actions by non-governmental organisations (NGOs);

4) decisive initiatives by retailers;

5) simultaneous introduction of the new concept replacing the conventional concept in supermarkets (i.e., depriving the consumer of a cheaper choice alternative).[169]

103 Recently, other initiatives to improve animal welfare in the EU have been fuelling change. In particular in the chicken industry, schemes such as RSPCA Assured (UK) and the Beter Leven (Netherlands) only permit slower growing breeds of broiler. Furthermore, the RSPA Assured stipulates requirements for higher welfare outcomes to be verified such as gait score. Other initiatives such as 'The Better Chicken Commitment' are encouraging food companies to commit to using higher welfare animal breeds within the conventional sector and improve rearing standards. The Soil Association, the UK's largest organic certifier has implemented a standard that requires farmers to use breeds or strains that 'avoid problems at birth', this would mean the Belgian Blue cattle could not be included under this stipulation.

---

[167] Armstrong DT, Kotaras PJ and Earl CR (1997) Advances in production of embryos in vitro from juvenile and prepubertal oocytes from the calf and lamb *Reproduction, Fertility and Development* **9**: 333-9; Cognié Y, Baril G, Poulin N and Mermillod P (2003) Current status of embryo technologies in sheep and goat *Theriogenology* **59**: 171-88

[168] European Commision (2007) *Attitudes of EU citizens towards Animal Welfare*, available at: http://ec.europa.eu/public_opinion/archives/ebs/ebs_270_en.pdf

[169] Saatkamp HW, Vissers LSM, van Horne PLM and de Jong IC (2019) Transition from Conventional Broiler Meat to Meat from Production Concepts with Higher Animal Welfare: Experiences from The Netherlands *Animals* **9**

104 There is a lack of public trust about livestock breeding, with lack of transparency from breeding companies often contributing to this. Whilst the details of sheep and beef breeding programmes in the UK are publicly available, public concern over pigs and poultry breeding is often fuelled by lack of data available, most likely due to confidential intellectual property. Breeding companies selecting traits for productivity and welfare will be collecting data on these traits and thus measuring them closely. Therefore, a level of transparency from breeding companies in the supply chain and breeding practices with regard to welfare traits will help consumers and retailers make informed choices. To improve this, the EFFAB implemented Code-EFABAR which aims to provide guidelines to breeding companies on methods to become more open and accountable on animal breeding practices, this has been widely endorsed by animal breeders.[170] Increasing transparency about the genetic breeding indices would make it easier to assign responsibility within the supply chain and allow food companies and retailers to select breeds based on welfare outcome.

Welfare definitions and assessments

105 Animal welfare is understood to be the physical and mental state of animals, ranging from total positive 'well-being' to extensive pain and suffering. However, numerous definitions of welfare exist which consist of different positive and negative events, including biological, physiological, psychological and behavioural presentations. The variation in welfare definitions presents challenges in assessing aspects of welfare in commercial breeding practices. Physical issues such as skeletal leg problems or skin lesions can be evaluated more easily by inspecting the animal's phenotype and using scoring systems. Behavioural and psychological assessments of welfare can be more difficult to accurately measure but can be achieved by recording stress responses and positive behaviours such as engaging with enrichment activities. Various welfare criteria and assessments have been developed, with the most sophisticated welfare assessment developed for on farm welfare assessment of farmed animals is described by the EU funded Welfare Quality® project.[171] However, issues with the scheme have been documented, including the applicability and therefore needs further development.[172] There are other species specific welfare assessments widely used such as the RSPCA Broiler Welfare Assessment Protocol.[173] There is no one comprehensive, fully-validated on-farm welfare assessment in the EU and efforts could be needed to find ways to improve current assessments and with some having the potential to be adapted to regulatory programs.

106 In the UK, selective breeding uses 'Estimated Breeding Values' (EBVs) to select key traits and provides an unbiased estimate of genetic worth of a range of traits. In order to address whether balanced breeding methods are effectively incorporating health and welfare traits, it could be valuable to implement welfare surveillance to accurately record, measure and monitor the extent to which a welfare or health trait is improving or getting better. An example of where successful animal welfare surveillance in breeding programmes has been achieved is in Scandinavia. Large integrated databases and

---

170 The European Forum of Farm Animal Breeders (EFFAB) (2020) *Code EFABAR "code of good practice for farm animal breeding organisations"*, available at: https://www.responsiblebreeding.eu/uploads/2/3/1/3/23133976/01_general_document_2020_final-code_efabar.pdf

171 Blokhuis HJ, Veissier I, Miele M and Jones B (2010) The Welfare Quality® project and beyond: Safeguarding farm animal well-being *Acta Agriculturae Scandinavica, Section A — Animal Science* **60**: 129-40

172 De Jong I, Hindle V, Butterworth A *et al.* (2016) Simplifying the Welfare Quality® assessment protocol for broiler chicken welfare *Animal* **10**: 117-27

173 RSPCA (2017) *RSPCA welfare standards for chickens*, available at: https://science.rspca.org.uk/sciencegroup/farmanimals/standards/chickens

comprehensive recording systems have been implemented for cattle and pig breeding. Timely welfare surveillance and on-farm inspections could help identify and highlight welfare problems as they arise, with the possibility to incorporate specific health and welfare traits in a timely fashion rather than, in many cases, addressed years later. Frequent monitoring of breeding facilitates could help highlight the most important welfare issues currently facing different animals to help inform and guide balanced breeding programs on where to focus attention. The model of Scandinavia shows the importance of on-farm surveillance of welfare of farmed animals and the ability to accurately record reliable information on the prevalence of health and welfare traits in farmed animals. There is a need for similar strategies to be adopted in other countries and in other types of farmed animals.

107 In the chicken sector, The Food Standards Agency (FSA) and the Animal Health Veterinary Laboratories Agency (AHVLA) are monitoring welfare outcomes by identifying issues at slaughter such as ascites, dermatitis and joint issues. A similar system is used to identify welfare outcomes at the abattoir for pigs in the UK (BPEX Pig Health Scheme). Regular reviews and evaluations of the welfare outcomes of the breeding programs are needed to ensure breeding companies are effectively incorporating health and welfare traits in their programmes, even if they may not be the primary breeding goal. Future research will likely be multi-disciplinary focusing on new genetic technologies, interrelationship with the environment, improvements in breeding programs.

Appendix

Table 1. Overview of articles examining the longitudinal impact selective breeding has had on broilers health and welfare

Author(s), years of publication	Country the study took place	Description of study	Comments
Rayner et al 2020	UK	A farm-based study exploring the broiler welfare in four conditions representing commercial systems varying in breed and planned maximum stocking density. Breeds A and B were slow-growing breeds and C was a widely used fast-growing breed. The breeds were assessed for both negative and positive welfare indictors and environmental outcomes. Results showed that the fast-growing breed experienced the poorest health despite being kept in larger stocking density environment. The study concludes there is a significant welfare improvement when moving away from fast-growing broilers.	The paper claims to be the "first study to utilise a comprehensive suite of measures to specifically identify the differences in negative welfare outcomes and positive behavioural outcomes across four commercial broiler systems of varying planned maximum stocking density and breeds." (i.e. suggests not much systematic research coming before). Suggests that breeding for fast growth (rather than husbandry conditions) bears a greater responsibility for poor welfare.
Dixon (2020)	UK	Used 1600 birds from four different breeds of broilers. The study assessed the health and welfare outcomes of three fast-growing birds compared to a slow growing birds kept in the same conditions. Results showed that slow-growing broilers had better welfare indicators than the fast growing breeds, including lower gait scores, feather scores, breast cleanliness scored and hock burn scores. The study concludes the welfare and behaviour of a slow-growing breed is improved in terms of the birds being more active as well as lower mortality rates than fast-growing broilers.	Large scale research at different commercial facilities is needed to fully quantify welfare measures under different type of commercial management systems.

Torrey et al (2020)	Canada	A study conducted over a two-year period to benchmark data on conventional and slower-growing strains of broiler chicken. Aim to understand the differences in behaviour, activity, physiology, anatomy and mortality, growth, feed efficiency and meat quality as they relate to the strains growth rate and age. Eight trials using over 7000 broiler chickens from 16 strains. The 16 strains were categorised into four groups: conventional, fast-growing, moderate-slow and slow-growing. All 16 strains were incubated, hatched, housed and managed, and fed the same diet, yet the different strains of broiler chickens differed in growth and efficiency. Aged day 48, strains in the conventional category were 835 to 1,264 g heavier than strains in the other categories. By the second target weight, differences in body weights and feed intake resulted in a 22 to 43-point difference in feed conversion ratios. The mortality rates between the different strains did not differ.	Future research should look at individualised optimised conditions for each strain.
Zhang et al 2018		Compared the genetic basis of cardiac development and occurrence of heart dysfunction between a modern fast-growing and a heritage slower-growing broiler. The study gave evidence for a genetic basis for the cardiac dysfunction in fast-growing broilers, and how cardiac health may be improved through setting targets in breeding programmes.	
Kapell et al (2012)	UK	The study presents the development of three broiler lines and examined	The data for the study originated from Aviagen UK breeding program.

		the changes in leg health during 25 years of selection against leg health deformities. The leg health traits included long bones, crooked toes, tibial dyschondroplasia and hock burn. Broilers were individually weighed and visually assessed for leg health at five weeks of age. The study concludes there has been improvements in leg traits and weight through breeding selection programs.	