Scientific Opinion on the influence of genetic parameters on the welfare and the resistance to stress of commercial broilers

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SCIENTIFIC OPINION

Scientific Opinion on the influence of genetic parameters on the welfare and the resistance to stress of commercial broilers[1]

EFSA Panel on Animal Health and Welfare[2, 3]

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ABSTRACT

This scientific opinion describes the influence of genetic parameters that have affected the welfare of commercial broilers. There is a lack of robust scientific data for Europe on welfare outcome indicators and these should be recorded independently and made publicly available. The major welfare concerns that have a genetic basis and that may interact with management factors to lead to poor welfare include skeletal disorders, contact dermatitis, ascites and sudden death syndrome. Most of these are linked with fast growth rates. There are also numerous interactions between the environment and the genetic traits that can seriously adversely affect welfare in areas such as lighting regimes, litter management, dietary deficiencies and contamination, air quality and temperature. In the risk assessment the probability of exposure to a hazard, and the magnitude of the poor welfare effects (consequences) of that exposure were estimated. The major risk scores were unbalanced body conformation, high stocking density, fast growth rate, low light intensity and wet litter. The top ranking environmental hazards were high stocking density, low light intensity and wet litter. It was recognised by the experts that probabilities vary from region to region, country to country and among different types of farming system. Recommendations include better data collection in Europe, greater selection strategies for improved welfare traits with birds being selected and tested for their subsequent rearing and production environments by the breeders. Finally, a high priority should be given to decreasing the proportion of birds with the higher gait scores, and to include contact dermatitis and other welfare traits in the selection schemes.

KEY WORDS

animal welfare, meat producing chickens, broilers, genetic selection, housing and management, environment-genetic interactions, risk assessment, systematic review

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SUMMARY

On the request of the European Commission, the European Food Safety Authority (EFSA) prepared a scientific opinion on the influence of genetic parameters on the welfare of commercial broilers.

Over the second half of the 20th century, the growth rate of commercially-produced broiler chickens has been increased greatly, with standard broiler chickens now reaching 1.5 kg body weight in 30 days whereas 120 days were needed in the 1950s. Simultaneously, the feed conversion ratio (the amount of feed eaten per kg of chicken growth) has been reduced from 4.4 to 1.47. It has been shown that this is largely the result of genetic selection and it is generally accepted that most of the welfare problems are caused by genetic factors. Only a small number of broiler breeder companies provide the various genetic strains of broilers used worldwide and so they have the opportunity to influence the welfare of all broilers through genetic selection, whether it promotes good welfare, robustness or productivity. This genetic change is so rapid that the exact strain when any published work was carried out has to be carefully considered and so data were collected with the help of the broiler breeder industry by means of technical hearings. In addition, information was received from other stakeholders and other interested parties, including the public, by means of technical meetings, web-consultation and a public call for data. One of the major sources of the information referred to in this report was the scientific literature search by systematic review under the framework of Article 36 of Regulation (EC) No 178/2002[4].

The layout of the Opinion covers an overview of scientific information on the welfare of broilers; welfare outcome indicators used in practice; the methods used in genetic selection; evidence for genotype-environment interactions; and, finally, a risk assessment was carried out.

Some birds are culled for humane reasons and others are found dead, and there is an increased mortality associated with faster growth rates whereas slower growth rates have a lower mortality. The major diseases with welfare implications are leg problems, contact dermatitis conditions, ascites and sudden death syndrome and these have been exacerbated by intense selection for fast growth rate and increased feed efficiency. However, there are also important interactions with the environment, e.g. type of production, feeding regime, and management. Because there is a lack of comprehensive scientific data, it is recommended that surveillance systems are set up in Europe to collect relevant data on diseases with major impact on welfare in commercial flocks, and to monitor trends in the prevalence and welfare consequences of these diseases. The data that should be recorded on farm should include the number of birds found dead, the number of birds culled, the reasons for culling, and the mortality rate at different ages.

There are serious welfare concerns about skeletal disorders in broilers that lead to lameness and this is measured by examining gait. High gait scores indicate a marked inability to walk normally and these abnormal gaits have been associated with fast growth rates and pain. However, there is considerable variation in the reported figures due to a variety of genotypes, management factors, age at scoring, and the scoring system used. Furthermore, gait abnormality does not always indicate pain and suffering, although it probably does in most birds. Nevertheless marked lameness is still likely to be a welfare problem for the affected birds because of the difficulties in obtaining resources (e.g. feed and water) and to interact socially. It is recommended that gait scoring should be monitored on farms in a standardised way and that birds that move with difficulty, or not at all should be culled. To reduce the problem in the future, it is also recommended that there should be a strategic objective that industry places a high priority, say over the next 10 years, to decreasing the proportion of birds with the higher gait scores in commercial flocks in order that lameness is minimized, even if this objective may require them to reduce growth rate.

[4] Regulation (EC) No 178/2002 of the European Parliament and of the Council of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety

Contact dermatitis is identified as another important welfare problem and its cause is multi-factorial involving environmental conditions such as wet litter as well as genetic predisposition. It can be reduced in part by good litter management to avoid wet litter but as contact dermatitis has a moderate degree of heritability it should also be included in selection programmes. A standard classification system for contact dermatitis should be developed for Europe and again there should be an objective by the industry to decrease the proportion of birds with contact dermatitis, over the next 10 years or so.

A genetic predisposition exists for both ascites and sudden death syndrome and there is a link with growth rate. The prevalence of ascites is thought to have decreased over the last 10 years as breeders have included this health problem in their selection schemes, but its prevalence should be monitored and given a high weighting in selection indices.

Genetic selection of broilers has changed considerably over the past 50 years and now encompasses welfare traits, including particular pathological conditions, and production traits. However, the level of genetic improvement, or otherwise, of individual traits cannot be quantified due to the lack of access to confidential breeder data. Therefore, data on welfare outcome indicators (such as mortality and culling rates and the reason for dying and culling, gait scoring and ascites in commercial rearing conditions) should be recorded independently and made publicly available by breeding companies for each genetic line of broilers.

There are considerable and numerous interactions between the environment and the genetic traits that can seriously adversely affect welfare in areas such as lighting regimes, litter management, dietary deficiencies and contamination, air quality and temperature. Sometimes the consequences for bird welfare may conflict, e.g. scratches (bad) may be exacerbated by increased activity of the birds (good) and this has to be taken into consideration.

Most studies on genetic selection and interaction with the environment have, to date, focussed on productivity and reproduction and not on welfare. Bird welfare would be improved if more emphasis were given to health and welfare traits particularly if birds were selected and tested for their subsequent rearing and production environments by the breeders. Genetic diversity should be maintained by breeding companies in order to meet future market demand and to develop lines that can withstand challenging environments. Slower growing lines should be used in conditions of high environmental stress and should be selected further for hot climates. Farmers should select strains of birds that are best able to cope with the environments in which they will be reared.

Genomic selection may provide a useful tool for the improvement of traits that have low heritability or are difficult to measure and welfare related traits should receive high propriety in order to benefit from any new technology.

In a systematic, scientifically based process, a risk assessment estimated the probability of exposure to a hazard, and the magnitude of the poor welfare effects (consequences) of that exposure. As mentioned above there is an overall lack of data on prevalence, e.g. conditional exposure, and exposure to the hazard. The major risk scores for likelihood of being exposed to a hazard that leads to poor welfare (welfare impact plus exposure to hazard) were unbalanced body conformation, high stocking density, fast growth rate, low light intensity and wet litter. The experts also considered a range of environmental hazards that may interact with broiler genetics, and indicated that the top ranking hazards among these are high stocking density, low light intensity and wet litter. These hazards are ranked highly either because the adverse effects are intense or prolonged or the probability of the birds being exposed to these hazards is high and the probability of experiencing adverse effects when exposed to these hazards is high. The ranking of hazard risk scores does not necessarily correlate with its welfare impact or magnitude of the adverse effect ranking. In the risk assessment, high ambient temperature, ammonia and carbon dioxide levels and relative humidity were positively correlated with production traits, whereas dust levels were positively correlated with health and other welfare traits. A standardised system for recording respiratory and mucous membrane diseases at the slaughterhouse should be investigated and developed.

It was recognised by the experts that probabilities vary from region to region, country to country and among different types of farming system and so probability estimates had large ranges. Routine data collection across Europe would help to make these estimates more accurate.

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The Community Action Plan on the Protection and Welfare of Animals has as one of the main areas of action "upgrading existing minimum standards for animal protection and welfare as well as possibly elaborating minimum standards for species or issues that are not currently addressed in EU legislation".

Council Directive 2007/43/EC[5] laying down minimum rules for the protection of chickens kept for meat production calls for the Commission to submit to the European Parliament and to the Council a report concerning the influence of genetic parameters on identified deficiencies resulting in poor welfare of chickens.

The report of the Scientific Committee on Animal Health and Animal Welfare of 21 March 2000 on the Welfare of Chickens Kept for Meat Production (Broilers) concluded that a wide range of metabolic and behavioural traits in broilers has been changed by selection practices. It seems that many welfare problems in broilers emanate from the way the animals and the parent stock are bred. In particular, major concerns for animal welfare are the metabolic disorders resulting in leg problems, ascites and sudden death syndrome and other health problems. Genetic selection practices might as well influence resistance to stress. The report also concluded there are also welfare concerns about the way broiler breeder birds themselves are kept in particular with regards to feed and space restrictions.

TERMS OF REFERENCE AS PROVIDED BY THE EUROPEAN COMMISSION

The Commission therefore considers it opportune to request EFSA to assess all the scientific and commercial information available on the genetics of broilers as well as on the welfare of grandparent and parent stocks and then to issue two scientific opinions, the first one on the influence of these genetic parameters on the welfare and the resistance to stress of commercial broilers and the second one on the welfare of grand-parent and parent stocks raised and kept for breeding purposes.

It is preferable to carry out the assessments in two steps.

As first step of the mandate, all data available worldwide on genetics either from scientific studies or from stakeholders and breeding companies should be collected and assessed. Furthermore, the data on the welfare aspects of the management and housing of the grand-parents and parents stocks raised and kept for breeding purposes should be also collected and assessed. Account should be taken of the results of the research project entitled "Broiler breeder production, solving the paradox" (Decuypere et al, 2006) as well as of the new scientific development in this area. The above mentioned scientific and commercial data should be assessed by 28 February 2010.

As a second step and considering the Scientific Report provided from the data collection, two parallel Scientific Opinions, following a harmonised approach, should be developed:

- to assess which elements of broiler breeder bird selection have an impact on the welfare of commercial broilers and on their resistance to stress. Recommendations on how negative impacts could be minimised through different selection criteria should be issued.

- to address the welfare aspects of the management and housing of the grand-parent and parent stocks raised and kept for breeding purposes.

[5] Council Directive 2007/43/EC of 28 June 2007 laying down minimum rules for the protection of chickens kept for meat production (Text with EEA relevance). OJ L 182, 12.7.2007, p. 19–28

ASSESSMENT

1. Introduction

Over the second half of the 20th Century, chicken meat has become a major source of animal protein in human diet. During this period, the growth rate of commercially-produced broiler chickens has been increased greatly: standard broiler chickens now reach 1.5 kg body weight in 30 days whereas 120 days were needed in the 1950s. Simultaneously, the feed conversion ratio (the amount of feed eaten per kg of chicken growth) was reduced from 4.4 to 1.47. It has been shown that this improvement is largely the result of genetic selection (Havenstein et al., 2003). The effect of broiler breeding is a dynamic process of the chicken populations that gradually change the various traits of interest. Traits that initially were of no-interest, may after a while (some years) start to change in an antagonistic way due to an unfavourable genetic correlation (e.g. leg disorders, metabolic diseases) causing the breeding company to include that trait in the breeding index. Selection for fast early growth rate has resulted in major changes in the anatomy and physiology of broilers, and led to various welfare problems (SCAHAW, 2000; Bessei, 2006). This dynamic selection process means that observations done 10 years ago may not be completely relevant today. Welfare implications of housing and feeding of broiler breeders are also important issues (Decuypere et al., 2006; Renema et al., 2007). It is generally accepted that most of the welfare problems are caused by genetic factors, environmental factors and interactions between them. Research on animal-based (outcome) indicators of animal welfare is making it increasingly feasible to assess broiler welfare and to monitor changes over time. With a good monitoring system in place it will be possible to evaluate the consequences of genetic and environmental changes on broiler and broiler breeder welfare.

Approximately 60-70 % of the broiler breeding is conducted by European companies and the demand for their products from outside Europe is increasing (see Appendix A). Breeding companies provide lines for the various types of broilers needed worldwide and only a few companies supply the world with broiler breeders and broiler chickens. They have therefore the opportunity to influence the welfare of all broilers through genetic selection, both on welfare and robustness as well as productivity.

2. Scope and objectives

The scope of this Scientific Opinion focuses on standard meat producing chickens that typically weigh approximately 2.5 kg by 42 days of age (i.e. broilers).

The present Opinion evaluates which elements of broiler genetic selection have an impact on the welfare of commercial broilers. It was agreed that the part of the mandate referring to "resistance to stress" was likely to form part of a later mandate on broiler health and so would not be considered in this opinion on genetics and broiler welfare.

This Opinion is laid out as follows. Chapter 3 gives an overview of welfare issues in broilers. In Chapter 4 some practical welfare indicators are described. Chapter 5 provides information on genetic selection of broilers. Chapter 6 addresses genotype by environment interactions. Chapter 7 presents a risk assessment identifying the hazards and evaluating the consequences of exposure to such hazards. Finally, conclusions and recommendations are given.

Two *ad hoc* expert Working Groups were established in response to the request from the Commission to prepare this Scientific Opinion; they have worked in close cooperation. The Working Groups have made use of technical hearings with experts from the breeding industry[6], information provided by stakeholders and collected by EFSA [7], as well as outcomes from a systematic review on the literature[8].

The lack of published data in some aspects of the question was, in part, compensated by information supplied by the technical hearings. Although this information could not be verified according to normal standards of peer reviewed publications, the working group decided to use industry based information (identified as such in the text) in this report to make it more complete and comprehensive.

3. Overview of the welfare of broilers

This section is a summary of the welfare problems encountered in broilers and is based on the conclusions of the report of the Scientific Committee on Animal Health and Animal Welfare adopted in 2000 (SCAHAW, 2000). Where appropriate additional recent update references have been included. As asked by the mandate of the Commission, this section is focussed on the influence of genetic parameters on the welfare and resistance to stress of commercial broilers.

Most of the welfare problems in broiler chickens are caused by multiple factors (genetic and environmental/management factors, Bessei, 2006). Even if there are interactions between these factors, it is recognized that some welfare problems are related to genetic factors (e.g. metabolic disorders such as sudden death syndrome and ascites, skeletal disorders and low locomotor activity, low tolerance to stress) and others (e.g. contact dermatitis, thermal discomfort) are mainly related to environmental/management factors such as stocking density and litter quality, light, and barren environment (Bessei, 2006).

According to the SCAHAW report (SCAHAW, 2000), major concerns for chicken welfare are the metabolic disorders resulting in leg problems, ascites and sudden death syndrome and other disorders such as footpad dermatitis. There are indications from Danish and Canadian sources that some of these (such as valgus-varus deformities or ascites measured on Canadian condemnation at slaughterhouse) have shown a decrease in recent years (according to data received in the public call for data) but this trend needs to be confirmed. According to Julian (2005), cardiovascular ailments are responsible for a major proportion of flock mortality whereas musculoskeletal disorders, even if they account for less mortality, cause lameness which remains a major welfare concern. Most of the welfare problems of broilers are associated with genetic selection for faster and more efficient production (SCAHAW, 2000), but other factors (environmental/management) which enable fast early growth, such as extended light regimen or nutrition and feed management, are also involved (Bessei, 2006).

The major concerns for animal welfare are leg problems, footpad dermatitis, ascites and sudden death syndrome.

These concerns for animal welfare have been associated with genetic selection for fast growth and more efficient production.

[6] The Working Group directly received information from Anne-Marie Neeteson (European Federation of Farm Animal Breeders, EFFAB), Mark Cooper (Cobb), Yves Jégo (Hubbard), and Ken Laughlin (Aviagen) as hearing experts.

[7] European Food Safety Authority (EFSA), Public call for data on health and welfare aspects of genetic selection of broilers. EFSA Journal 2009; 7(12):1439, 195 pp. Available online at: http://www.efsa.europa.eu.

[8] Lefebvre D, Tatry MV, Shepers F, Rodenburg BT, Huneau-Salaün A, Allain V, 2010. Toward an information system on broiler welfare: Genetic selection Aspects (TOGA). Technical report submitted to EFSA. Available at: http://www.efsa.europa.eu.

Monitoring of the trends in these welfare issues in commercial flocks in Europe is needed to confirm that the suspected improvements are genuine and continuing; and to identify emerging new welfare problems.

3.1. Mortality

Mortality in broiler flocks can imply complex and different calculations. Mortality can be defined as the sum of found dead and culled animals in a given time interval divided by the number of original birds at the beginning of that interval. Consequently, for a given overall mortality figure, the difference between birds culled and found dead could be an important measure of welfare. Culling can be carried out for several reasons but in this context we separate 'voluntary' and 'involuntary' culling. Voluntary culling is when birds unsuitable to be farmed are killed, e.g. wrong sex, wrong body conformation, surplus to requirement. Involuntary culling, on the other hand, occurs when animals suitable for production have poor welfare, e.g. injury, disease, lameness and unable to walk to access feed and water. Birds can also be found dead or suffer and die over a period of time. Culling of birds, is a way of minimizing suffering and the ratio of culled birds to those birds found dead could be used as a welfare indicator for a given mortality rate.

For example if 10% of birds are culled (involuntary) and a further 10% are found dead then the total mortality is 20% then the ratio C:FD is 1. If for the same mortality 5% are culled and 15% are found dead then the ratio is 0.33 indicating a greater welfare problem and poorer management.

For a given mortality figure, the difference between birds found dead and culled birds is not always made clear and it is helpful to do so for the reasons outlines above. Moreover the extra day-old chicks delivered at the farm and the culled birds are not always taken into account in the calculation. Mortality can be calculated at the farm or at the slaughterhouse (that would include dead-on-arrivals). Furthermore, there are currently no general rules on culling in most countries. In most cases culled birds are small or injured birds or birds with leg problems which are unable to have a normal access to food and water supplies. The EU Directive (2007/43) indicates that culled birds should be integrated into the mortality figures. The Directive specifies that if one wants to produce more than 39 kg/m², the mortality (%) of the 7 previous flocks should not be more than 1 + 0.06 x age of the flock at slaughter (in days). Nevertheless, the current directive 98/58/EC[9] already requires that mortality records are kept, i.e. that the number of dead or culled birds is recorded regularly. In 2011, the OIE will probably propose to its members to include two new chapters on animal welfare and animal production systems into the Terrestrial Animal Heath Code, one of them will concern broiler production system. The current draft text mentions mortality as one of the possible welfare indicators for broiler chicken.

Death of an individual is not necessarily a welfare problem, but the way an animal dies can cause poor welfare, e.g. the time it takes to die and the extent to which it suffers before death. High levels of mortality due to poor health, disease or injury could reflect poor animal welfare. On the other hand, high levels of culling can also reflect the best way to prevent animals from suffering when they are sick or injured. But the ideal situation regarding welfare is when involuntary culling is not needed. The Annex I of the Directive 2007/43/EC indicates that the number of birds found dead with an indication of the causes, when known, as well as the number of birds culled with causes should be recorded.

The link between mortality and genetic selection was assessed mostly through experimental reports since no field data are published in a validated way, but we can assume that the global tendency is the same in the field.

[9] Council Directive 98/58/EC of 20 July 1998 concerning the protection of animals kept for farming purposes. OJ L 221, 8.8.1998, p. 23–27.

Embryonic and early mortality can be influenced by age of breeders, egg storage, shell and chick quality, and incubation conditions (Scott and Mackenzie, 1993; Roque and Soares, 1994; Reis et al., 1997; Bruzual et al., 2000; Elibol et al., 2002; Decuypere et al., 2006; Elibol and Brake, 2008). Early mortality can be partly reduced by appropriate screening of hatching eggs. Breeders that are either too young or too old often have poorer fertility and hatchability resulting in chicks that have increased embryonic and early mortality (Pedroso et al., 2005; Elibol and Brake, 2006; Almeida et al., 2008). Delay in housing day-old chicks can also cause increased mortality (Stamps and Andrews, 1995). Raju et al. (1997) reared, separately or mixed together, chicks issued from different weight categories of eggs (category by category) or mixed together (different weight categories in the same pen). Correlation coefficients between egg weight and body weight at all ages of measurement were positive. Day-old chick weight increased significantly ($P < 0.01$) with an increase in egg weight. Mortality was highest in the group with lighter eggs. Rearing of chicks according to body size yielded higher body weight with low mortality and reduced variation in chick performance among the groups.

Fries and Kobe (1992) looked at 6 flocks under conventional intensive rearing conditions (0 to 35 /37 days) and found a mortality rate between 3.00 % and 5.02 %. According to Ellendorf (2002), the mortality of broilers ranges between 3.6 % and 4.5 % under different field conditions. Meluzzi et al. (2008) found a significantly lower mortality in broiler groups when kept at a low stocking density, a short photoperiod and a large amount of litter than in controls with a higher stocking density, a longer photoperiod and smaller litter amounts (1.61 % versus 3.20 % (0 to 43 d) and 2.18 % versus 3.79 % (0 to 49 d)). In a study performed in 2008 in The Netherlands, Italy and the UK on 46 flocks of broiler reared in an intensive and in a less intensive production system (RSPCA, 2008) the mean percentage of dead and culled birds measured in each country varied from 2.2 to 5.0 % (Welfare Quality deliverable 4.34, 2009).

Mortality in older birds is often related to metabolic disorders caused by rapid growth or by infectious and/or digestive disorders (See Section 3.6). Havenstein et al. (2003) compared a 1957 Athens-Canadian Random Bred Control (ACRBC) with a 2001 Ross 308 modern strain, and fed with 1957 and 2001 representative diets. Performances (Body Weight and Feed Conversion) were higher for the modern line but, in males, mortality was higher with Ross 308 (4.76 and 3.57% with 2001 and 1957 feed respectively) than with ACRBC (2.38 and 1.19%) at 42 d. In females no meaningful differences were seen at this age. At the end of the experimental period, differences in mortality were increasing (for females as well as males) but significant differences were not detected because of the small sample size (except at 84 days where a strain effect was significant). But it should be noted that the Ross strain was not selected or generally kept for such a long rearing period. Berhe and Gous (2008) studied the effect of dietary protein content on growth, uniformity and mortality of two commercial broiler strains (Ross 308 and Cobb 500) in two experiments (1) in cages until 21d and 2) on the floor until 42d). Mortality did not appear to be related to the nutritional treatments imposed on the Ross strain in either of the experiments, although the difference between strains was statistically significant ($P <0.01$) only in Experiment 2. In both experiments the Cobb birds showed a tendency to a higher mortality at the lowest dietary protein contents, and in the second experiment mortality increased exponentially on the highest feed protein contents. Casey et al. (1989) studied the influence of breed and sex on mortality and the incidence of skin tears in broiler carcasses. In their experiment, mortalities among the Hubbard strains were significantly higher than among the Ross with hens showing a slightly higher mortality rate than males, which was tending towards significance at the 5 % level. Van Middelkoop et al. (2002) compared experimental broilers I957 (Hubbard/ISA) reared until 56 days with Cobb 500 reared until 42 days of age. They showed a significantly lower mortality in I957 slow growing genotype (1.5 % vs 5.6 %) which was associated with significantly lower heart and circulation syndromes. Cooper (in EFSA, 2009_- Public call for data) compared mortality of a fast growing genotype (Cobb 500) under standard industry practice in the UK with a slower-growing genotype (Hubbard JA 757) reared with higher "welfare" standards (maximum genetic growth rate restricted to 45 g/bird/day, a lower stocking density, environment enrichment items and increased light intensity). Mortality was significantly lower for the slower-growing genotype (1.9 % vs 5.1 %). Even if it was not possible to distinguish the effect of genetics and rearing conditions, we can assume from these repeated results that slower growth can lead to decreases in mortality as well as other welfare problems.

Genetic selection can also have an impact on mortality due to ascites (see Section 3.5). Some slow growing lines, and those inheriting the naked neck appear resistant (Hernandes et al., 2002). Restriction of dietary treatments, i.e. reduced quantity, access time, and nutrients, has been effective in decreasing mortality due to ascites. Camacho-Fernandez et al. (2002) showed that feed restricted broilers resulted in the best profit-cost relationship, the lowest mortality due to ascites, the best feed conversion and increased economic benefits (even if weight gain was higher in non-restricted animals).

Mortality itself does not directly reflect animal welfare but can impact welfare if we consider the way and the reason for animals dying.

Mortality is composed of the number culled involuntarily and the number found dead and the relationship between these two is an important welfare indicator. Nevertheless culling and mortality should be as low as possible. The causes of culling and mortality should be identified, recorded and monitored.

When animals are sick or injured culling is the best way to prevent them from suffering. In this case the ratio of involuntary culls relative to those found dead can reflect good welfare management.

There is some experimental evidence that higher growth rates of certain genotypes are associated with increased mortality.

Mortality rates in slow growing stains may be lower than in standard lines but also depends of other factors e.g. type of production, feeding regime, rearing duration and management.

3.2. Musculoskeletal disorders

Skeletal problems affect predominately the locomotor system in broilers and cause lameness. The causes can be infectious (femoral head necrosis, synovitis, infectious stunting), developmental (bone deformity such as valgus-varus, dyschondroplasia, rickets, weak bones) or degenerative. Restricted movements are thought to cause a higher incidence of bone deformity (Haye and Simons, 1978). Tibial dyschondroplasia (TD) has a strong genetic component (Wong-Valle et al., 1993) and is also heavily influenced by nutrition (see SCAHAW 2000 for review). Leterrier and Nys (1992) comparing tibial growth of slow and fast growing broilers showed that rate of growth was associated with lower mineral density and higher porosity of the tibial cortices (comparison at similar weights). However, according to Leterrier et al. (1998), the reduced occurrence of valgus-varus in slow growing chicks cannot be related to an improvement in the composition of bone tissue. There is another report that shows that the bones of a fast-growing selected strain are more porous and less well mineralised than those of a slower-growing control strain (Williams et al., 2000). On the other hand, the recent study of Talaty et al. (2010) comparing four commercial broiler crosses shows that bone mineral density was similar between crosses. However, even if some of these crosses differed in lameness, no information was given on the growth rate characteristic of the crosses. Degenerative disorders may represent the progressive effects of abnormalities occurring at early age or may be the consequences of load bearing or trauma throughout life. Some lesions can also result from viral infections.

Leg problems are a major cause of poor welfare in broilers. Several gait scoring methods are used for assessing broiler lameness in the field (Butterworth and Arnould, 2009). Kestin et al. (1992) (the group that developed the Bristol Gait Scoring System (BGSS: 0 - normal to 5 - unable to walk) pointed out that their score reported on abnormal walking movements and stated that “Birds which have difficulty in moving around are likely to suffer some restriction of behaviour and could suffer physical discomfort, in addition to any pain associated with the condition.” Although a few birds may have a non-painful structural abnormality, the most likely cause of "a definite and identifiable defect in gait (score 2)" in a broiler chicken is some localised pain or lesion. There is often progression from score 2 to higher scores so a greater likelihood of pain and other poor welfare. A gait score of 3 or more is the most important welfare outcome indicator and gait scores (3-5) could be given a high weighting in selection indices even though it has a low heritability. An objective to decrease the proportion of birds with gait scores 3, 4 and 5 could be a priority and factors contributing to high gait scores (3-5) should be given high weighting in selection indices in order to reduce this important welfare problem (see also Knowles et al., 2008). At present there is no standardised gait scoring system for broilers or broiler breeders but such an instrument/tool could help in farm management and in genetic selection strategies.

Gait scoring surveys have shown that in several European countries large numbers of broilers have impaired walking abilities. Birds with moderate to high lameness scores, i.e. score 3 or above using the Bristol Gait Scoring System (BGSS; scores ranging from 0-5) can experience pain and discomfort according to Mc Geown et al. (1999) and also Danbury et al. (2000). But, there is much debate as to whether pain is a significant causal factor of abnormal gait (Corr et al., 2003) as the lameness could result from abnormal gait patterns from biomechanical limitations rather than from pain. According to these authors, these biomechanical limitations are a likely consequence of the morphological changes such as the rapid growth of breast muscle moving the centre of gravity forwards and the relatively short legs in relation to the birds' bodyweight. If there is a link between lameness and pain it probably depends on the cause of lameness. It has been demonstrated that the ankle joint is well supplied with nociceptors (Gentle 1992) which respond to abnormal movements of the joint. In inflammatory articular disease, the joint capsule nociceptors become sensitized and even small movements can become painful (Gentle & Thorp 1994; Gentle 1997). The behaviour of broilers is modified by lameness: for example the time spent lying is increased in broilers with BGSS gait scored 3 and their feeding strategy was modified (lower number of visits and higher meal durations compared with sound birds) (Weeks et al., 2000). Score 4 in BGSS indicates that birds have a severe gait defect, only walking when driven or strongly motivated and score 5 indicates that bird cannot walk at all (Kestin et al., 1992 for more details). Even if there is no consensus on pain experienced by broilers, it is clear that the welfare of the birds will be compromised if, for example, they are less capable of reaching the feeders or drinkers.

Van Middelkoop et al. (2002) showed experimentally that slow growing broilers (I 957 Hubbard/Isa) reared until 56 days had significantly better walking ability (gait score) than Cobb 500 reared until 42 days of age. Similar results have been obtained in France in 2007 comparing commercial flocks of fast growing broilers (17 flocks) and slow growing broilers (15 flocks): mean percentage of birds with moderate to low walking ability (score 3 and above with BGSS) was 2.0% and 0.6% respectively (Arnould, member of the WG, unpublished data). An important field survey undertaken in UK on 176 flocks (51,000 broilers) showed that risk factors associated with impaired locomotion and poor leg health are those specifically associated with rate of growth (Knowles et al., 2008). Kestin et al. (1992) observed that more birds were severely affected by lameness in intensive broiler genotypes reared under intensive commercial condition (4 flocks) or in conditions similar to commercial free range broilers (1 flock) when assessed at approximately the same weight. According to Bradshaw et al. (2002), femoral head necrosis is the most common disorder and is often severe in form. In this review, based on data obtained before 2000, it is also stated that TD and rickets are common, often sub-clinically but when severe there is a considerable impact on welfare. Valgus-varus disease and rotated tibia can be common but tend not to be painful unless another condition is present. According to these authors, growth rate should be decreased to reduce the prevalence of leg disorders. In a review chapter on skeletal problems associated with increased production by Whitehead et al. (2003) it is concluded that the major part of specific leg disorders in broilers has a heritable part. In the study by Le Bihan-Duval et al. (1997) in two commercial broiler strains, varus and valgus deformities showed moderate heritabilities (estimated at 0.22 when based on the sire component). Very low genetic correlations were found between susceptibility to leg deformities and growth performance (with average genetic correlations with body weight at 6 weeks of 0.05 and 0.01 for valgus and varus respectively). In this study, moderate unfavourable genetic correlations were found between varus and conformation traits (with genetic correlations of 0.16 and 0.19 between the susceptibility to this deformity and the measurement of breast angle and that of breast meat yield, respectively). This showed that care had to be taken about the impact of the intensive selection applied in the meat type strains for greater conformation on the incidence of varus deformity. Kuhlers and McDaniel (1996) took advantage of the existence of two lines of chickens divergently selected from a male-type commercial strain for either high or low frequency of TD to study the genetic control of this deformity and its genetic relationship with growth. In this selection experiment, only birds provided *ad libitum* access to a broiler diet developed TD while those fed on a restricted basis (i.e. the future reproducers) did not. After 7 generations of selection, the frequency of TD (measured by a lixiscope) was 93.4 % and 24 % in the line with a high incidence of TD, the line with a low incidence of TD respectively. TD showed quite a significant level of heritability at both 4 and 7 weeks (0.37 and 0.42, respectively). It was also noticeable that the genetic correlations of TD either at 4 or 7 weeks) with body weight were low (between -0.01 and +0.10). As concluded by Whitehead et al. (2003), the genetic correlations between specific skeletal problems and growth should permit a genetic improvement in leg health along with a continued, though more modest improvement, in growth rate. However, the gait score seemed useless as a selection criterion as it had a low heritability and a strong antagonistic correlation with growth rate. In the study from Garner et al. (2002), the presence or severity of TD did not affect gait score, suggesting that other leg problems had more influence on gait impairment than did TD. During the hearing of the three breeding companies they affirmed that several aspects of leg disorders were included in their breeding programme, which is consistent with the fact that recent surveys in commercial flocks report a decrease in the incidence of leg problems, such as TD and valgus-varus, during the last decade (ref. technical hearing).

Since gait scores vary with the age of the bird it may be difficult to compare studies. Two surveys performed in Denmark (1999) on 28 flocks and Sweden on 31 flocks (2002) to estimate the prevalence of leg problems in conventional broiler production showed a prevalence of a gait score 3 or above (scores ranging from 0 to 5, BGSS) varying from 14.1 to 30.1 %, a prevalence of TD varying from 45.2 to 57.1 % and a prevalence of valgus-varus varying from 21.6 to 48.5% according to the genotypes (Ross 208 and Cobb) and the country (Sanotra et al., 2003). From recent examinations of 30 commercial broiler flocks in Denmark it was shown that the prevalence of TD had decreased from 47 % in 30 flocks surveyed in Denmark in 1999 to less than 1 % 6 years later in the same number of flock (Pedersenet al., 2005). In the survey cited above (Sanotra et al., 2003), the mean percentage of birds with valgus-varus deformities varied from 36.9 % in Denmark to 52.6% in one strain in Sweden. However, broilers with serious cases of valgus-varus angulations, rotation of tibia or crooked toes are seldom seen in broiler flocks these days in Denmark. In spite of reduced prevalence of some leg problems like TD, valgus-varus and rotations, other leg problems have evolved later in the chicken's life primarily in relation to the femur (Whitehead et al., 2003). Diagnostic tools have not yet been developed to identify these types of leg disorders. A cross-sectional survey conducted in UK in 79 flocks between 1994 and 2000 (divided in 5 periods) showed an overall prevalence of leg weakness (gait score 3 or above, scores ranging from 0-5) of 2.5 % varying from 1.9 to 3.5 % according to the period concerned (Pfeiffer D et al., personal communication, 2003). In another study performed in UK, 0.9 % of gait score 2 (scores ranging from 0 to 2 with score 2 corresponding to birds reluctant to move and unable to walk many strides before sitting down) and 23.3 % of leg deviation (valgus-varus and rotation) were found (Dawkins et al., 2004). However, a recent survey performed in UK on 176 flocks showed that 27.6 % of birds showed poor locomotion (gait score 3 and above; BGSS) and 3.3 % were almost unable to walk (scores above 3) (Knowles et al., 2008). In a study performed in 2007 during the Welfare Quality project® on 60 flocks reared in intensive production system in France, UK and The Netherlands the mean percentage of birds with a gait score 3 and above (BGSS) measured in each of the countries varied from an average of 2.0 to 23.3 % (it varied from 0 to 70.0% according to the flocks) (Bassler A et al., personal communication, contacted by WG member, 2009; Arnould and Colin, 2009). In a similar study performed in 2008 in The Netherlands, Italy and UK on 46 flocks of broilers reared in intensive and less intensive production system (RSPCA, 2008) the mean percentage of birds with a gait score 3 or above (BGSS) measured in each of the countries varied from 9.4 to 32.6 % (Welfare Quality deliverable 4.34, 2009). In the UK survey cited above (Knowles et al., 2008) the primary risk factors associated with impaired locomotion and poor leg health were those specifically associated with rate of growth. Factors significantly associated with high gait score included the age of the bird (older birds), bird genotype (two genotypes from either one of two major international breeder companies), not feeding whole wheat, a shorter dark period during the day, higher stocking density at the time of assessment, no use of antibiotics, and the use of intact feed pellets.

There are serious welfare concerns over skeletal disorders in chickens.

High gait scores have been associated with fast growth rates

However, there is considerable variation in the reported figures due to a variety of genotypes management factors, the age at scoring, and the scoring system used.

Some skeletal disorders are already being addressed in selection (e.g. TD).

Overall gait scoring has low heritability but some of the reasons contributing to high gait scores (valgus-varus, TD) are heritable.

Gait abnormality does not always indicate pain and suffering. However high scores (i.e. 4 and 5 in BGSS) probably reflect suffering; moderate score (3 in BGSS) may also do so.

Gait scoring could be monitored on farms in a standardised way with the goal of decreasing the proportion of birds scoring 4 or higher in the near future.

Decreasing the proportion of birds with score 4 and 5 should receive a high propriety and should be addressed through increased selection pressure on all factors contributing to high gait scores as well as through improved management.

3.3. Muscle disorders

Myopathies (deep pectoral myopathy, muscular dystrophy) and biochemical indices of muscle damage have been identified in broilers. Some are induced by stress (acute heat stress) and have a genetic component (SCAHAW, 2000; Sandercock et al., 2006, 2009). Sandercock et al. (2006) comparing two chicken lines showed that heat-stress-induced myopathy was more pronounced in the broiler than in the layer line at the same age or at similar live weights. These authors suggested that genetic selection for high muscle growth in broiler lines has compromised their capacity to respond to an acute thermal challenge, leading to detrimental consequences for muscle function. Recent research showed that there was considerable (genetic) variation between lines for the activity of creatine kinase, a blood enzyme that is an indicator of muscle damage. Approximately 50% of the total variation in enzyme activity was attributable to differences between broiler lines suggesting that genetic selection could improve muscle function (Sandercock et al., 2009 a and b).

Heritability of the incidence of deep pectoral myopathy has been estimated to be 0.48, and body weight and breast angle are greater in affected than non-affected birds, and are positively correlated phenotypically with the incidence of deep pectoral myopathy (Hollands et al., 1986). This relationship between wide breast angle and deep pectoral myopathy had already been observed in a study comparing different meat-type chicken genotypes from broiler stock from 1958 to 1977-1978 (Grunder et al., 1984). The impact of myopathies on bird welfare is not really known but Julian (2004) considered that deep pectoral myopathies are likely to be a very painful condition during the acute phase because of the swelling and the pressure inside the muscle. However, deep pectoral myopathy is apparently not a problem in modern broiler production (technical hearing).

3.4. Contact dermatitis

Skin diseases are disorders increased considerably from 1969 to 1988 (1.4 % - 34.5 %) (Hartung, 1994 cited in SCAHAW, 2000). Contact dermatitis (skin conditions or lesions of the breast, hock and feet which may be scored slightly differently in different countries) is a widespread problem in European broiler production even if the incidence is highly variable (Bessei, 2006; Berg, 2004). In severe cases the erosions develop into ulcerations with inflammatory reactions of the subcutaneous tissue. The lesions can become infected with a variety of bacteria. Such lesions can cause pain, whether infected or not, which constitutes a welfare issue. In a study by Martland (1985) broilers with severe foot-pad dermatitis showed slower weight gain. This author suggested that this could be due to pain-induced inappetence. It might also due to lower feed intake as a result of fewer visits to the feeders due to pain when walking. Furthermore, lesions can be a gateway for bacteria which can lead to joint inflammation.

Management practices seem to be the most important factor in preventing the occurrence of wet litter which is believed to be the main underlying factor of the disease together with feed composition to a lesser extent (SCAHAW, 2000; Mc Lean et al., 2002; Jones et al., 2005; Mayne, 2005). Experience from Sweden and Denmark has clearly demonstrated that monitoring programmes for foot-pad dermatitis, in combination with relevant management advice to broiler producers, can substantially decrease the incidence of foot-pad dermatitis in broilers (Algers and Berg, 2001; Berg & Algers, 2004).

In Sweden it decreased from 11 % in 1994, when the surveillance program started, to 6 % in 1996 (Algers and Berg, 2001). However, mild lesions did not show any significant decreasing trend (Ekstrand et al., 1998). In 1998 the prevalence of severe foot-pad lesions had further decreased to 6% (Algers and Berg, 2001). The type of rearing system, including the use of different genotypes, clearly affected the prevalence of contact dermatitis. In Denmark a monitoring programme was initiated in 2001 using the same principles as in Sweden. For each batch of chickens slaughtered at a slaughter plant 100 feet were sampled and scored, classifying each foot with either no, mild or severe lesions with scores of 0, 1 or 2, respectively. They found a decrease between 2002 and 2007 corresponding with the experience in Sweden (Pedersen, 2007) and was thought to be due to farmers with repeated to high FPD-values reducing the flock density, combined with and advice to improve the litter quality. Thus by governmental regulation it was possible in Denmark and Sweden to reduce FPD and in Norway The Netherlands and Belgium similar approaches are being discussed.

In the Pagazaurtundua and Warriss (2006) survey, performed in the UK in 91 farms on 359 flocks, the flocks that had access to the outside (slaughtered at a minimum age of 56 or 70 days) showed a higher prevalence of foot-pad dermatitis than those kept entirely indoors (slaughtered at an average age of 39 or 49 days). The lowest prevalence of foot-pad dermatitis and the lowest severity of lesions occurred in Freedom Food systems (2 farms, 85 flocks), and the highest prevalence and highest severity in organic systems (23 farms, 128 flocks). Opposite results have been obtained in France comparing commercial flocks of fast growing broilers (17 flocks) with slow growing broilers (15 flocks): mean percentage of birds with severe FPD and hock burn was 23.0 % versus 7.9 %, and 5.2 % versus 0.0 % respectively (Arnould, member of the WG, unpublished data). These results are consistent with those of Cooper (in EFSA 2009 - Public Call for Data). In these studies it is not possible to distinguish between genotype and type of housing/management effect. However some research results comparing different genotypes of fast growing broilers reared under commercial conditions (e.g. Ross 208 and Cobb) suggest that genotype can also influence the prevalence of contact dermatitis (Allain et al., 2009, Sanotra et al., 2003). Furthermore, Van Middelkoop et al. (2002) showed experimentally that hock and footpad burns were less severe in slow growing than in fast growing broilers. In this case slow and fast growing broilers were reared in similar conditions except that slow growing broilers were slaughtered 14 days later compared with the fast growing broilers. A study by Kjaer et al. (2006) showed a heritability of 0.31 for footpad dermatitis and a low genetic correlation with body weight (-0.08) which suggests that selection against susceptibility to footpad dermatitis should be possible without adverse effect on weight. This conclusion is reinforced by similar analysis of different lines of broilers. Recently a heritability estimate of 0.34 for foot-pad dermatitis and 0.17 for hock burn was reported by Akbas et al. (2009). In another recent study performed on male broilers from multiple commercial broiler pure lines it was shown that the probability of having foot-pad dermatitis and hock burn differed significantly among the 10 commercial broiler pure lines tested (male and female lines), and both foot-pad dermatitis and hock burn were heritable in the 2 lines tested (heritability of 0.21for foot-pad dermatitis and 0.08 for hock burn: mean of 0.10 in both lines) (Ask, 2010). In this study, the genetic correlation with body weight was -0.51 in one line but low and non significant in the other (0.08). For foot-pad dermatitis it was significant in one line (0.14) but not for the other (0.16) for hock burn. The genetic correlation between foot-pad dermatitis and hock burn was -0.07 and 0.29 according to the line but it was not significant for both cases. These results show that there is genetic variation between lines and confirm that selection against foot-pad dermatitis and hock burn is possible. According to Ask (2010) selection can be done against both foot-pad dermatitis and hock burn, and it should not have a negative influence on the genetic improvement in body weight.

Prevalence of contact dermatitis varied with scoring system and the results also differed according to age of the birds at the time of assessment, so comparisons between studies are difficult. In surveys performed in Denmark (23 flocks assessed in 1999) and Sweden (15 and 16 flocks according to the strains assessed in 2002) the prevalence of foot-pad dermatitis in conventional broiler production was estimated to have a prevalence varying from 21.6 to 48.5 % according to the genotype (Cobb, Ross 208) and the country (Sanotra et al., 2003). In this paper there is no explanation of the scoring system used. In the UK, a prevalence of 2.8 % for footpad score 2 (> 5 mm lesion on pad) and 1.5 % for hock burn score 2 (> 10% hock lesion) was found by Dawkins et al. (2004). In Italy, on 24 flocks of light, medium and heavy broilers, 16 out of the 24 flocks showed severe foot-pad dermatitis but the percentage of affected birds varied considerably from 1 – 90% (Melluzzi et al., 2008a). Twenty two flocks out of the 24 showed the presence of hock burn but again a high variability in the percentage of affected birds: 4 – 87 %. Similar variability was observed in France on high growth rate chickens. Fifteen flocks out of 17 had severe foot-pad dermatitis but the percentage of affected bird was highly variable: 2 - 76 % (Arnould and Colin, 2009). The percentage of broilers with hock burn was lower with 8 flocks out of 17 with severe hock burn but with a considerable variability between flocks: the percentage of affected birds varied from 1 to 27%. In another study in France the prevalence of severe food-pad dermatitis, hock burn and breast burn (55 to 52 flocks according to the lesions) was 70.8, 17.1 and 15.8 % respectively (Allain et al., 2009). A study performed in Portugal on broilers from the same strains reared in extensive indoor or traditional free-range system showed that footpad dermatitis was common (79.2 % in a extensive indoor system using a scoring system of only 2 scores) with a higher incidence in the older birds: 94.3% at 91-100 days old and 71.9% at 70-80 days old (Gouveia et al., 2009). In a study performed in 2007 during the Welfare Quality project ® on 60 flocks reared in intensive production system in France, UK and The Netherlands the mean percentage of birds with severe footpad dermatitis (score 4 on scores that ranged from 1 to 4) and hock burn (score 2 on scores ranged from 0 to 2) varied from 23.0 to 50.1% and 5.2 to 14.0%, respectively according to the country (Bassler A et al., personal communication, contacted by WG member, 2009). In a similar study performed in The Netherlands, Italy and UK on broilers reared in intensive and less intensive production systems (RSPCA, 2008) the mean percentage of birds with a footpad dermatitis score >2 and hock burn score >2 (scores ranged from 0 to 4) varied from 4.8 to 52.8 % and 0 to 10.0 % respectively according to the country (Welfare Quality deliverable 4.34, 2009). The mean percentage of birds with breast burn varied from 0.04 to 1.8 %. The prevalence of dermatitis on chicken carcasses has also been estimated at the point of sale by Broom and Reefmann (2005) who found that of 384 “Grade A” chickens scrutinised in British supermarkets, 82% had detectable hock burn.

Contact Dermatitis is an important welfare problem.

The aetiology of contact dermatitis is multi-factorial involving environmental conditions such as wet litter and genetic predisposition.

There is a need to recommend development of a standard classification system across Europe.

Contact dermatitis has a moderate degree of heritability and genetic selection against contact dermatitis should be implemented to reduce this major welfare problem.

The impact of contact dermatitis can also be reduced by good litter management.

3.5. Ascites, pericarditis, sudden death syndrome and spiking mortality syndrome

Ascites and Sudden Death Syndrome (SDS) are two important lethal diseases of broilers that are both metabolic in origin. Ascites is a result of dilatation and hypertrophy of the right side of the heart which leads to cardiac failure and changes in liver function causing accumulation of ascitic fluid in the abdominal cavity (Riddell, 1991; Julian, 2005). SDS affects mainly fast growing male birds. It is generally assumed that the central problem for both is a lack of oxygen for the myocardium caused either by shortage of supply (e.g. respiratory failure) or by too high a demand for oxygen (SCAHAW, 2000). Spiking mortality syndrome usually occurs within the first two weeks of rearing (Brown, 1991). This syndrome corresponds to a hypoglycaemia and a deficit of pancreatic glucagon and can lead to elevated mortality with neurological signs (Burns et al., 2002; Davis and Vasilatos-Younken, 1995). The aetiology of this syndrome is quite obscure and a controlled lighting programme as well as a specific diet (glucose & vitamins) can decrease the problem (Davis et al., 1996).

Ascites was originally considered as a high altitude disease caused by the low oxygen pressure (Cueva et al., 1974). This disease has become prominent in many low and moderate altitude countries since the early 1980s (Julian, 2005). As the broilers grew faster, ascites was increasingly seen at low altitude particularly when reared in houses in which ambient temperature was down at 14 to 18 C (Albert and Frankenhuis, 1990). In healthy flocks of broilers, SDS is the most frequent cause of death (Julian, 2005). Maxwell and Robertson (1997; 1998) concluded that 4.7 % of broilers on a world basis were affected and that 25 % of the overall broiler loss in the UK was due to ascites.

Genetic, nutrition and environmental conditions such as air quality or light conditions can influence the incidence of ascites and SDS (Hernandes et al., 2002; de Smit et al., 2005; Baghbanzadeh and Decuypere, 2008, Ghazani et al., 2008, Balog 2003). Fast growth rates increase the risk of these two diseases by increased oxygen demand which puts pressure on the cardio-pulmonary system (Greef et al., 2001; Druyan et al., 2007). As growth rate and oxygen demand coincide with other physiological challenges, this may lead to cardiac failure. The study of Gonzales et al. (1998) shows clearly the relationship between high productivity and high incidence of SDS and ascites syndrome and indicated that slow growing male broilers (Label Rouge, naked neck) are resistant to these metabolic disturbances unlike the males in the other strains tested under the study conditions (Arbor Acres, Avian Farms, Cobb-500, Hubbard-Peterson, ISA and Ross). Hernandes et al. (2002) showed significant differences in mortality due to ascites between Hubbard broilers and naked neck broilers raised in thermoneutral (4 % vs 0 % mortality) and cold conditions (41 % vs 0 %).

Van Middelkoop et al. (2002) also reported a higher percentage of mortality caused by ascites in fast growing broilers (slaughtered at 42 days of age) than in low growing broilers (slaughtered at 56 days of age)

Cahaner (2007) pointed out that management approaches were used to control the disease since the 1990s by increasing ambient temperatures and reducing intake of dietary energy but these also increased production costs. Simultaneously research was conducted to control or reduce ascites through genetic approaches and several studies showed that susceptibility to ascites had a hereditary background. Moreover, it was possible by appropriate selection (Druyan et al., 2007a) to develop a resistant line and to show that early growth rate had a very low genetic correlation with ascites (Druyan et al., 2008). Several studies were then made to select for resistant and susceptible lines for ascites (Druyan et al., 2005; Pavlidis et al., 2007; Druyan et al., 2007a), but without compromising broiler performance (Balog et al., 2003; Druyanet al., 2008). It appears that there are only a few genes responsible for ascites susceptibility (Druyan and Cahaner, 2007; Druyan et al., 2007b). The relatively high heritability estimates for ascites-related traits and the significance of maternal genetic effects for most of the traits indicate that direct and maternal genetic effects play an important role in the development of the ascites syndrome (Baghbanzadeh and Decuypere, 2008). The impact of rearing temperature either cold (10 C by 22 days of age) or normal (17-18 C by 35 days of age) on the genetic parameters of several ascites-related traits (haematocrit, accumulation of fluid in the pericardial sac or in the abdomen, weight of the right ventricle as a ratio of the total weight of right and left ventricles) and of body weight (BW) have been estimated (Pakdel et al., 2005a). They concluded that single-trait selection for BW at normal temperature is likely to increase susceptibility to ascites syndrome revealed at cold temperature, but that there are also realistic opportunities for multi-trait selection for improved BW and resistance to ascites (Pakdel et al., 2005b).

The ratio of right to total ventricular weight measured under normal temperature was suggested as a good indicator for resistance to ascites (Pakdel et al., 2005c). It was also shown that it was possible to use non-invasive indicators such as oxygen saturation of haemoglobin to predict chickens with an inherited resistance to ascites (Druyan et al., 2007b). Greff et al (2001) showed that parameters correlated with ascites were different if animals between lines (blood gas traits) and within lines (performances traits) were compared.

In a study conducted to evaluate the genetic association between potential growth rate (GR) of broilers and their responses to heat-induced growth depression and cold-induced ascites syndrome (Deeb and Cahaner, 2002), a significant positive correlation was found between potential GR and prevalence of ascites (r = 0.479) when exposed to cold, indicating that families with higher potential GR under normal conditions are more likely to suffer from ascites under cold stress compared with families with lower GR. Heat stress markedly reduced weight gain in all families. However, the genetic potential GR was negatively correlated with actual GR under heat stress (r = -0.411). A negative correlation was found between growth under heat stress and prevalence of ascites during cold stress (r = -0.439), indicating that families whose GR is more depressed under heat stress are more likely to suffer from ascites under cold stress. These results suggest that the 2 stress responses may share similar control of the genetic variation in each trait and their negative genetic correlation with potential GR.

Hassanzadeh et al. (2004) showed that different atmospheric pressures during incubation interact with the endocrine functions of the embryo and hence affect hatching parameters, thereby influencing ascites susceptibility (see De Sit et al., 2008; Hassanzadeh et al., 2008).

Genetic factors such as sire and dam lines, hybrids and sex have an impact on SDS which is higher in males than in females and in the parental lines than in the hybrids (Grashorn, 1994). Genetic parameters were estimated in meat-type chickens using two breeds (Cornish and White Rock) selected for body weight (Moghadam et al., 2005). Results showed a heritability of SDS of 0.30 and 0.25 in the Cornish and White Rock breeds, respectively, and a positive genetic correlation with ascites of 0.3. Heritability of SDS calculated using male records only was 0.45 and 0.35, and the correlation with body weight was 0.30 and 0.27, in the Cornish and White Rock breeds, respectively. Mortality from SDS can be decreased by lowering energy intake (changing feed texture or density) or by management procedures such as feed restriction or long dark periods (Julian, 2005). Low light intensity and low disturbances of flocks are also effective.

The prevalence of ascites has decreased over the past 10 years according to industry data who indicate that they integrate this health problem in the selection scheme.

A genetic predisposition exists for both ascites and Sudden Death Syndrome.

Low energy intake can decrease Sudden Death Syndrome because of slower growth rate.

Selection against these conditions, particularly in fast growing lines, should continue and the prevalence needs to be monitored to ensure it remains at a low level.

There is a link between growth rate and ascites and probably also Sudden Death Syndrome.

Slow growing genotypes are more resistant to ascites.

3.6. Respiratory and mucous membrane diseases

Infectious bronchitis, avian pneumovirus infection and chronic respiratory disease (mycoplasmosis) are currently the main infectious respiratory diseases affecting the welfare of broilers and their incidence varies between EU member states. Some respiratory disease may contribute to the appearance of ascites (Tottori et al., 1997). Furthermore, respiratory disease is not always a result of infection and can be due e.g. high ammonia levels.

Respiratory tract infection and associated septicaemia due to *Escherichia coli* in broiler chickens cause major economic losses. The infection is usually secondary to viral or mycoplasmal infections or environmental stresses and most frequently involves avian pathogenic *E. coli* (APEC) of serogroups O1, O2 and O78 (Gomis et al., 2001). Disease occurs most commonly as air sacculitis but may involve septicaemia with pericarditis, perihepatitis, synovitis and osteomyelitis (Gross, 1994; Barnes and Gross, 1997). Mortality is usually about 5 % and morbidity around 50 %, but mortality can reach 20 %, especially under poor management conditions and in the presence of concurrent infections (Wray et al., 1996; Dho-Moulin and Fairbrother, 1999). Disease prevention using antibacterial agents is expensive and not always desirable and effective due to the rapid development of antibiotic resistance. Developing vaccines to protect chickens and vaccinating broiler breeders has succeeded in providing passive protection of progeny chicks against respiratory septicaemic disease caused by APEC (Kariyawasam et al., 2004).

Exposure to ammonia, dust and other aerial pollutants has been shown to cause changes in the pulmonary ultrastructure, such as the loss of cilia from the epithelium lining the lumen of the trachea, probably reducing the effectiveness of the mechanical defence mechanism of the respiratory system (Kristensen and Wathes, 2000). Kristensen and Wathes (2000) concluded that all the reviewed evidence suggests that exposure to ammonia concentrations of 60-70 ppm may cause keratoconjunctivitis that may cause pain in the birds and also difficulties in finding food and water. The authors draw the hypothesis that impaired vision may also influence a bird's ability to orientate, recognize conspecifics and intent, as well as affecting mate choice in breeder flocks, thus affecting aggression and possibly causing distress. Concentrations of 25 ppm ammonia has been shown to have deleterious effects on the respiratory tract in poultry (Anderson et al., 1966; Anderson et al., 1968, Moum et al., 1969), including the loss of tracheal cilia and histopathological changes to the tracheal epithelium (Nagaraja et al., 1983, Nagaraja et al., 1984). This reduced effectiveness of the mechanical defence mechanism of the respiratory system may increase the frequency of respiratory diseases. In birds, a higher incidence of lung damage was found in broilers raised on litter compared with a netting floor system (Madelin and Wathes 1989). Carpenter et al. (1986) demonstrated that reducing the dust concentration in broiler houses reduced the severity of structural and lymphocytic reaction in the lung tissue of the birds.

The possibility for developing a standardised system for monitoring respiratory and mucous membrane diseases at the slaughterhouse should be investigated.

The lung damage and respiratory disease problem could be exacerbated by high ammonia and dust levels.

3.7. Thermal discomfort

Thermal discomfort can be assessed by observing broiler behaviour. Broilers (mainly chicks) huddle to conserve heat, especially before they are able to effect homeothermy. At the other extreme, increased respiration (panting) is related to discomfort due to high temperatures (hyperthermia). Reducing hyperthermia can be achieved by increasing heat dissipation and decreasing heat production. In high growth rate broilers under hot conditions, especially in hot climates, feather coverage hinders the dissipation of excessive internal heat. It is why reduced plumage coverage could help broilers to be more comfortable. It has been shown that broilers with reduced feather coverage inheriting the (naked-neck gene) reared at 35 C compared to 25 C are able to minimize their elevation of body temperature compared with their fully feathered counterparts (commercial broilers) but tolerance to heat stress was limited (Cahaner et al, 2008). When environmental temperature is the same as the body temperature of birds, non-evaporative heat loss fails and heat can only be lost through increased respiration (Ahmad and Sarwar, 2006). Hyperthermia is the main thermal discomfort encountered during broiler production and according to Ahmad and Sarwar (2006) modern fast-growing broiler chickens face difficulties in coping with heat stress. The risk of thermal discomfort increases with age as declining space diminishes the opportunity for heat dissipation and is exacerbated at high stocking densities especially in warmer climates. High stocking densities favour radiant transfer from bird to bird and heat in the floor litter is less easily dissipated. It has been shown that the temperatures beneath the surface, at the surface, or 10 cm above litter surface increased significantly with increasing stocking density (from 6 to 8 C at 19 to 40 kg/m²) and the temperature at bird level is reduced immediately if birds are removed (Reiter and Bessei, 2000). In a study where Ross 308 broilers were allocated to three terminal (42 days) stocking densities (28, 34 and 40 kg/m²) a reduced proportion of time spent panting deeply during weeks five and six was observed at the lowest density (McLean et al., 2002). Increased (shallow and deep) panting shown by females in weeks two to five suggests that if thermal discomfort becomes a problem at high stocking densities later in the growing period, it may do so earlier in females, despite the lower feed intake and body weights of females compared with males of the same age. This may be due to differences in insulation because of the faster feathering and greater body lipid content of females.

The risk of heat stress increases as birds get bigger, are better insulated and eat more food (and so generate more heat) which, together with the declining space all contributes to poorer heat dissipation. Metabolic heat production has been estimated to be 10-15 watts for a bird of 2kg, which means that in a 30,000-bird house the heat production is estimated to be equivalent to 350-450 one-kilowatt heaters (Mitchell and Kettlewell, 1998).

The effects of heat are exacerbated by a rise in atmospheric relative humidity which increases the apparent equivalent temperature (AET). AET is the true index of thermal load and physiological stress effects are moderate for AET between 40 to 60 C, but are severe and potentially lethal for AETs above 65 C (Mitchell and Kettlewell, 1993). It is necessary to control ventilation especially during summer and in hot climates to avoid mortality.

Several management techniques such as improving insulation, providing adequate ventilation, and reducing bird density have been developed to decrease heat stress and will have the effect of improving welfare by making the birds feel more comfortable. Dietary modifications have also been recommended to minimize the negative effects of heat stress (see Ahmad and Sarwar, 2006, for review).

In a study comparing the effects of an environmental temperature of 21, 32, or 38 C in an Athens-Canadian Random Bred (ACRB) population with commercial broilers (BR), it has been shown that resistance to heat stress varies according to genotype (Berrong et al., 1998). The decreased body weight gain of the BR in response to heat stress was much more severe than that of the ACRB. The body temperature of the BR (41.9 C) was significantly higher than that of the ACRB (41.5 C). The BR showed an increase in mortality in both the 38 and 32 C environments, but the mortality for the

ACRB was unaffected by environmental temperature. In the study of Khan et al. (1987) dwarf egg layer, dwarf broiler and its normal bodied sib hens were studied under heat stress of 21.1 to 45.5 C. Mortality was less in the dwarf egg layer compared with the dwarf broiler, but normal bodied hens showed more mortality than dwarfs. These authors concluded that the dwarf gene enhances the viability of hens under heat stress. The results from Sandercock et. al. (2006) show that genetic selection for high muscle growth in broiler lines has compromised their thermoregulatory capacity. These authors compared male grandparent lines of broiler and layer-type chickens at the same age or body weight. There were major differences in thermoregulatory and respiratory responses to heat stress in these lines selected for either greater reproductive or meat traits. Exposure to acute heat stress (32 C / 75% RH compared to 21 C / 50 % RH) caused an increase in deep body temperature and panting-induced acid-base disturbances (blood pCO_2 decreased and pH increased).

Al-Murrani et al. (1997) examined Heterophil/Lymphocyte ratio (H/L) as criterion for selection for resistance to heat stress in laying hens. H/L ratio was highly heritable. Resistant and Sensitive groups produced progeny with significantly different H/L ratios and there were indications of differences in mortality between the progeny of these two groups. These results show that H/L indicator could be used as a criterion to select for heat stress resistance. Selection for H/L ratio in cross-bred hens is positively correlated with several important production and reproduction traits (such as egg production, fertility, hatchability and mortality, etc.) which suggest a general 'resistance' of the birds (Al-Murrani et al., 2006).

Modern fast growing broilers are susceptible to heat stress.

There are management techniques available to reduce heat stress on farm.

The recommended ambient temperature for fast growing broilers should be re-evaluated as it may be too high considering current growth rates and expected future growth rates.

The optimal growth rate of the genetic lines should be evaluated in hot climates and slow growing lines selected for these climates.

3.8. Behavioural restriction

Restriction of behavioural expression is partly due to a lack of space available for each bird. This lack of space depends on stocking density and is most likely to occur in the last week of life. Other environmental factors such as barren environment, very low light intensity level and poor litter quality may also contribute to low levels of activity and may restrict the birds' behavioural repertoire. The greatest threat to broiler welfare appears to be reduced locomotion and reduced litter directed activities (e.g. scratching) leading to leg weakness, poor litter quality and contact dermatitis. The study of Dawkins et al. (2004) suggested that management is more important than stocking density for leg deviations, leg culls, and contact dermatitis, at least in a range of 30 – 46 kg /m², but no observations were made on bird behaviour except for jostle rate which increased with stocking density.

Some results suggest that broilers may spontaneously limit their physical efforts at the end of the rearing period even if space is available (Arnould and Faure, 2004). This is in agreement with a study comparing the same strain in free-range and deep litter systems where there was little use of extra space outdoors (Weeks et al., 1994). Several studies have shown differences in behaviour between lines. A comparison between an experimental low growth rate broiler (experimental cross) and a fast growth rate broiler (Ross) reared with access to an outdoor area showed that the fast growth rate had a low usage of the outdoor area due to impaired mobility (Nielsen et al., 2003). Comparisons between a commercial laying hybrid (Isabrown, IB) and a fast growth rate broiler (Ross 308, R) showed that IB spent more time moving and less time resting than R in the second part of the rearing period (Lichovnikova et al., 2009). Similarly, as soon as they reached 2 or 3 weeks of age, fast growth rate chicks (IJC915) have been shown to spend less time standing and more time lying down than low growth rate chicks (T551) (Bizeray et al., 2000). In this study, differences between low growth and fast growth rate broilers were observed very early, e.g. during the first 3 days of life they showed differences in duration of walking per standing bout (19±4 sec and 45±4 sec, respectively), even if they spent the same time standing (Bizeray et al., 2000). Several breed types (fast growing, medium to fast growing, slow growing and very slow growing) were characterised for behaviour (DEFRA research report, OF0153, 2002, call for data). It showed that lying down was the main behaviour for the fast-growing breeds (Ross birds) and also in the fast to medium growing breeds. Master Gris birds and the slow growing breed-type were moderately active and only the very slow growing breed-types were classified as being active. Time spent feeding did not differ between breeds but time spent ground pecking was different with the active very slow growing breeds spending a large proportion of time ground pecking. Experimental studies performed on slow and fast growing broilers (Bokkers and Koene, 2004) and on fast growing broilers divided into heavy and light broilers compared with what they would normally weigh in commercial condition (Bokkers et al., 2007) suggest that motivation is the dominant determinative factor for walking in birds with a low body weight, while physical ability is the dominant determinative factor for walking in birds with a high body weight. According to Bokkers et al. (2007), the high body weight of broilers can be considered as a physical constraint to be active.

Selection has had an impact on behaviour leading to reduced mobility and utilisation of space.

It is not clear whether the birds show reduced mobility because of a lack of motivation or because of an inability to do so. However, some studies suggest that these two aspects coexist.

Slow growing birds do not show reduced mobility to the same extent than fast growing birds.

Management of birds will also affect mobility such as light, barren environments and stocking density.

Selecting to decrease growth rate and for increased motivation to walk would lead to more active birds.

3.9. Environmental factors linked to welfare

A number of environmental factors are linked to welfare problems and have an impact on many of the welfare problems cited above together with others such as hyperthermia, kerato-conjunctivitis, tracheitis, cold and heat stress, functional development of the eyes, discomfort with fluorescent light, scabby hip syndrome, disturbance of resting, fear and its deleterious effects, injuries such as bruising and fractures, and the level of distress. Scabby hip syndrome might not be a problem at the present time but data are missing. These environmental factors include: air quality (humidity, ammonia, and dust), litter quality (substrate used, depth, water equipment, ventilation, feed composition), temperature, light (photoperiod, intensity, source and wavelength), stocking density, stockmanship (contact with human, quality of contact), environmental enrichment (perches or other objects, music), and broiler catching (manual, mechanical/automatic). Many of these management factors are covered in the manuals produced by the industry.

Environmental factors can reduce and increase bird welfare and so should be managed carefully.

3.10. Nutrition and feed management, water

Overt nutrient deficiency is rare. Nutritional management (qualitative and quantitative food restriction, feed in meals rather than *ad libitum*) can have an impact on metabolic disorders such as leg or cardio-pulmonary disorders.

Nipple drinkers have advantages over bell drinkers in that they improve water hygiene (e.g. by reducing bacterial load), reduce evaporation and spillage. However this system may constrain an individuals' water intake (and hence food intake) through inefficient use of nipples (drinking takes twice as long with nipples as with bell drinkers). It is important that good management systems are in place for water so that wet litter does not occur.

Dietary deficiencies and contamination are rare but when they do occur they can have a major welfare effect for many birds.

It is important that the watering system is managed in a way that reduces the risk of wet litter and water contamination.

3.11. Digestive function

During the last decade, successive events including the ban of meat and bone meal and fat from animal origin, the ban of in-feed antibiotics, and the limitation on the number of available coccidiostats have promoted a phase of digestive instability in broiler rearing (Balloy, 2003). There is a recrudescence of dys-bacteriosis in broilers, implying an increase in the episodes of diarrhoea and wet litter (Hermans et al., 2006) both of which can affect adversely broiler welfare (wet litter increases the risk of contact dermatitis, and ammonia on the respiratory tract). This involves an additional cost for the farmer due to the increasing mortality risk, reduced feed conversion ratio and the use of therapeutic antibiotics. Avrain et al. 2003 studied the isolation and antimicrobial résistance and *Campylobacter jejuni* and *C. coli* strains from broilers arriving at French slaughterhouses in the first six months of 1999 (before prohibition of antimicrobial growth promoter in France). Results were analysed according to production types (e.g. standard, export and free range) and antimicrobial administration in flocks. The prevalence of *Campylobacter* was 56.6 % in standard, 51.3 % in export and 80 % in free-range broilers. Statistical analysis revealed significant difference in distribution of *Campylobacter jejuni* and *Campylobacter coli* and antimicrobial resistance according to production type or antimicrobial administration. Antimicrobial use is uneven between productions, with, for example, no growth promoter and less antimicrobial treatments used in free range and less coccidiostats in standard systems of production.

Ask et al. (2006) found an effect of genotype on mortality, lesion prevalence, and growth retardation, indicating the presence of genetic variation in susceptibility of broilers to colibacillosis. There were large between-genotype differences in mortality (up to 46 %) and in lesion prevalence (up to 41 %). These preliminary results suggest that an impact of genetics on the level of susceptibility to colibacillosis may exist, but further analyses are needed to estimate to what extent it could be improved by genetic selection.

In a study performed in 2007 during the Welfare Quality project® on 60 flocks reared in intensive production system in France, UK and The Netherlands the mean percentage of birds affected by diarrhoea within a flock varied from 0.0 to 21.75 % according to the country (Bassler A et al., personal communication, contacted by WG member, 2009). In a similar study performed in The Netherlands (n=18) and Italy (n=18), the average percentage of birds with diarrhoea within a flock varied from 0.04 to 7.5 according to the country (Welfare Quality deliverable 4.34, 2009).

In growing chicks, genetic differences can have an influence on the digestibility of certain meals as shown by the development of divergent lines (Carré et al., 2006). Despite a genetic selection for high feed efficiency, modern broilers may not show optimal digestibility in certain cases. This could induce a negative effect on litter quality that may also affect body condition and animal welfare.

4. Indicators used in practice

In the past decade there has been a change in thinking about indicators. For example, there is now a distinction made between 'input' and 'outcome' indicators, somewhat equivalent to the distinction between 'design' and 'performance' criteria in the building and design industries (Rushen and de Passille, 1992; Blokhuis et al., 2003). A distinction is also made according to what the indicator is based upon, that is to say whether it is a measure of resources, management or taken on the animals themselves (Keeling and Veissier, 2005). Several measures and indicators relevant to welfare of broilers have been referred to previously in this report. This section gives a brief review of some of the terminology regarding indicators and an introduction to some of the issues that will need to be considered when proposing welfare indicators for commercial broilers. .

There are several assurance and auditing schemes in place for broilers and some of these voluntary schemes are used for labelling of chicken meat based on compliance with animal welfare standards or other parameters. However, these are not harmonised between Member States and there is little consistency in the thresholds for the different indicators that are monitored.

Traditionally, indicators used in practice have been indirect indicators of welfare, describing the housing and equipment (e.g. a loose housing system with a specified amount of feed trough space per bird) or the management of the birds (e.g. how many times per day they are inspected). Hence they are often referred to as resource-based and management-based measures. Both can be considered 'input' measures and because they can be used to reduce the risk of poor bird welfare in the future, they are the type of indicator usually used in animal welfare legislation. But sometimes factors interact in complex ways and, in that case, 'outcome' measures are used in animal welfare legislation (e.g. to specify a maximum allowed level of ammonia in a building). Outcome measures can also be measured on the animals themselves (on-farm or at the abattoir) and it is these animal-based (outcome) indicators of animal welfare that are the main focus of this section of the report. Ideally, inputs should always relate to outcome measures, but some inputs may be there for emergencies e.g. back-up generators. Other inputs such as access to an outdoor area or perches could be important but cannot be related to outcome measures if birds do not use the outdoor area or the perches. Ongoing re-evaluation of the link between inputs and outcomes is recommended to ensure that they continue to be relevant and valid for welfare.

The systematic recording of outcome measures can help in determining trends over time. If the aim is to monitor the consequences of breeding strategies on welfare then it is important that there is reliable surveillance of those animal-based indicators that reflect the areas of welfare concern influenced by genetic selection. When there is a genetic environment interaction, as is usually the case, then it will be necessary that these animal based (outcome) measures are monitored in commercial practice. The crucial factors when deciding on an indicator are that it is valid (it really says something about the welfare of the bird) and that it can be measured reliably (by different people and under different conditions). If it is going to be applied in practice, it is also necessarily for the measure to be feasible. See Keeling (2009) for information on how these factors were addressed in the Welfare Quality project. See Manning et al. (2007) for a further discussion of key welfare indicators for broiler production and in particular how benchmarking can be used proactively in management.

The potential use of records of mortality, dead on arrival at the slaughterhouse and the *post mortem* inspection controls carried out at the slaughterhouse, such as contact dermatitis, parasitism and systemic illness are outlined in the broiler directive (Council Directive, 2007/43/EC). The EU funded research project Welfare Quality proposed an assessment protocol for broilers on farm, during transport and at slaughter (Welfare Quality, 2009) that uses as much as possible, animal-based measures that had been scientifically evaluated with regard to validity, reliability and feasibility (Forkman and Keeling, 2009). The World Organisation for Animal Health (OIE) is currently developing standards and has an *ad hoc* Group on Animal Welfare and Broiler Chicken Production Systems that is also developing a list of outcome based measures that could be useful indicators of broiler welfare. Although sometimes expressed differently, the following is a list of most of the animal-based indicators of welfare referred to in those three documents, as well as some additional indicators, that could be collected on farm, at the slaughterhouse or both

- **On Farm**:

  mortality, feed conversion rate, growth rate, feed and water consumption,
  panting and wing spreading, huddling, shivering,
  lameness and gait scoring,
  spatial distribution of the birds, fearfulness (human avoidance behaviour, responses to novel object), dust bathing behaviour, qualitative behavioural assessment.

- **At slaughterhouse**:

  dead on arrival,
  pre-stun shock and flapping on the slaughterhouse line,
  clinical signs of disease e.g. ascites, emaciation, dehydration, hepatitis, pericarditis, abscesses, septicaemia,
  wing damage and bruising, broken limbs, dislocation of hip and other joints, carcass quality.

- **Farm and slaughterhouse**:

  contact dermatitis (footpad dermatitis, hock burns, breast blisters or burns), plumage condition and cleanliness, skin lesions and injuries, condition of the eyes,
  clinical signs of parasitic, gut and respiratory disease, leg deformities.

Several of these, and the scientific studies underlying them, have also been referred to earlier in this report under the various sections.

In addition to the choice of measure, when a particular measure is taken will influence the result and consideration may be given to taking it at the most critical point in time, in accordance with the approach used in HACCP. How exactly the measure is taken will also influence the results, and whether it is based on a sample of birds or not. If the measure is based on a sample of birds, how these are selected is important and will need to be standardized if results are to be comparable. Some of these issues can be demonstrated by taking three indicators namely mortality, gait scoring and food pad scoring, as examples.

Mortality can be recorded in many different ways. From a management point of view, and to help identify causes so mortality can be reduced, it may be most useful to record it separately for the different stages in the bird's life e.g. to distinguish between mortality within the first 3 days post hatching, during the main on-farm production period and that occurring during transport to the slaughterhouse. Likewise, even if the aim is to monitor and reduce overall mortality, the number of birds found dead should be considered separately from the number culled, since culling of sick birds is desirable to reduce suffering. Recording the causes of culling allows to identify the problem encountered and then could help reduce mortality. Thus mortality is not a straightforward indicator to use in practice, although it can be useful for monitoring trends if the exact way to record it is carefully defined. The measure 'dead on arrival' at the slaughterhouse is a measure of mortality that is increasingly being used in commercial practice to monitor the transport of broilers.

Another example of an animal-based outcome indicator of animal welfare is that of gait scoring. The Bristol Gait Scoring System (BGSS) has six categories ranging from 0 (normal) to 5 (bird incapable of sustained walking) (Kestin et al. 1992). There is a modified version of this system (MGSS) (Garner et al., 2002) as well as a three category system (Dawkins et al. 2004). All have been used in commercial flocks. As discussed in section 6.2, a poor gait may have many potential causes and minor deviations from a perfect gait may not necessarily reflect pain. Therefore, if gait scoring is to be implemented in practice, it would probably be most effective to restrict the scoring to the worse gait scores e.g. 3, 4 and 5 according to the BGSS/MGSS, which are unlikely to be attributable to the body morphology of modern broilers (Corr et al., 2003). Gait scoring is also a measure that is clearly sensitive to when the measure is carried out (older/heavier birds are more likely to have a poorer gait than younger/lighter ones) and how the sample of birds is chosen.

Finally, if an indicator is to be implemented in practice, then the long term consequences of implementing the measure should be taken into consideration. The complexity of this is perhaps illustrated using the example of footpad dermatitis. In the short term, incentives to reduce contact dermatitis are likely to lead to improved litter management, which in turn will lead to improved air quality through lower levels of ammonia etc. However, there is some evidence that this trait is heritable (Kjaer et al. 2006; Akbas et al, 2009). Genetic selection against footpad dermatitis would contribute to reducing any pain and suffering for a particular bird experiencing contact dermatitis, which is beneficial, but it would also eventually lead to it being a less useful outcome based measure of litter management in the building. Such aspects would need to be carefully considered and re-evaluated over time to maximise welfare benefits. It also underlines that several indicators should be used to assess welfare to obtain an overall assessment.

5. Genetic selection of broilers

Breeding programmes are organised to supply commercial flocks with day-old broiler chicks in a multiplication pyramid illustrated in Appendix A. The figure (Figure 8) indicates the importance of birds in the pedigree nucleus but in practice many more birds contribute to the top of the pyramid than are shown in the diagram (Figure 1). The box in bold at the top of the Figure 1 corresponds to the pedigree selection level and is followed by the multiplication (crossing) phase that consists of a number of generations (left). The number of broilers that result from this process (lowest level) illustrates the power of the multiplication process to generate very large numbers of broilers from relatively few Great-grandparents. The time required for (usually small, incremental) genetic changes at the pedigree level to appear in commercial flocks is indicated on the right hand side of Figure 1. This structure of breeding programmes is made possible by the high rate of reproduction in broiler chickens and enables breeders to spread the huge costs of biosecurity, trait recording and selection over a very large number of commercial broilers. The breeding pyramid facilitates crossbreeding genetically distinct lines to capitalise on hybrid vigour (also called heterosis) for health and reproduction traits and the combination of different traits from “male” and “female” lines.

Table 1: Traits in current broiler selection programmes (Information provided by EFFAB EPB)

Areas for selection	Major trait categories[1]
Health and welfare	Immune response, skeletal integrity, heart and lung fitness, liveability/survival/low mortality, feathering, absence of breast lesions
Reproduction	Hatchability, egg number, fertility, age at sexual maturity
Production	Feed conversion, growth profile, meat quality, breast meat yield, weight, lower fat content

[1] Trait categories may include multiple traits;

Heritabilities and genetic correlations among traits, and their potential role in breeding and selection programmes are presented in Sections 5.1-5.5.

A large number of traits may be measured on selection candidates and their relatives. A list of traits currently included in genetic selection programmes is presented in Table 1. In general, the way these traits are included in genetic selection programmes constitutes commercially sensitive information and is not divulged by breeding companies. Some information related to the heritability of the various traits along with the potential role of these traits in selection schemes is given in the following sections.

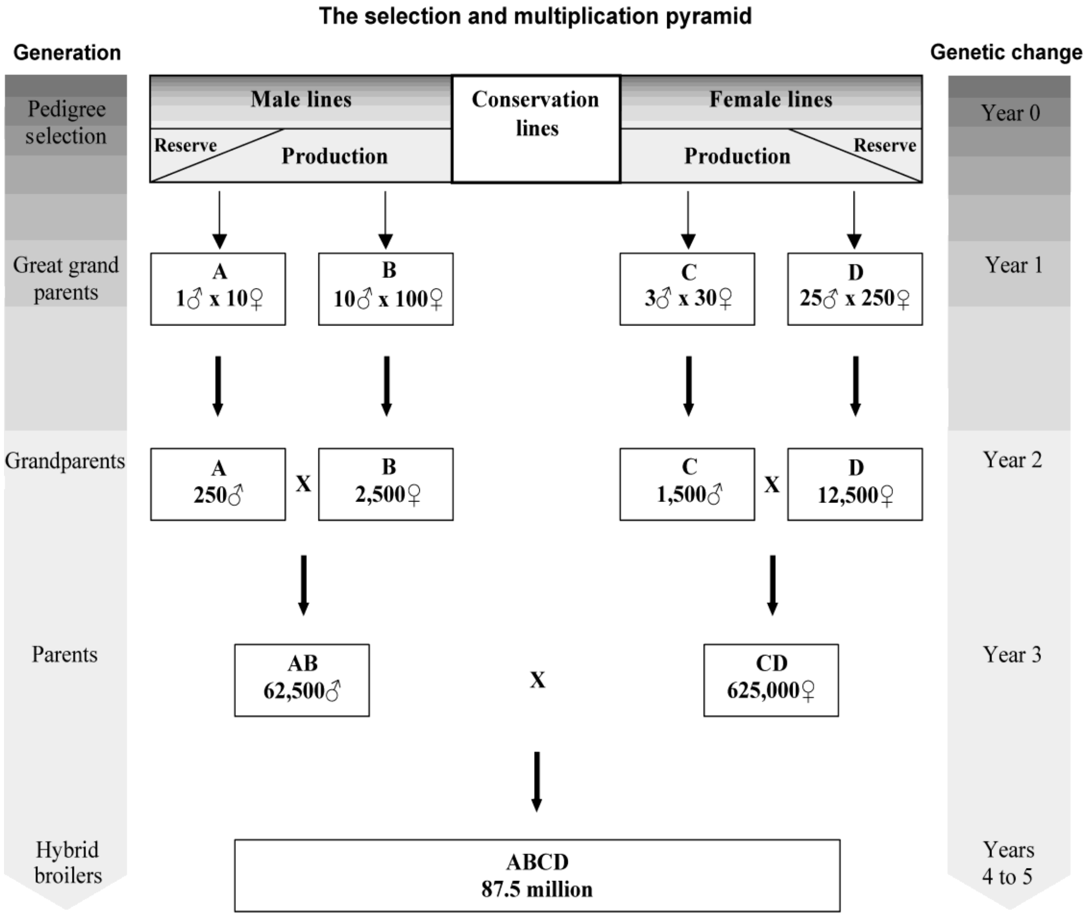

Figure 1: Industry selection and multiplication pyramid for a commercial broiler line.

Figure 1 indicates the genetic significance of birds in the pedigree nucleus. In practice many more birds contribute to the top of the pyramid than indicated here. The box in bold at the top of the figure corresponds to the pedigree selection level and is followed by the multiplication (crossing) phase that occur over a number of generations (left). The time required for genetic changes at the pedigree level to appear in commercial flocks is indicated on the right; numbers in boxes refer to minimum numbers of birds needed in each case to generate individuals of the next generation. The numbers of male and female birds in each line and generation are based on the numbers of male and female chicks from male line, female line and parent broilers from commercial flocks reported by Hocking and McCorquodale (2008) (from Hocking, D'Eath and Kjaer, in press).

5.1. Production traits

The cost of feed is the major factor affecting the economics of chicken meat production and feed conversion efficiency is the major selection criterion among fit and healthy birds. Age is a major factor affecting feed conversion as older heavier birds require more feed for maintenance compared with younger lighter birds. In the early history of genetic selection in broilers, live body weight and conformation of the breast muscle were simple and effective indirect measures of feed conversion efficiency and carcass value that could be measured on large numbers of birds. Subsequently keel bone conformation was added as a selection criterion to decrease the prevalence of breast blisters.

The importance of Food Conversion Rates (FCR), which refers to the amount of feed consumed to increase body weight by one kg, led in the 1980s to the direct measurement of feed intake in selected broilers housed for 2 weeks in individual cages. Recently this method was replaced in a large breeding organisation by group housing combined with individual recording of feed intake (and behaviour) using electronic bird identification and feed intake measurements. This change represents a move to better welfare and more relevant selection (broiler chickens are not kept in cages).

Carcass composition has an important effect on the economic value of the bird, in a particular market, one of the most important frequently being the relative proportion of breast meat. Selection for breast conformation has been supplemented by information on the direct measurement of breast muscle mass in sibs (brothers and sisters) of selection candidates. Abdominal fat is also weighed and used as an indirect measure of carcass fatness. Finally ultrasonic measurements of body composition (breast muscle depth and fatness) may also be used on the selection candidates.

Broilers that pass the initial selection criteria are then measured for a number of additional traits. These may include measures of bone quality (absence of tibial dyschondroplasia) by X-ray methods (e.g. the lixiscope) and cardiovascular efficiency. Measures of robustness (health, welfare and performance) and resistance to ascites may be measured in sibs kept in a poor environment and the information considered in selection decisions by appropriate weighting in a selection index. These aspects are further discussed in the following sections.

The genetic background of most broiler production traits has been extensively studied. Hereditary differences for traditional production traits among individual birds have been found to account proportionally for between 0.25 and 0.50 of performance differences, although for some current traits this may be as low as 0.10 or as high as 0.60; this proportion has been scientifically termed "heritability" of a trait. In practical terms a heritability of 0.30 means that for a difference between individuals of e.g. 100 g, 30 g is due to genetic factors.

In the past, production traits were the sole criteria in breeding and selection programmes. Over the past 30 years, however, this has been changing with emphasis being increasingly placed on other, non-production traits. The relative selection pressure on production and non-production traits is not widely known as it constitutes commercially sensitive information of the breeding companies. However, selection theory suggests that when selection applies to several traits at the same time, response to selection per trait is less than if this trait was the only one selected for. For example, assuming that selection programme A includes growth rate and disease resistance and selection programme B includes only growth rate, response to selection (reflecting the difference between the current and following generation) for growth rate in programme A will be slower that in programme B. The extent of this difference will depend on the relative weighting of the two traits and their genetic correlation in programme A.

5.2. Health, fitness and welfare traits

Birds must be functionally fit to reproduce: they must be able to walk, eat and drink, and be disease free; therefore selection candidates with poor fitness are culled.

According to the poultry breeding sector (public consultation), health, fitness and welfare related traits currently included in the major breeding programmes are: i) skeletal integrity (leg condition, toes, keel straightness, breast blisters, footpad lesions, hock burn, tibial dyschondroplasia, hip condition, joint integrity), ii) heart/lung fitness, iii) robustness (selection in different environments including e.g. different feed specifications; feather cover during rearing especially in slow feathering lines; absence of diseases etc.), iv) behaviour (pecking behaviour in production) and v) miscellaneous (egg size/weight; liveability in production; number of poor quality chicks culled; male aggressiveness in floor pedigree pens).

According to the technical hearing, reducing FPD through family selection has been successful. The value of feet for export purposes and the cost of downgrades from hock burns combined with welfare benefits were the drivers to implement a selection program to reduce FPD. Market driven economic incentives/penalties could provide the incentives needed to motivate breeding companies as well as farmers to reduce FPD.

Heritability of health and fitness traits varies widely from 0.05 to 0.25. As explained in the previous section, this represents the proportion of differences observed among individual birds that is due to hereditary factors. The remaining proportion of the variability between individuals is mostly due to environment but also to the way genes from paternal and maternal lines combine and interact with each other. The latter has important consequences for mating decisions.

Some of the health and welfare traits have an antagonistic genetic correlation with production, meaning that genetic improvement for one trait (e.g. growth rate) usually compromises the other (e.g. lameness). In modern breeding programmes these antagonistic effects are dealt with by multiple trait selection indices, as described below (Section 7.4). Other health and welfare traits show no obvious genetic correlations with health and welfare or there may be some delay before such correlations become overt. So this presents a challenge that can be dealt with in a balanced breeding programme with the use of appropriate selection indices.

Recent advances in DNA technology have enabled research for the identification of specific genes and DNA markers that are involved in disease resistance in birds. Pending on successful completion of research, selection of DNA markers for disease resistance (e.g. Marek's Disease, etc.) may be conducted.

The study of Cheema et al. (2003) suggested that genetic selection for improved broiler performance has resulted in a decrease in the adaptive arm of the immune response but an increase in the cell-mediated and inflammatory responses. Ongoing EU funded research projects (e.g. http://www.quantomics.eu/) aim at improving the understanding of the genetic mechanisms of disease resistance and enhancing the role of such traits in genetic selection and breeding.

5.3. Reproduction traits

The general aim is to produce broilers from broiler breeders (hens) that lay fertile eggs that hatch to produce healthy chicks. Minimum levels of fertility and hatchability are necessary to maintain lines of broilers and maximum hatch of eggs set (the product of fertility and hatchability) in commercial flocks. Breeding programmes used to place virtually all selection emphasis on egg production and hatchability in female lines and the minimum necessary to maintain male lines to provide adequate scope for selection for production traits. However, today reproduction traits in both male and female lines are important in modern breeding programmes (see below).

Heritability of reproduction traits is generally modest (< 0.15) meaning that the biggest proportion of differences observed among birds is due to non-heritable (mostly environmental) factors. Here, too, genetic interactions between paternal and maternal genes contribute to these differences.

Despite the small heritability, genetic variance associated with reproduction traits may be considerable. Genetic variance reflects the variability in genes carried by different individuals that render some more reproductive than others. Thus, the presence of genetic variance implies the existence of individuals with a genetic propensity for better (or worse) reproduction. Existence of genetic variance means that genetic selection is possible; low heritability suggests that genetic change will be slow.

Genetic correlations between reproduction and production traits are antagonistic suggesting that selection for production traits may adversely affect reproduction. As before, genetic correlation means that the same genes or genes located very close to each other influence both reproduction and production traits. These biological unfavourable relationships have led poultry breeders to specialize the lines into ‘male’ lines which are more intensively selected for production traits (such as growth, meat yield or feed conversion) and ’female‘ lines in which reproductive performance is given a higher weight in the selection process. Broiler breeders fed *ad libitum* have characteristically low rates of lay, poor persistency and produce a large proportion of eggs with defective egg shells that cannot be used for incubation (Renema and Robinson, 2004). For example, in the study of Hocking et al. (2002) birds fed *ad libitum* produced only 28 chicks to 60 weeks of age (restricted birds produced 134). This improvement in egg laying and the substantial reduction of mortality are the main reasons for feed restricting broiler breeders (EFSA Panel on Animal Health and Welfare, 2010).

5.4. Trait combination – selection indices

From a breeding and genetic standpoint, the desirable outcome of selection will be a bird that effectively combines production, health, fitness, welfare, and reproduction traits. To achieve this outcome, selection indices that combine the individual traits summarised in Table 1 and discussed in Sections 5.1-5.3 have been developed. One breeding company records over 40 traits grouped into about 10 categories. Within each group there may be sub-traits corresponding to different ages (e.g. liveability of broilers, young and adult breeders; different types of skeletal disorders etc). Traits are combined into a selection index that takes into account the potential for genetic improvement and the economic value of a change in each trait. The relative weight given to each trait will differ depending on the specific objectives of each line: for example, for male lines the emphasis may be on feed efficiency and breast muscle yields whereas reproduction may be given more weight in female lines. However, selection will only take place among birds that satisfy minimum levels of health and fitness as described above: thus birds that are unable to walk or show evidence of skeletal disorders, for example, will not be selected for breeding.

The move towards more balanced breeding programmes presents a serious development over previous, sub-optimal practices. For example, in 1960 live body weight was the only criterion for broiler selection. This resulted in several related health, fitness and welfare problems that have subsequently been addressed by improved selection criteria. At present, and for the past 20 years or so, inclusion of many traits like those described above and in Table 1 safeguards against undesirable consequences of one-sided selection.

The effect of balanced selection on health and welfare traits can be easily predicted based on the relative weights placed on the various traits in an index and the relevant genetic parameters (heritability of each trait and genetic correlation between traits) used. However, the actual numbers are commercially sensitive and not disclosed by companies running their own competitive breeding programmes. Furthermore, it is not always clear exactly which specific welfare traits are being selected and what weighting they are given in a selection index. DEFRA reported in its answer to the call for data (EFSA, 2009) several surveys of leg problems over time. Kestin et al. (1992) reported that 26 % of commercial intensively reared broilers had leg abnormalities leading to gait scores 3 or above (but on a sample of 5 flocks only). In 2006, a DEFRA research project undertaken in 5 UK broiler companies (on 51,000 birds) indicated that 27.6 % of broiler had a gait score 3 or above (Knowles et al., 2008). Even if prevalence seems stable, it is very hazardous to draw conclusions since samples are not comparable and scoring methods rely on inter-observer reliability and intra-observer consistency which can make it difficult to compare data sets generated by different teams. These data are at variance with many other scientific papers and industry records and reliable and consistent data from commercial flocks in all European countries are necessary to draw any conclusions on the welfare impact of genetic selection of broiler chickens.

Cooper (EFSA, 2009 – public call for data) gave a description of the selection points related to health and welfare. He stated that among the parameters are considered for the selection of broilers are:

quality and liveability of chicks produced, valgus-varus deformities, rotated legs, loose joints, crooked toes, back defects, and cardiovascular health. Considering all the traits mentioned, a delicate balance is required to meet consumer and industry demand. No validated data were available to assess precisely the weight of such criteria in selection and the impact on broiler welfare.

However, historic shifts of selection emphasis from production to health, fitness, welfare and reproduction traits could effectively be monitored by observing phenotype trends in broiler populations. Such figures, however, are also commercially sensitive and are not divulged by the industry. Moreover, their testing of new strains in a variety of environments may not be comprehensive and there is a need for better and more comprehensive monitoring of practical on-farm welfare outcomes.

Recently, DNA-array technology has enabled the large scale genotyping of individual animals/birds simultaneously for tens of thousands of DNA markers, paving the way for the so-called genomic evaluation and selection (Meuwissen et al., 2001). Genomic selection is rapidly becoming a very useful tool to identify birds which naturally carry desirable genes. This development is expected to assist in the genetic improvement of traits that are difficult to record, such as welfare traits. Furthermore, several traits with low heritability, such as those related to health and reproduction, are particularly expected to benefit from genomic selection compared with conventional selection based entirely on phenotypic records. By definition, the latter type of selection has mostly benefited traits with higher heritabilities such as production and growth.

5.5. Genetic selection by production system

For optimal results, specific conditions prevailing in specific production systems may warrant the presence of different lines of birds. Whilst birds that are the outcome of a well-rounded balanced breeding programme, as described above, would be suitable for most conventional circumstances, other systems may require individuals of a different genotype. For example, feet-and-leg conformation and robustness become even more crucial for free-ranging birds. Furthermore, organic systems that prohibit the use of antibiotics and certain other medicines would require more selection emphasis on an inherited resistance to disease.

5.6. Policies of breeding companies regarding selection for welfare versus production

The response to one generation of selection depends on the heritability of the trait and the selection pressure (the proportion of birds that are used as parents of the next generation). Heritability is not a fixed quantity, and is specific to a given population at a certain time, and several hundred birds are required for reliable estimates. Heritability, which, as explained above, reflects the proportion of differences among individuals that is due to additive genetics, is also a measure of the accuracy of estimating breeding value and, if measurements are available for relatives, the combined accuracy can be much greater than an estimate based on the bird's own value.

Genetic correlations between two traits such as growth and leg health are even more variable than estimates of heritability and require thousands rather than hundreds of birds for precise estimates. Genetic correlations are calculated on a scale that runs from -1 through 0 to +1 and are seldom greater that ±0.4 unless they are part-whole traits like growth and feed conversion. A positive correlation will make the reduction in selecting for more than one trait less than it would be if the correlation were zero or negative. However, as discussed in previous sections, selecting for two or more traits will reduce the selection intensity on a single trait even if the two are not correlated. Animal breeders manage the major problem of a negative correlation between growth and reproduction by selecting male lines (Figure 1) primarily for growth traits and female lines for a balance between both with the relative emphasis depending on the objectives for a particular line. This strategy has the advantage that fewer traits are selected in each line (increasing the rate of change) and, when the lines are crossed (Figure 1), reproduction and other fitness traits are improved as a result of hybrid vigour (heterosis).

Many welfare traits are so important that, for example, a bird that cannot walk will not be selected for breeding. This is termed an 'independent culling level' in contrast to traits included in a 'selection index' which gives a weighting to each measurement depending on its economic value and the genetic scope for change. The index will also weight information from antecedents, offspring and contemporary relatives to provide a comprehensive evaluation of the genetic merit of the bird.

The genetic correlation between several skeletal disorders and body weight have been summarised in this report. These are largely based on simulation models and are generally not large (i.e. less than ±0.4, one trait being associated with less than 20 % of the variation in the second). Breeding companies were already selecting for leg traits before 1980 (Mercer and Hill, 1984). Specifically it is well known that breeders have included absence of tibial dyschondroplasia (TD) and resistance to ascites in their selection programmes. Anecdotally we believe that both disorders are not commonly observed in today's commercial flocks. Evidence provided from one of the commercial breeders of data from flocks of several thousands of pedigree broilers evaluated for TD using the Lixiscope from 1989 to 2007 presented in Figure 2 This an example of selection in practice to diminish the incidence of a welfare trait in a commercial selection programme.

Evidence that genetic progress has been made in pedigree flocks does not guarantee that a similar change will be observed in commercial boilers. The environments in which broilers are kept commercially are not the same as that in breeder's flocks and an even greater difference exists between these and experimental facilities in universities and research institutes. The only way to assess changes in welfare traits of practical relevance is to record them in commercial flocks which generally consist of many thousands of birds. According to Agristats and EFFAB data (EFSA call for data, 2009), there has been a decrease in the prevalence of skeletal disease and other welfare traits since 2000.

Table 2: Range of expected change in body weight (g) for one generation of selection in a large population of broilers for different intensities of selection (Percentage of selected birds) and heritability, when selection is on body weight only[1].

Proportion of birds selected		Heritability		
Male	Female	0.1	0.2	0.3
0.1	1	75	151	226
0.5	5	62	142	186
1	10	55	111	166
2	20	46	91	137

[1] The gain from one generation of selection is the product of the average intensity of selection, the heritability and the phenotypic standard deviation of body weight. The intensity of selection was obtained from standard statistical tables of the normal distribution for different proportions of bird selected for breeding the next generation. Selection intensities in male and female broilers is based on the assumption that 1 male is mated to 10 females. The mean body weight at selection is taken as 2500 g and assuming a coefficient of variation of 10 % the phenotypic standard deviation of body weight is 250 g.

Welfare organisations complain that poultry breeders place too much emphasis on growth rate to the exclusion of the welfare of the birds whereas breeders state that the welfare of their stock is paramount and they do select for welfare traits. Although the actual weights placed on various traits in practice are unknown, we can estimate the relative emphasis on growth versus all other traits by using standard genetic theory. In a large population such as a broiler section flock, the rate of change after one generation of selection can be predicted for a range of likely selection intensities (i.e., proportion of selected birds) and heritabilities. Table 2 summarises these calculations and assumes that the selection intensity of males is ten times greater than in females. We expect selection intensities to be of the order 0.1 to 1% for males and 1 to 10 % for females. As an example for selection for body weight which has a heritability of 0.3, the annual change in body weight in commercial breeding programmes is in the order of 40-80 g (last column in Table 2) which is between 20 and 50 % of the theoretical rate of change. Clearly the difference will not be due entirely to selection for welfare but these calculations do not support the contention that poultry breeders over-emphasise growth rate. There is commercial support for this conclusion from turkey breeding in which it was shown that 50% of the potential selection pressure for body weight was 'lost' by selection for welfare traits (Bentley, 2003).

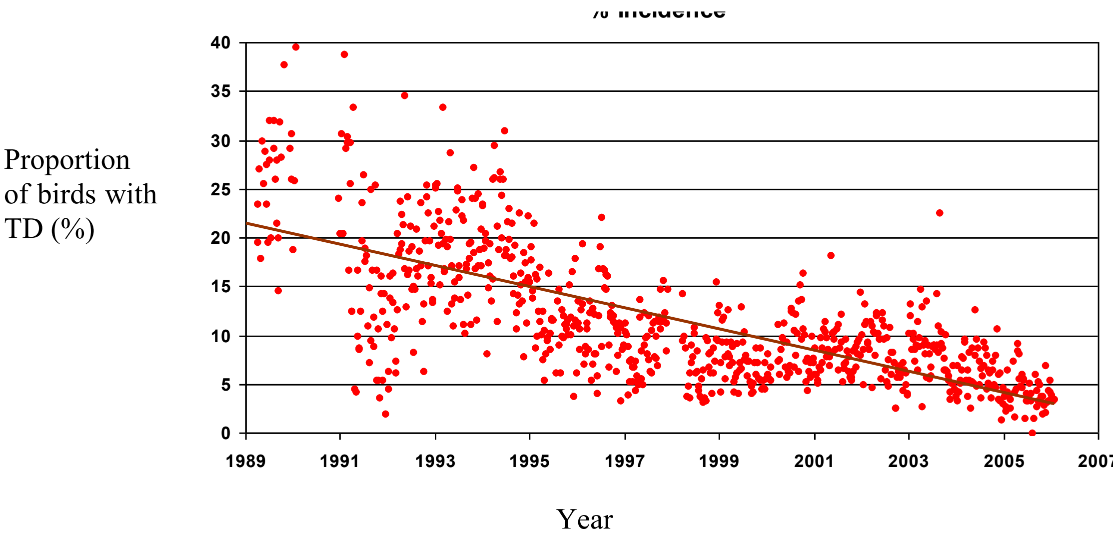

Figure 2: Trend in the incidence of tibial dyschondroplasia (TD) at selection by year of observation in pedigree broiler flocks. (Unpublished information from Aviagen).

Note. The lixiscope provides an assessment of the incidence of TD on live birds using NASA developed low emission X ray technology. The graph shows the trend in incidence from the initial use of the technique until 2007. Over this period the same equipment and criteria were used for assessment. Each point represents the average of all birds placed for selection for the genetic lines contributing to the Ross 308 product at each selection – therefore each point represents several thousand birds.

Genetic selection of broilers has changed considerably over the past 50 years and now encompasses production, health, fitness, welfare and reproduction traits.

The level of genetic improvement of individual traits cannot be quantified due to the lack of access to pertinent data.

Genomic selection may provide a useful tool for the improvement of lowly heritable, difficult to record traits related to health, fitness, welfare and reproduction.

More studies should be sought on specific welfare traits (e.g. aggression during mating, reactivity/fear) in terms of recording, and genetic evaluation and selection.

There should be standardised objective monitoring of welfare in commercial flocks in a system harmonised across different countries, to assess phenotypic trends of various traits as well as the impact of genetic selection on these traits.

Studies are needed in order to develop practical methods for independent health and welfare surveillance and to objectively assess and record welfare indicators in large-scale operations.

Welfare traits that are found to be heritable should be included in breeding programmes and selection indices.

6. Genotype by environment interaction

There are three main breeding companies in the European market that provide the majority of the world's supply of day-old broiler chicks. For these companies a convenient situation might be to supply the whole world with the same crossbred but two reasons stop that happening. First, their customers in various regions have different requirements regarding performance and characteristics of the chickens, e.g. some prefer breast meat and consider the residual as a by-product, while other regions prefer the bony part of the chickens. Furthermore, there are a range of other wishes regarding skin colour and even bone colour. Secondly there are large differences in the environments (housing facilities, ambient temperature, altitude, available nutritional sources, quality of the water, etc.) and it might be that chickens of one strain or crossbred producing well in one environment will perform poorly in another. One can look on these two phenomena as a question of a genetic adaptation to a particular region/environment. For the environment part (not determined by human preference) Genotype × Environment interaction or G × E interaction is referred to, wherein genotypes rank differentially across environments (see Appendix B).

6.1. Welfare aspect of interaction between genotype and environment

Introduction of a breed to a novel environment may cause them to perform less well than in their original selection environment and may even cause their welfare to be adversely affected. It is clear that where growth rate decreases it may sometimes improve leg conditions and thus improve the welfare of the birds. It may be generally thought that novel environments to which the selected genotype has not been exposed will cause harm the welfare of the chickens but the evidence is sparse. As few G x E investigations have specifically included welfare examinations there is sparse evidence that novel environments to which the selected genotype have not been exposed to, will harm the welfare of the chickens. However, there are some clear examples in which birds suffered from hyperthermia when kept in a hotter environment than the environment in which they were selected (see Appendix B, last section).

6.2. How do the breeding companies deal with G × E interaction?

The traditional attitude in animal breeding was that the character required is best selected under environmental conditions that favour its fullest expression (Hammond, 1947). However, the research from Falconer and Latyszewski (1952) later found that progress was more rapid in a good environment than in a restricted one, and that a trait is best improved by selection under the conditions in which the trait will be measured. Increased sensitivity to environmental stress, such as nutritional stress (Appendix B), appears to be evident when the selection environment is better than that in which the birds will eventually be evaluated. Following the adoption of quantitative genetic theory applied by breeding organisations from the beginning of the 1960s, the concept that testing of potential breeding animals should be conducted in environments similar to commercial practice was gradually adopted. As the poultry breeding companies became international and operate on a world wide scale they introduced a system in which they had copies of their lines of elite birds at 3-4 regions in the world so that they covered the high altitude, the warm areas, and perhaps with basic farms from where they originated. These satellite farms with a full selection programme in the pure lines, and from which the multiplying programmes run at that particular region, ensure that the cross-bred offered in a region also had had some generations of genetic adaptation to the region in which they are to be marketed.

6.3. Importance of the genetic diversity

Maintaining a high genetic diversity between commercial lines may be considered key to the selection of lines well adapted to challenging environments. Recent genomic studies confirm that individual breeding lines show a (numerical) loss of diversity. However most of this loss occurred before the development of the current intensive industry and many rare alleles were already lost. Although some of these rare alleles were semi-lethal or lethal, the loss in genetic diversity is of concern. The recent reduction in the number of breeding companies has been the result of merging companies or acquiring companies: this did not lead to additional loss of genetic diversity because the majority of pure lines were actually maintained during this process.

While fast-growing lines are increasingly used, alternative coloured slow-growing lines are also produced by poultry companies. These are used for specialty or ‘niche’ markets in which mature carcass and meat quality is important. One example is the Label Rouge chicken in France which is slaughtered at a minimum age of 81 days. Those lines contribute to the production of intermediate ‘certified’ chickens (usually obtained by the crossing of a fast-growing sire and a slow-growing dam) slaughtered around 56 days (see for example Hubbard Management Guide-broiler – Hubbard, 2009 and EFSA call for data, 2009). These slow-growing chickens are well adapted to free range production (Castellini et al., 2008) and show reproductive performance (Heck, 2004), meat and carcass attributes (Bizeray et al., 2000; Debut et al., 2003; Berri et al., 2005a) as well as behavioural characteristics (Debut et al., 2005; Berri et al., 2005b; Castellini et al., 2008) different from those of standard fast-growing chickens.

It has been shown that G x E exists for nutrition, ambient temperature and managements systems.

Breeders should select birds able to adapt to the environments in which they will be reared, e.g. organic, climate, etc.

Bird welfare will be improved if they are selected to their rearing and production environments.

Breeding companies and farmers should ensure that the most appropriate strain of bird is used for the local environment.

Most G x E studies have so far focussed on productivity and reproduction and not on welfare.

Welfare traits should be included in the G x E studies and the selection of birds.

Farmers or producers should select a suitable genotype for the environmental conditions on their farm.

Information, independent of the breeding companies, on welfare and production, should be provided to farmers for them to make a suitable choice.

Genetic diversity should be maintained by breeding companies in order to meet future market demand and to develop lines that can withstand challenging environments.

Breeding companies to follow up more thoroughly the ability of the birds to adapt to different kinds of environments from a welfare as well as productivity and marketing perspectives and not simply on a ‘no complaints basis’. This will provide better information on G x E Interactions for future selection.

It is critical that the producers themselves are aware of the welfare issues and feed any welfare issues back to the breeding companies.

Other systems are being developed that affect welfare e.g. organic, natural, free range and that requires even closer collaboration between producers and their breeding companies. More research is required here. Robustness of the lines to adapt to different producer environments is a key issue.

7. Risk assessment to comment on possible welfare improvement by selection criteria for broilers, including management interactions

Risk assessment is a systematic, scientifically based process to estimate the probability of exposure to a hazard, and the magnitude of the effects (consequences) of that exposure. A hazard in animal welfare risk assessment may be defined as a factor with the potential to cause a negative animal welfare effect (adverse effect). Risk is a function of both the probability that the hazard and the consequences (characterised by the adverse effect) occur, and the intensity and duration of the consequences.

Factors which adversely affect the welfare of broilers which are thought to be linked to the birds' genetics are considered in the risk assessment.

The conceptual model for this question is presented by Figure 3. In this model the question of selected birds and their welfare is addressed through: 1) specific genetic sensitivity of the bird to the hazards; 2) the influence of genetically selected birds on their environment; and 3) the influence of environmental factors on the welfare of genetically selected birds.

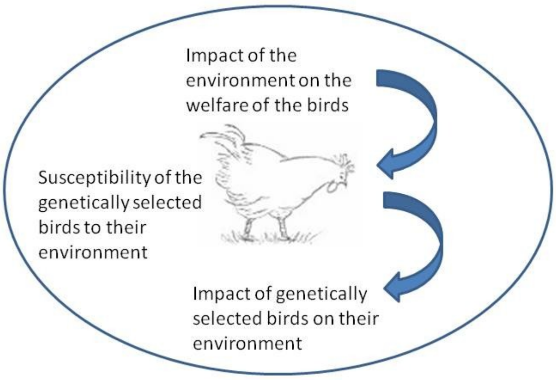

Figure 3: Model of interaction of genetic selection and environment on the welfare of birds.

Four parameters were scored to assess the importance of a hazard; the intensity of the adverse effect that the hazard causes, the duration of the adverse effect; the probability of an adverse effect given exposure to a hazard; and the probability of exposure to the hazard. The probability of exposure to the hazard corresponds to the percentage of all birds exposed to the hazard. The consequence of exposure can be assessed by scoring the intensity and the duration of the adverse effect in the individual.

The risk assessment was based on the following assumptions:

1. All birds exposed to the hazard experience the same intensity and duration of the adverse effect.

2. In the absence of complete prevalence data by country, it is assumed that (i) all birds in all countries that are exposed to the hazard have an equal probability of experiencing the adverse effect; and (ii) exposure to the hazard is equal for all countries.
3. There is no dependence or association between different hazards, or different consequences. The occurrence of a hazard or consequence does not affect the probability of occurrence of other hazards or consequences.
4. Individual expert opinions are independent and unbiased.

7.1. The risk assessment process

The general risk assessment is in line with the approach previously used in the EFSA welfare reports with some modifications according to the risk question posed. In the following paragraphs the risk assessment process for hazard identification and characterization and the probability of exposure to the hazard are described as well as the way they were scored. Finally the risk scoring process is described.

7.1.1. Hazard identification

The objective of hazard identification is to identify potential welfare hazards associated with the genetic selection of broilers. Identification was based on a review of the literature and field observations. The adverse effects (consequences) caused by each hazard is described.

7.1.2. Hazard characterisation

Intensity

The approach taken has been to refer to the level of deviation from an optimal (hazard-free) state. Consequently, intensity ranged over six categories: no deviation from optimal, very small deviation from optimal, small deviation from optimal, moderate deviation from optimal, large deviation from optimal, and extreme deviation from optimal: In addition, an "I don't know" option was offered to experts.

Duration of the adverse effect

The time during which an animal will on average experience the adverse effect was estimated in hours. As broilers live for an average of 42 days, this translates to a total lifetime of approximately 1008 hours. The duration of an adverse effect (consequence) can be longer than the duration of the hazard. The possibility that birds are exposed to hazards in a discontinuous manner, or repeatedly exposed was also considered, by estimating the frequency of repeated occurrences over the course of the birds' lifetime multiplied by the duration of the adverse effect (consequence) at each exposure. For example, if a bird performs abnormal behaviour for one hour every day, the duration would be 1 hour*42 days = 42 hours in total over the lifetime of the bird.

Conditional exposure assessment

The conditional exposure assessment is performed by assessing the probability of adverse effects (consequences) given there has been exposure to a hazard. For example, if there is high temperature and humidity within a house, what proportion of the birds contained in the house will develop hyperthermia?

Exposure assessment

The exposure assessment is performed by assessing the probability of exposure to the hazard. For example, what is the probability of being exposed to high temperature and humidity? It is recognised that the proportion of the population exposed to a selected hazard will vary depending on the farm of origin and slaughterhouse.

Uncertainty and variability

The degree of confidence in the final estimation of risk depends on the level of uncertainty and variability for each hazard and its consequences (Vose, 2008). Uncertainty arises from incomplete knowledge and/or when results are extrapolated from one situation to another (e.g. from experimental to field situations). Uncertainty can be reduced by carrying out further studies to obtain the necessary data, however this may not always be a practical possibility. It can also be appraised by using expert opinion or by simply making a judgment.

Variability within a population is a natural phenomenon – given constant, equal conditions for all individuals in a population, there will always be observable differences between the individuals, even when measurements are perfect and we have all the data we could possibly wish to collect. The frequency and magnitude of welfare hazards will inevitably vary between farms and countries and over time, and birds will vary individually in their responses. However, it is not always easy to separate variability from uncertainty. Uncertainty combined with variability is generally referred to as total uncertainty (Vose, 2008).

To assess uncertainty and variability in this risk assessment, each working group member independently scored each hazard and its consequences for the four parameters listed previously and recorded their level of certainty in each attributed score. The certainty scores were used to calculate ranges (minimum and maximum estimates) about the point estimate of each score. If certainty was low, the range around the estimated score was wider than if the certainty was high. Attributed scores from the independent working group members were pooled and for each hazard and consequence, the median score and level of certainty for the group was calculated. Variability between members' attributed scores was interpreted from the minimum and maximum scores given by members of the group for each parameter.

To assess variability within the population, working group members could indicate a range of values for each score to show variability within the population, where such information was available. Variability in the scores attributed between experts was taken into account and used to calculate a range (minimum and maximum values) around each of the risk measurements (magnitude, welfare impact, risk score).

7.1.3. Risk Characterisation

The scoring process was discussed by the working group in plenary but was undertaken by the individual experts separately. The estimates were based on current scientific knowledge, published data, field observation and experience (as summarised in this report).

Calculation of magnitude of adverse effect

The magnitude of the adverse effect is the product of the scores for intensity and duration.

Magnitude = [intensity/max possible intensity score] * [duration/max possible duration] * 100%

Calculation of conditional welfare impact

The welfare impact of the adverse effect is the product of the scores for intensity, duration, and probability of adverse effect given exposure to hazard.

Welfare impact = [intensity/max possible intensity score] * [duration/max possible duration] * [Conditional exposure probability/100] * 100%

Calculation of the risk score

All four factors (intensity of adverse effect; duration of adverse effect; probability of adverse effect given exposure to hazard; probability of exposure to the hazard), were included in calculating the final risk score of a hazard. The score for each parameter was standardised.

Risk score = [intensity/max possible intensity score] * [duration/max possible duration] * [Conditional exposure probability/100] * [Hazard exposure probability/100] * 100%

Interpretation of the risk score

Due to the limited amount of quantitative data on many effects of hazards on broilers, the risk assessment is entirely based on expert opinion. The methodology used does not give a precise numerical estimate of the risk attributed to certain hazards; however the output can be used to rank the problems and designate areas of concern, as well as highlight areas where further research is needed.

The methodology assumes that there are no interactions between different hazards and consequences. However, many hazards and consequences are associated, so the calculated risk scores may underestimate the welfare risk of certain hazards that lead to multiple collateral effects and associations with other hazards. Likewise, risk scores may be overestimated if a hazard has many associated consequences, but some of these are attributable at least in part to the co-occurrence of another hazard. The risk scoring is semi-quantitative. Thus the scores allow a ranking but the absolute figures are not on a linear scale (e.g. a risk score of 12 should not be interpreted as being twice as important as a risk score of 6).

7.1.4. Genetic and Environment interaction

In addition to the risk assessment, experts were asked to give opinions on two further questions relating specifically to (i) the effect of bird genetics on the environment and (ii) how susceptible or resistant to different hazards and their associated consequences broilers are. For each of these questions, genetic traits were considered in one of three categories: those relating to health and welfare; those relating to production; and those relating to reproduction.

The effect of bird genetics on the environment

Given a list of environmental variables, experts were asked to score whether the broilers' genetic traits impacted on the environment using a 5-point scoring system: -1 trait causes a large decrease in the environmental variable; -0.5 trait causes some decrease in the environmental variable; 0 trait has no impact on the environmental variable; 0.5 trait causes some increase in the environmental variable; and 1 trait causes a large increase in the environmental variable. As with the risk assessment, experts were asked to rate their level of uncertainty in the score. These were then used to calculate a range around the calculated median genetic impact score.

Susceptibility/resistance offered by genetic traits to environmental/housing hazards

Experts were asked to score whether the broilers' genetic traits offered them any resistance or susceptibility to a range of environmental hazards, using a 5-point scoring system: -1 trait renders bird susceptible to hazard; -0.5 trait renders bird slightly susceptible to the hazard; 0 trait has no effect on resistance or susceptibility to the hazard; 0.5 trait offers some resistance to the hazard; 1 trait offers full resistance to the hazard. As with the risk assessment, experts were asked to rate their level of uncertainty in the score. These were then used to calculate a range around the calculated median susceptibility score.

7.2. Assessment of welfare impact of genetic selection in broilers, including management interactions

Table 3 shows the aggregated hazard scores and calculated results of the risk assessment. For a breakdown of the risk assessment calculated by the adverse effects associated with each hazard, please refer to appendix C.

This table shows that the top ranking hazards according to risk scores on the genetics of broilers are unbalanced body conformation, fast growth rate and reduced mobility. The experts also considered a range of environmental hazards that may interact with broiler genetics, and the Table shows that the top ranking hazards among these are high stocking density, low light intensity and wet litter. These hazards are ranked highly either because the adverse effects are intense and/or prolonged, and/or the probability of the birds being exposed to these hazards is high and the probability of experiencing adverse effects when exposed to these hazards is high.

Table 3: Magnitude, welfare impact and risk score of welfare hazards associated with the genetics of broilers. The Table is ranked by median risk score (highest to lowest), then minimum and maximum risk scores.

HAZARDS	c[1]	Intensity (max of 5)			Duration (hours)			L of exper. Cons2			L of exp. To haz3			Magnitude			WF Impact4			Risk Score		
		med	min	max	med	min	max	med	min	max	med	min	max	med	min	max	med	min	max	med	min	max
High stocking density	9	3.5	1.0	5.0	420.0	168.0	672.0	32.5	15.0	62.5	70.0	10.0	90.0	29.2	3.3	66.7	9.5	0.5	41.7	8.5	0.4	37.5
Unbalanced body conformation	4	3.5	2.0	3.5	546.0	168.0	672.0	25.0	15.0	62.5	90.0	70.0	90.0	37.9	6.7	46.7	9.5	1.0	29.2	6.6	0.0	26.3
Low light intensity	4	2.0	0.0	4.0	672.0	168.0	672.0	25.0	7.5	87.5	10.0	10.0	60.0	26.7	0.0	53.3	6.7	0.0	46.7	4.7	0.0	42.0
Fast growth rate	8	3.5	2.0	4.0	420.0	168.0	672.0	20.0	7.5	32.5	90.0	70.0	90.0	29.2	6.7	53.3	5.8	0.5	17.3	4.1	0.1	15.6
Wet litter	5	3.5	1.0	5.0	168.0	168.0	672.0	25.0	3.0	62.5	45.0	30.0	60.0	11.7	3.3	66.7	2.9	0.1	41.7	2.6	0.1	37.5
Crusted litter	1	3.0	2.0	4.0	672.0	168.0	672.0	7.5	1.0	15.0	10.0	0.0	30.0	40.0	6.7	53.3	3.0	0.1	8.0	1.4	0.0	4.8
Barren environments	3	1.0	0.0	4.0	672.0	672.0	1008.0	15.0	7.5	87.5	70.0	0.0	90.0	13.3	0.0	80.0	2.0	0.0	70.0	1.2	0.0	56.0
Inappropriate diet	4	3.0	2.0	4.0	546.0	420.0	672.0	20.0	15.0	32.5	0.0	0.0	0.0	32.5	16.7	53.3	6.5	2.5	17.3	0.7	0.3	1.7
Light cycle (long photoperiod)	1	3.0	0.0	4.0	672.0	168.0	1008.0	15.0	7.5	87.5	60.0	10.0	80.0	40.0	0.0	80.0	6.0	0.0	70.0	0.6	0.0	42.0
Reduced mobility	4	3.5	2.5	4.5	420.0	168.0	672.0	20.0	7.5	32.5	70.0	0.0	90.0	29.2	8.3	60.0	5.8	0.6	19.5	0.6	0.1	9.8
Poor ventilation	2	4.0	1.0	4.5	132.0	12.0	420.0	7.5	2.0	20.0	30.0	0.0	50.0	10.5	0.2	37.5	0.8	0.0	7.5	0.2	0.0	3.8
High temperatures and humidity	1	4.0	4.0	5.0	24.0	24.0	672.0	11.3	3.0	25.0	10.0	10.0	50.0	1.9	1.9	66.7	0.2	0.1	16.7	0.0	0.0	5.0
High light intensity (incl. Natural lighting)	1	2.0	0.0	4.0	168.0	42.0	672.0	7.5	3.0	15.0	10.0	10.0	10.0	6.7	0.0	53.3	0.5	0.0	8.0	0.0	0.0	0.0

[1] Number of associated consequences
[2] Likelihood of experiencing consequences if exposed to hazard (%)
[3] Likelihood of exposure to hazard (%)
[4] Welfare Impact

The top ranking hazards by risk score, welfare impact and magnitude are given in Tables 4 (genetic hazards) and 5 (environmental hazards with a link to genetics).

Table 4: Top five Genetics ranking hazards by welfare impact and magnitude

#	Risk Score	Welfare Impact	Magnitude
1	Unbalanced body conformation	Unbalanced body conformation	Unbalanced body conformation
2	Fast growth	=Reduced mobility	=Reduced mobility
3	Reduced mobility	=Fast growth	=Fast growth

Table 5: Top ranking Environmental hazards[1] by risk score, welfare impact and magnitude

#	Risk Score	Welfare Impact	Magnitude
1	High stocking density	High stocking density	Crusted litter
2	Low light intensity	Low light intensity	Long photoperiod
3	Wet litter	Inappropriate diet	Inappropriate diet

[1]The hazards may affect different genetic lines of birds in different ways

In Table 4 it can be seen that unbalanced body conformation is the highest ranking welfare hazard for risk score, welfare impact and magnitude, followed by fast growth and reduced mobility. In Table 5, high stocking density emerges as the highest ranking environmental hazard that may be exacerbated by, or may interact with genetic traits, followed by low light intensity and wet litter.

Note that a hazard's risk score ranking does not necessarily correlate with its welfare impact or magnitude ranking. This reflects the observation that a hazard's intensity or duration may be high, but the probability of a bird experiencing the adverse effect may be low. In this case, magnitude may be relatively high, but welfare impact or risk score would be relatively low. This is shown clearly in Figures 4 and 5, where some hazards with high magnitude have relatively low welfare impact and risk scores (i.e. reduced mobility). As the absolute values for each score are not linear, only the relative ranking of the hazards is meaningful. We can see that some hazards that rank relatively low for magnitude rank higher for risk scores (e.g. wet litter and barren environments) because of the higher probabilities of exposure and of exposed birds being adversely affected by them.

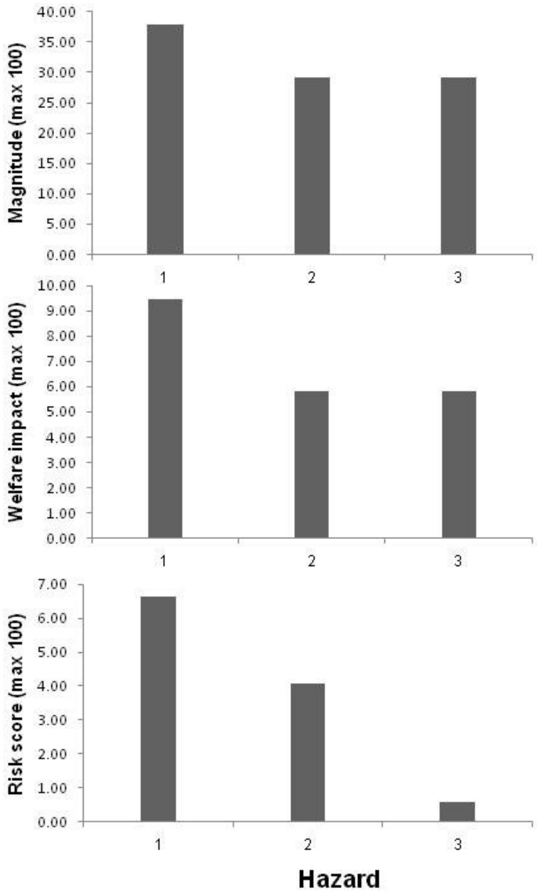

Figure 4: Relative Magnitude, Welfare Impact and Risk Scores for the 3 hazards identified in relation to the genetics of broilers, ranked on median risk score (high to low).

Note that values are not linear, hence a hazard with a risk score of 20 is not twice the risk of a hazard with score 10.

Hazard code: 1 Unbalanced body conformation; 2 Fast growth; 3 Reduced mobility.

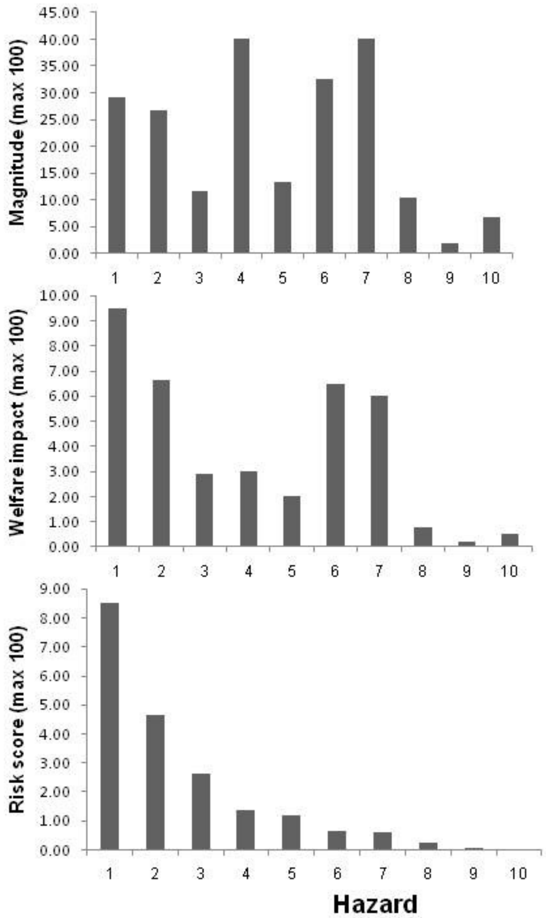

Figure 5: Relative Magnitude, Welfare Impact and Risk Scores for the 10 environmental hazards exacerbated by, or interacting with the genetics of broilers, ranked on median risk score (high to low).

Note that values are not linear, hence a hazard with a risk score of 20 is not twice the risk of a hazard with score 10

Hazard code: 1 High stocking density; 2 Low light intensity; 3 Wet litter; 4 Crusted litter; 5 Barren environments; 6 Inappropriate diet; 7 Light cycle (long photoperiod); 8 Poor ventilation; 9 High temperatures and humidity; 10 High light intensity (incl. Natural lighting).

Uncertainty and variability

Experts did not have uniform uncertainty across the attributes they scored on. Figure 6 shows that experts were less certain of conditional probability of exposure than intensity and duration scores, and there was greater variability in hazard scores for conditional probability of exposure than intensity or duration. This is likely to be a true reflection of knowledge in the field – there is relatively more information available describing adverse effects – their intensity and duration, than quantifying how extensive the problem is. Further to this, it was recognised by the experts that probabilities vary from region to region, country to country and between different types of farming system. Probability estimates consequently had large ranges. Routine data collection across Europe would certainly help to make these estimates more accurate, not least because prevalence information from each country could be included directly in the risk assessment.

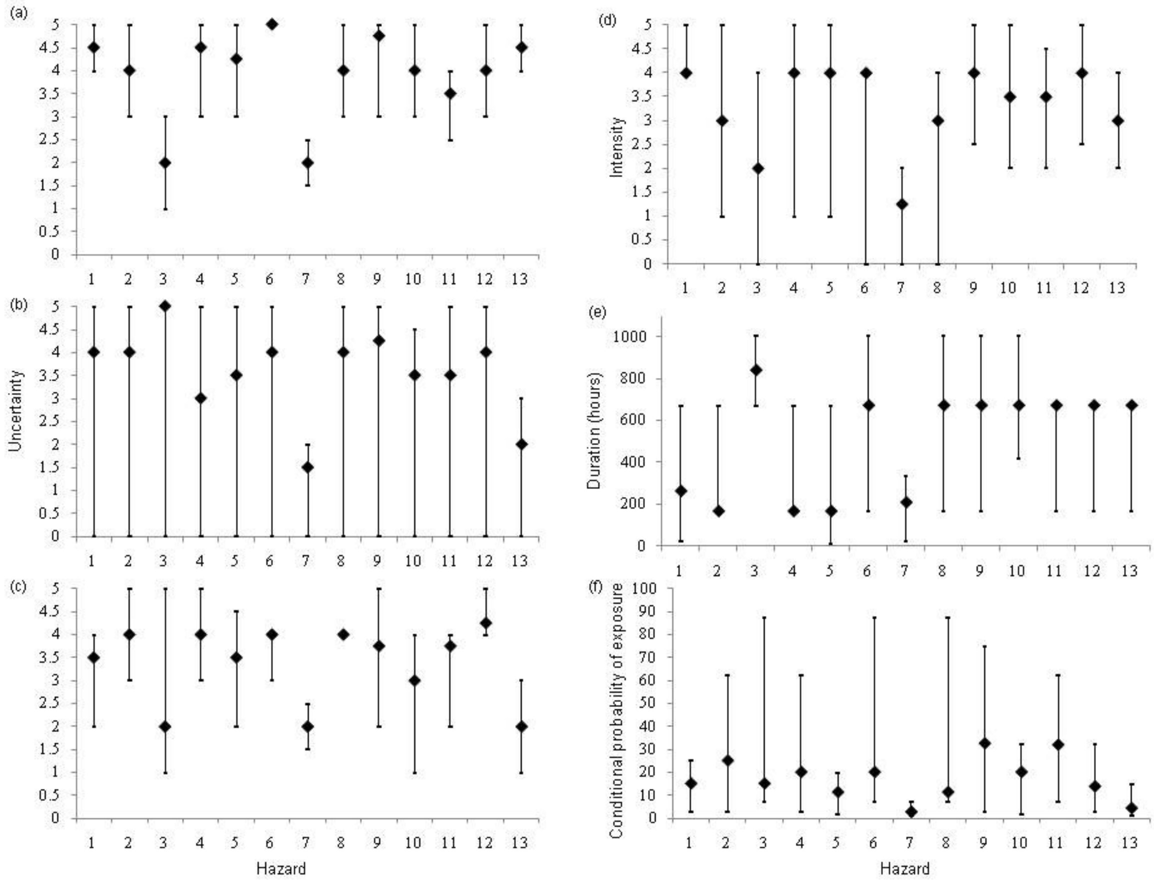

Figure 6: Representation of the uncertainty (left column, a-c) and variability (right column, d-f) of hazard intensity (top row, a,d), duration (middle row, b,e) and conditional probability of exposure (lower row, c,f).

Hazard code: 1 High temperatures and humidity; 2 High stocking density; 3 Barren environments; 4 Wet litter; 5 Poor ventilation; 6 Low light intensity; 7High light intensity; 8 Long photoperiod; 9 Reduced mobility; 10 Inappropriate diet; 11 Unbalanced body conformation; 12 Fast growth rate; 13 Crusted litter.

Genetics x Environment interaction

Considering first the question of how genetic traits impact on the environment, Table 6 shows that in almost all cases, production-related traits impact on the environment, and in each case, the production-related trait tends to increase the environmental factor. For example, in relation to ambient temperature, production traits tend to lead to increase in ambient temperature. Health and welfare traits and reproduction traits tend to have no effect. The exception is for quantity of dust in the atmosphere, where production-related traits tend to reduce the level of dust in the air, but health and welfare-related traits (such as an increased propensity to dust-bathe) leads to an increase in the quantity of atmospheric dust.

Table 6: Effect of three types of broiler genetic traits (health and welfare traits, reproduction traits and production traits) on the environment.

Table shows the median, minimum and maximum scores attributed by experts. Impact code: -1 Large decrease; -0.5 Some decrease; 0 No impact; 0.5 Some increase; 1 Large increase; U Unknown.

	EFFECT OF GENETIC SELECTION ON ENVIRONMENT		
ENVIRONMENTAL FACTOR	Median	Min	Max
Ambient temperature			
Health and welfare traits	0	0	0
Reproduction traits	0	0	0
Production traits	0.5	0.5	1
Litter wetness/cleanliness			
Health and welfare traits	0	0	0
Reproduction traits	0	0	0
Production traits	0.5	0.5	1
Concentration of atmospheric ammonia			
Health and welfare traits	0	0	0
Reproduction traits	0	0	0
Production traits	0.5	0.5	1
Concentration of carbon dioxide			
Health and welfare traits	0	0	0
Reproduction traits	0	0	0
Production traits	0.5	0.5	1
Relative humidity within the house			
Health and welfare traits	0	0	0
Reproduction traits	0	0	0
Production traits	0.5	0.5	1
Concentration of endotoxins			
Health and welfare traits	U	U	U
Reproduction traits	U	U	U
Production traits	U	U	U
Quantity of dust in the atmosphere			
Health and welfare traits	0.5	0.5	0.5
Reproduction traits			
Production traits	-0.5	-0.5	-0.5

The second question to investigate the genetics and environment interaction assessed whether genetic traits impart resistance or susceptibility to environmental hazards. The full results from this assessment can be found in appendix C. To summarise, overall, there were few cases where genetic traits offered any resistance to the adverse effects of environmental hazards. The notable exceptions included health and welfare-related traits offering some resistance to the pain of footpad dermatitis and hock burn, and production traits offering resistance against scratches from other birds. On the whole, genetic traits either had no effect of resistance of susceptibility against the adverse effects of environmental hazards, or they increased the broilers' susceptibility to experiencing the adverse effects of the environmental hazards. The most notable example here include all three types of genetic trait rendering birds more susceptible to hyperthermia, production traits making birds more susceptible to a reduced behavioural repertoire (although by contrast, health and welfare traits may make birds more susceptible to disturbed rest periods), and more susceptible to atmospheric ammonia irritating the respiratory tract and eyes, experiencing pain from footpad dermatitis, hock burn and breast blisters and spending more time in contact with the litter.

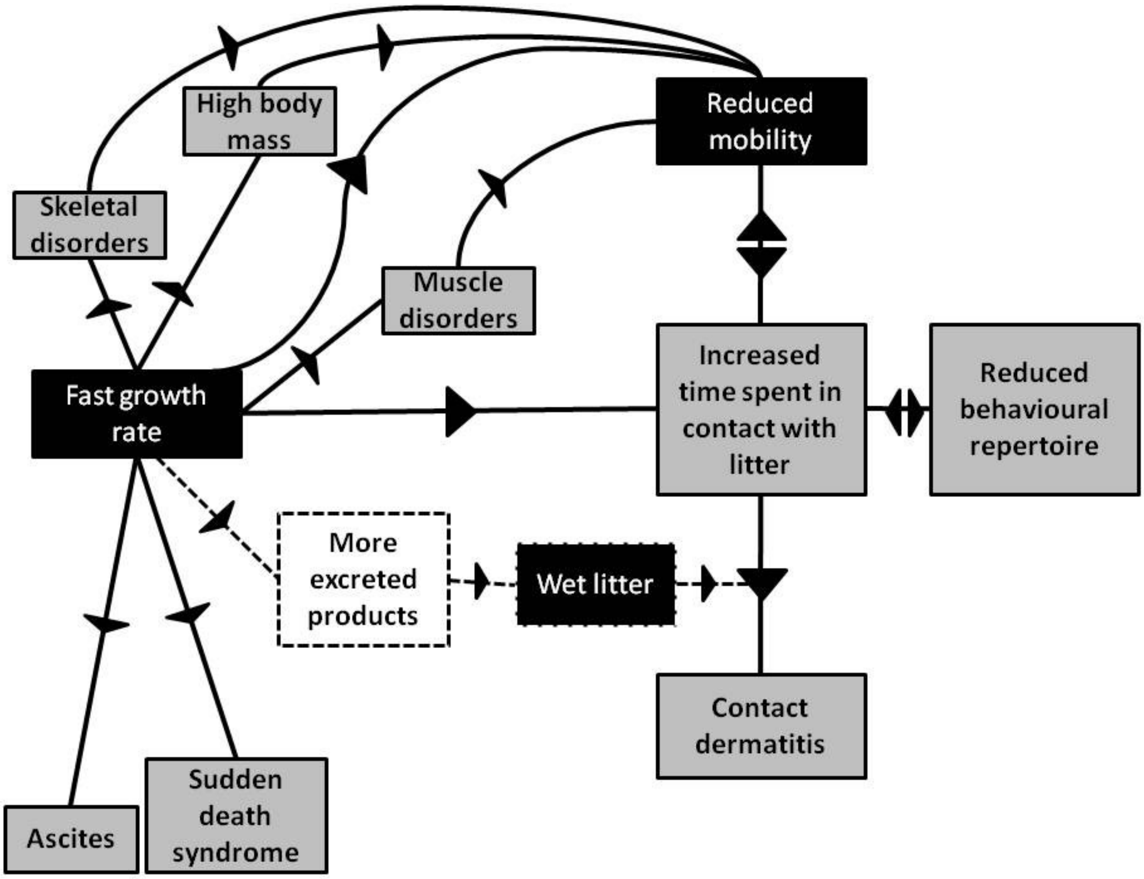

Figure 7: The non-independence of hazards and consequences, using fast growth rate as an example starting hazard. Fast growth rate is shown to be linked both directly and indirectly to other hazards characterised in the risk assessment, which are considered as independent factors.

Black boxes are hazards characterised in the risk assessment. Grey boxes are hazard consequences. White boxes explain the relationship between hazards where necessary. Arrows show the direction of causality. Note that this image does not contain all the possible consequences of all the hazards shown.

We must note here that these results were based on the opinions of experts and not directly on experimental data. The results also highlight how strongly interactive the relationship between genetics and environment is, and re-emphasises the lack of independence between the individual welfare hazards considered in the risk assessment. This is highlighted by the ontological analysis conducted as part of Article 36. The implications of this in terms of the results of the risk assessment are not inconsiderable. For highly interlinked factors, the risk score may be slightly over- or (more likely) substantially underestimated, as the calculated scores in this risk assessment do not take into account second, or higher- order consequences (i.e. consequences of consequences). The number of consequences a hazard has does not in itself affect the final aggregated scores of magnitude, welfare impact and risk score (as seen in table 1), as the aggregated scores were calibrated for the number of consequences. However, the characteristics of the consequences (intensity, duration, conditional exposure) did affect the aggregated scores. For highly interlinked factors, therefore, the key information will not be the quantity of links with other factors, but rather the quality of those links – i.e. the characteristics of second and third order consequences, that will determine whether our risk assessment scores are under- or overestimates.

We must also consider that this risk assessment represents the independent opinions of a small group of experts. Each expert scored each hazard once, therefore we have no means of investigating intra-expert reliability of scoring. It is possible that should the same group of experts be asked to complete the same surveys in six months time, they would each give answers that differed to some extent from the answers provided for this report. Similarly, a random sample of different experts may give different values for the risk assessment. This is one of the key criticisms of expert opinion-based risk assessment procedures. However, at the present time, we lack the raw data that would enable us to conduct a fully data-driven, quantitative risk assessment. Given these restrictions, the risk assessment should be interpreted with due caution, bearing in mind that hazards are not independent and that expert opinion is not the equivalent of raw data.

CONCLUSIONS AND RECOMMENDATIONS

Overall

1. The major welfare concerns for broilers are leg problems, contact dermatitis, especially footpad dermatitis, ascites and sudden death syndrome. These concerns have been exacerbated by genetic selection for fast growth and more efficient food conversion.

2. As shown in the risk assessment, there is an overall lack of data on prevalence, e.g. the number of birds that will be exposed to a hazard, and the number of birds that when exposed to the hazard will experience the adverse effect.

3. The major risk scores for likelihood of being exposed to a hazard that leads to poor welfare (welfare impact plus exposure to hazard) were: unbalanced body conformation, high stocking density, fast growth rate, low light intensity, and wet litter.

Recommendations:

1. Surveillance systems to collect relevant data on broiler welfare, including health, in Europe should be put in place to monitor trends in the prevalence and magnitude of poor welfare (i.e. degree of suffering) of leg problems, footpad dermatitis, ascites and sudden death syndrome in commercial flocks. This would also help to identify emerging problems.

Mortality and culling

4. Mortality itself does not directly reflect animal welfare but can impact welfare if we consider the way and the reason for an animal dying.

5. Mortality is composed of the number culled involuntarily and the number found dead and the relationship between these two is an important welfare indicator. Nevertheless culling and mortality should be as low as possible.

6. When animals are sick or injured culling is the best way to prevent them from suffering.

7. The causes of culling and mortality should be identified, recorded and monitored There is some experimental evidence that higher growth rates of certain genotypes are associated with increased mortality.

8. Mortality rates in slow growing strains may be lower than in standard lines but this also depends on other factors e.g. type of production, feeding regime, rearing duration and management.

Recommendation

2. Data on welfare outcome indicators such as mortality, found dead and culling rates should be recorded. In addition, the reasons for mortality and culling, the numbers of birds found dead, gait scoring and ascites in commercial rearing conditions should be recorded and made publicly available by breeding companies for each genetic line of broilers. This information could be used by farmers when selecting lines to purchase and by competent authorities checking on welfare.

Skeletal disorders

9. There are serious welfare concerns over skeletal disorders in chickens leading mainly to lameness. At present a high proportion of broiler chickens have serious leg disorders indicated by gait abnormality (3 or more) and by other measures.

10. High gait scores (3, 4 and 5) which indicate an inability to walk normally have been associated with fast growth rates. However, there is considerable variation in the reported figures due to a variety of genotypes, management factors, the age at scoring, and the scoring system used.

11. Gait abnormality does not always indicate pain and suffering, although it does indicate some degree of poor welfare for the bird because of difficulty in obtaining resources or interacting socially. However, the highest scores (Bristol Gait Score System 4 or 5) indicate substantial pain.

12. Although a few birds may have a non-painful structural abnormality, the most likely cause of "a definite and identifiable defect in gait (Bristol Gait Score System 2)" in a broiler chicken is some localised pain or lesion and there is often progression from score 2 to higher scores so a greater likelihood of pain and other poor welfare

13. Overall gait scoring has a low heritability within the range of genetic lines considered (technical hearing) but several contributing factors such as valgus-varus and tibial dyschondroplasia have high heritability. There are some differences between strains but there are other factors such as management that contribute to high gait scores.

14. Some skeletal disorders are already being addressed in genetic selection (e.g. valgus-varus, TD).

Recommendations

3. Decreasing the proportion of birds with score 4 and 5 should receive a high priority and should be addressed through increased selection pressure on all factors contributing to high gait scores as well as through improved management.

4. Gait scoring should be carried out in a standardised way on all broiler production and breeding farms. If a significant proportion of birds have scores of 3 and above then this should trigger a review of systems of genetic selection, management or housing to be changed to improve the birds' welfare. Thresholds of concern should be established and depending on the threshold chosen, it is expected that the eradication of this welfare problem will take some years.

5. Birds that move with difficulty, or not at all, (gait scores 4 and 5) should be culled.

6. Breeding companies should be encouraged to identify traits suitable for selection that would improve gait scoring of birds in their commercial lines.

Contact dermatitis

15. Contact dermatitis is an important welfare problem and its cause is multi-factorial involving environmental conditions such as wet litter and genetic predisposition

16. The impact of contact dermatitis can be reduced in part by good litter management to avoid wet litter.

Recommendations

7. Contact dermatitis has a moderate degree of heritability and should be included in selection programmes.

8. A standard classification system for contact dermatitis should be developed in Europe.

9. There should be an objective by the industry to decrease the proportion of birds with contact dermatitis over the next 10 years through management and genetic selection.

Ascites and Sudden Death Syndrome (SDS)

17. A genetic predisposition exists for both ascites and SDS and there is a link between growth rate and ascites and probably also SDS.

18. Low energy intake can decrease SDS because it leads to a slower growth rate, and slow growing genotypes are more resistant to ascites.

19. The prevalence of ascites may have decreased over the last 10 years and breeders now consider this health problem in their selection schemes.

Recommendation

10. Selection against these conditions, particularly in fast growing lines, should continue and the prevalence needs to be monitored to ensure it remains at a low level

Mobility

20. Genetic selection has had an impact on bird behaviour leading to reduced mobility and utilisation of space.

21. Slow growing birds do not show reduced mobility to the same extent as fast growing birds.

22. It is not clear whether the reduced mobility is because of a lack of motivation or because of an inability to do so e.g. lameness, generalised weakness and hyperthermia. However, some studies suggest that both these aspects coexist and it is likely that more mobility will lead to fewer skeletal abnormalities.

23. Management of birds will also affect mobility such as light levels, barren environments and stocking density.

Recommendation

11. Birds should be selected for motivation for activity to increase mobility

12. Management systems that encourage bird mobility should be developed.

Thermal discomfort

24. Broilers with fast growth rates are susceptible to heat stress and there are management techniques to reduce heat stress on farm.

Recommendation

13. Management techniques should be adapted to avoid heat stress in birds

Other issues

25. Lung damage and respiratory disease problems are exacerbated by high ammonia and high dust levels.

26. High ambient temperatures, high ammonia, carbon dioxide, dust and RH levels were all positively correlated with poor welfare and all but dust levels with decreased productivity.

27. Environmental factors, genetics and their interactions can seriously adversely affect welfare in areas such as lighting regimes, litter management, dietary deficiencies, diet contamination, and air quality and temperature.

28. Digestive problems have increased recently and this may be related to change in food composition or removing food additives (antibiotics, coccidiostats) or to a change in bird digestibility capacities and susceptibility to disease. It may also lead to wet litter and contact dermatitis.

Recommendations

14. Ambient temperature in the environment and genetic strain should be compatible to reduce heat stress. This may also mean reducing the growth rate by management techniques.

15. A standardised system for recording respiratory and mucous membrane diseases at the slaughterhouse should be developed.

Genetic selection and interaction with the environment

29. Most studies on genetic selection and interaction with the environment have, in the past, largely focussed on productivity and reproduction and not on welfare but now they encompass welfare traits, including certain pathological conditions, in addition to production traits.

30. The level of genetic improvement, or otherwise, of individual traits cannot be quantified due to the lack of access to breeder's confidential data.

31. It has been shown that genetic selection and interaction with the environment exists for nutrition, ambient temperature and management systems and strong correlations were found in the Risk Assessment.

32. Broilers' welfare would be improved if they were selected for their subsequent rearing and production environments.

33. There are considerable and numerous interactions between the environment and the genetic traits of the birds in terms of their welfare.

34. Genomic selection may provide a useful tool for improvement for traits with low heritability or that are difficult to measure, particularly welfare traits.

Recommendations

16. Welfare traits that are found to be heritable should be included in breeding programmes and selection indices and should also be included in the genetic selection and interaction with the environment studies.

17. Genetic diversity should be maintained by breeding companies in order to meet future market demand and to develop lines that can withstand challenging environments.

18. Slower growing lines should be used and should be selected further for hot climates.

19. There should be standardised (objective) monitoring of welfare in commercial flocks in a system harmonised across different countries, to assess phenotypic trends of various traits as well as the impact of genetic selection on these traits.

20. Breeding companies should test and follow-up more closely the ability of the birds to adapt to different kinds of environments from a welfare as well as productivity and marketing perspectives, and not simply on a 'no complaints basis'. This will provide better information on genetic selection and interaction with the environment for future selection.

21. Breeders and farmers should select birds able to adapt to the local environment, so that their welfare is good,

22. An independent monitoring system that provides information on welfare and production, should be provided to farmers for them to make a suitable choice of breed for their specific circumstances.

23. Genomic selection and other new technologies should be considered when selecting welfare related traits.

RECOMMENDATION FOR FUTURE RESEARCH

Further research is needed on causes of reduced mobility and associated welfare implications e.g. pain, social interactions.

Further research is needed on the interaction of environmental factors and genetics with regard to welfare.

Studies are needed in order to develop practical methods for independent health and welfare surveillance and to objectively assess and record welfare indicators in broiler flocks.

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APPENDICES

A. THE POULTRY BREEDING SECTOR

Broiler breeding consists of selecting animals with a blend of various desired characteristics, mating the selected animals, taking the wide range of offspring, rearing and crossing them with others within the flock produced in various combinations (multiplying). The results of breeding are cumulative and so add up generation after generation, and are widely disseminated. For example, a group of 1 male and 10 females in one of the male great grandparent populations can contribute 25 % of the genetic material of approximately 87.5 million broilers in 5 years (Figure 1, main text).

Over time the selection of broilers has evolved from selection for 'simple' and 'single' criteria (e.g. growth and body conformation) to selection programmes with multiple traits which balance between meat production, growth rate, reproduction and disease resistance. During the hearing with three breeding companies it was stated that they included several aspects of leg disorders in their breeding programme. According to these breeding companies, other welfare related critical conditions known to be heritable have been included in selection programmes as selection traits (ref. technical hearing).

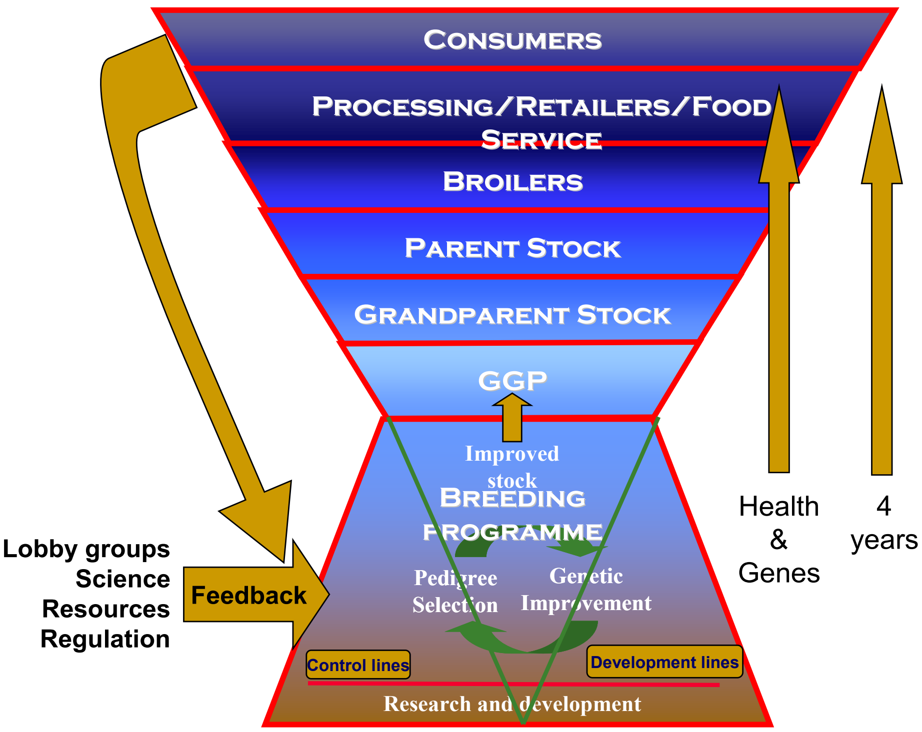

Figure 8: Industry structures for broiler breeding programmes (Laughlin, 2007).

The figure illustrates the role of the breeding companies in providing the stock that eventually provides consumers with poultry meat.

The reproductive rate of birds has enabled just a few companies to provide the world with breeding stocks. These breeding companies have evolved into multiple brand/breed companies providing lines for the various types of broilers needed worldwide. The final choice from the available phenotypes is made by the producer/customer within each market and region (e.g. different amounts of breast versus leg meat, slow growing, coloured skin, coloured feather, tolerance to different environments). The breeding companies provide management guides for the farmers for the different types of breeds in order to optimize performance.

There is a generation interval of 4 years from pedigree stock to broiler production stock.

Approximately 60-70 % of broiler breeding stock has developed within European companies and the demand for their products from outside Europe is increasing (Van Horne and Achterbosch, 2008). There is a global production shift to developing economies (e.g. China, Brazil, India). These emerging production regions have brought needs for specific phenotypes and specific tuning of existing phenotypes for the different markets.

B. Examples on Genotype × Environment interaction

Example

Consider a line selected for high growth capacity in a given environment (Env. A). Imagine that over five years there is an improvement of additional 160 g at 42 days above the background weight of 2,000 g at 42 days, meaning that the breeding line has a growth capacity of 2160 g at 42 days. Further imagine that the line at the start of the selection procedure was tested in another environment and had the same growth capacity (Env. B). The expectations for growth in Env. B after the improvement based on test in Env. A would be 2160 g at 42 days.

Actually we experienced a lower progress in Env. B such that the body weight was just 2064 g corresponding to a progress of 64 g or 40% of the progress obtained in Env. A. This lack of progress in body weight in Env. B compared to the progress in Env. A, is thought to be due to the fact that some of the genes that are important for growth in Env. A have no importance in Env. B and vice-versa. In the above example, the improved line obtained 2064 g in Env. B instead of the expected 2160 g at 42 days. These 40 percent increase of the expected, can be regarded as the proportion of genetic variation that is common for growth in the two environments, while the remaining 60 % of the genetic variation that influence growth in Env. A do not influence growth in Env. B. According to the concept of set theory, 40 % of elements are common to both, which is close to saying that the correlation is 0.4. This concept was first introduced by Robertson (1959) and later explained by Falconer and Mackay (1996). Genetic correlation used in this connection is often referred to as the cross-environment correlation. When this cross-environment correlation is less than one, we speak of a genotype by environment (G × E) interaction. Different statistical approaches (analyses of variance, genetic correlation estimation and reaction norm models in case the environmental factors are continuously distributed) may be used to evaluate the G × E interactions. In some cases, they can also be demonstrated in a simple way, by comparison of the mean performance between the different environments as demonstrated in Figure 7.

It is also possible for the cross-environment correlation to be less than zero, causing different genotypes to perform best in different environments. This requires that genes with a positive effect on growth in Env. A have directly negative effects in Env. B. Cross-environment correlations of less than zero have been shown in model organisms, for example for egg size in butterflies (Steigenga et al., 2005). If the genetic correlation is less than zero, selection in an inappropriate environment (Env. A) may result in animals that perform poorly in comparison to the unselected stock in Env. B.

Practical examples of G × E

There are a number of reports that document the existence of G × E in broiler chickens for various traits and environment factors. The way to document is either by comparing two or more lines or crossbreds in two or more environments, or by statistical analyses using a genetic model on data from half-sib groups raised in two or more environments. In the following examples from the literature both methods have been applied.

Nutrition is a key-factor in broiler growth. During a protein-supply crisis in which the price of soybean meal rose by a factor of 4, a selection experiment was initiated on two experimental lines derived from a common base population (of White Plymouth Rock breed) and selected for 6 generations for high growth to 42 days on either a normal broiler diet with 218 g/kg protein (the HP line) or a low protein diet with 168 g/kg protein (the LP line) (Sørensen, 1985). In the initial phase, a cross-environment correlation of 0.33 was found (Sørensen, 1977) and after 5 generations clear interactions ($P<0.0001$) were observed (Sørensen, 1986). The male chickens appeared more susceptible to diet variation, which probably was due to their higher requirement for protein. Further it was clear during the early generations that some of the chickens in LP line suffered from diverse illness that may have resulted in poor welfare.

A review by Sørensen (1985) reported considerable indications of genetic variation in adaptability to reduced concentrations of important nutrients such as amino acids. Thus, breeding birds under selection for increased performance should receive a ration similar to that which they can be expected to receive in the region they are expected to grow in. For example, the study by Mignon-Grasteau et al. (2004) has revealed a large influence of genetics on the digestion ability of birds being fed with a diet based on low quality wheat (Rialto variety). Digestion ability assessed by AMEn (apparent metabolisable energy corrected to zero-nitrogen retention) has been efficiently selected. After five generations of a divergent selection, it was increased by 36 % in the High D+ line by comparison to the low D- line (fed a normal diet) (Garcia et al., 2007). One can expect that the selection applied on FCR in broilers fed with good quality diet had a greater impact on their metabolic efficiency than on their digestion ability. Interaction between genetics and diet characteristics is certainly an important field to consider for improving the efficiency and the health status of birds fed with local "non optimal" diets.

It is well established that birds from small breeds adapt better than larger birds to high ambient temperature (Mathur and Horst, 1989). Detailed genetic studies of small and large breeds in a temperate climate (Berlin) and a hot climate (Kuala Lumpur) showed that the genetic correlation of egg yield measured in the two environments was low (0.34 to 0.17), while body weight had a somewhat higher genetic correlation (0.73 to 0.78). The consequence of these genetic correlations is that for egg production, 10 % genetic progress achieved in Berlin would be manifested by a 1.7 to 3.4 % increase in Kuala Lumpur, while for body weight a 10 percent genetic improvement achieved in Berlin would be manifested by a 7 to 8 % increase in Kuala Lumpur (Mathur and Horst, 1989). Beaumont et al. (1998) found similar genetic correlation for body weight of broiler chickens raised at 22 or 32 C. The cross-environment genetic correlations between temperatures were less than one (0.73 for weight gain and 0.74 for food conversion rate) showing that genes controlling these traits differed to some extent between the two temperatures. Studies in Middle East countries showed that fast growing broilers (75 gram per day at 22 C) suffer more from high ambient temperature (32 C) than slower growing broilers (65 gram per day at 22 C) (Deeb and Cahaner, 2002). In Turkey, Settar et al. (1999) found a G x E interaction for growth capacity corresponding to a cross-environmental genetic correlation of 0.26 between growth in the spring and the summer. Deeb and Cahaner, (2002) hypothesise that selection programs to overcome the genetic adaption to high temperature should include traits such as water consumption and body temperature.

Although broiler production does not take place in cages, the broiler breeders were faced with the problem of a cross-environment genetic interaction regarding cage and floor management when they began to include food conversion ratio (FCR) in the breeding index. In order to record FCR individually the chicken has to spend 3 weeks in an individual cage. The question then as the whether the growth they obtained in cages was based on the same genes that regulated the growth on floor. Sørensen (1989) run an experiment in which 2 lines were tested for body weight at 40 days obtained entirely on floor and at 18-39 days in individual cages. The model was based on estimating the sire components from a dataset with about 2000 chicks derived from 74 cocks each of them mated to 4 hens. The result was a cross-environment genetic correlation of 0.3 on weight obtained on respectively floor and cages. That result indicates a considerable G × E interaction, and also the warning that the body weight obtained in cages should not be used as selection criteria in the chickens supposed to grow under floor condition. From the two first generations of a selection experiments for better FCR in which the chickens were held in cages it was clear that many chickens had to be culled due to their poor leg conditions (Sørensen, 1986)

N'Dri et al. (2007) studied a slow-growing breed used in France for "Label Rouge" production which has to take place under free-range conditions. Selection for a better feed conversion ratio (FCR) requires measurement of the individual feed intake of chickens in individual cages. The study showed that it was more efficient to improve FCR in a free-range system by indirect selection for a change in the growth curve by postponing the age at the inflection point, than selecting directly for FCR in cages (ibid.). The indirect measures could be done on chickens reared under free-range conditions. This demonstrates the importance of taking G × E interactions into account in selection schemes.

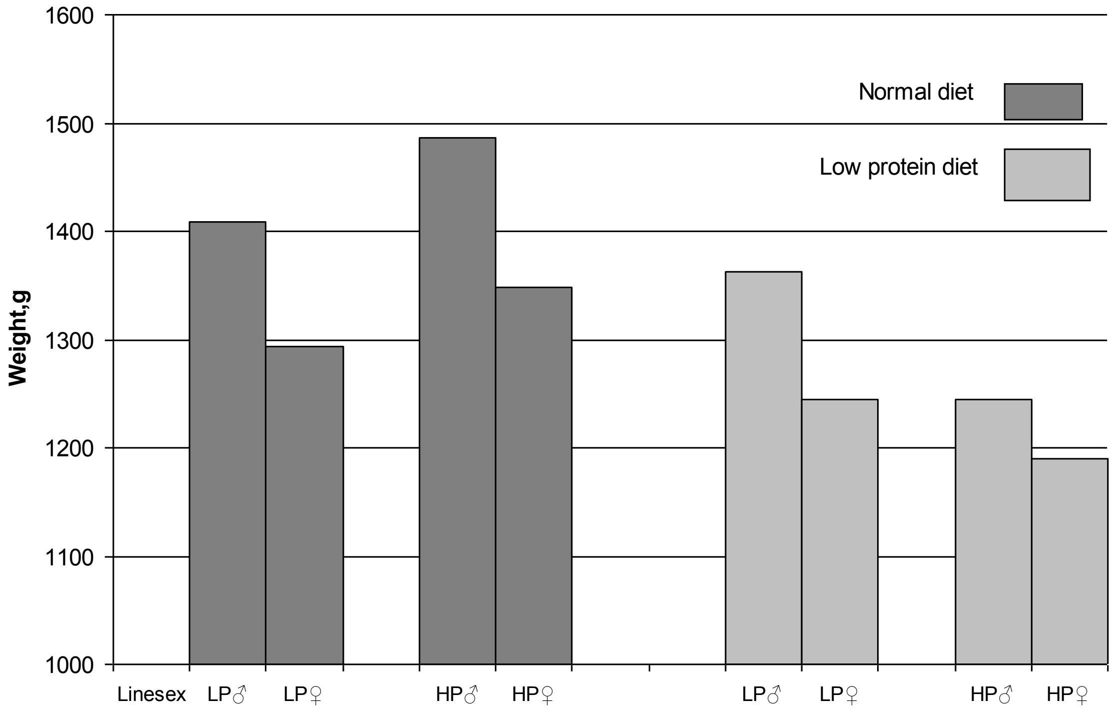

Figure 9: Line × Diet interaction for body weight at 6 weeks after 5 generations of selection for high growth rate when fed low protein diet (The LP line) or normal diet (The HP line).

Diets are represented in light grey for Low protein diet, and dark grey for Normal diet (Sørensen, 1986).

C. RISK ASSESSMENT TABLES

Table 7: Magnitude of the welfare consequences of hazards associated with the genetics of broilers, ranked by highest to lowest relative scores.

		MAGNITUDE		
HAZARD	**Consequence**	**MEDIAN**	**MIN**	**MAX**
Fast growth rate	Inactivity (long periods of time in contact with litter)	66.67	55.94	66.74
High stocking density	Increased transmission of infectious diseases	60.00	49.98	70.00
Reduced mobility	Birds experiencing pain	53.33	44.40	62.28
Unbalanced body conformation	Pain from FPD	53.33	43.76	62.93
Unbalanced body conformation	Lameness	53.33	43.76	62.93
Inappropriate diet	Pain from footpad dermatitis, hock burn etc (see wet litter)	53.33	43.29	63.39
Low light intensity	Reduced perception ability of the bird	53.33	43.29	63.40
High stocking density	Reduced air quality (irritation of respiratory tract and eyes etc)	53.33	43.29	63.40
Fast growth rate	Skeletal disorders	53.33	43.29	63.40
High stocking density	Reduced litter quality (increased chance of FPD, etc)	53.33	43.28	63.40
Fast growth rate	Leg weakness	53.33	43.28	63.40
Reduced mobility	Reduced ability to reach feed/water when motivated	53.33	42.91	63.78
Low light intensity	Increased time spent in contact with litter	53.33	42.62	64.07
Reduced mobility	Reduced ability to perform normal behavioural repertoire	53.33	42.62	64.07
Low light intensity	Reduced activity	53.33	42.62	64.08
Reduced mobility	Increased time spent in contact with litter	53.33	42.62	64.08
Inappropriate diet	Digestive problems	46.67	36.63	56.73
Inappropriate diet	Cleanliness of plumage	46.67	36.63	56.73
Fast growth rate	Muscle disorders	46.67	36.63	56.73
Unbalanced body conformation	High body mass	40.00	35.52	44.49
High stocking density	Disturbed rest periods	40.00	29.97	50.05
Light cycle (long photoperiod)	Disturbed rest	40.00	29.97	50.06
Inappropriate diet	Diet-related bone problems	40.00	29.97	50.06
Fast growth rate	Reduced behavioural repertoire	40.00	29.97	50.06
Crusted litter	Pain from breast blisters	40.00	29.61	50.41
Low light intensity	Reduced behavioural repertoire	40.00	29.30	50.72
Barren environments	Boredom	33.33	24.98	41.71
Barren environments	Reduced normal behavioural repertoire	33.33	22.20	44.49
Fast growth rate	Sudden death syndrome	25.25	21.25	25.33

HAZARD	Consequence	MAGNITUDE MEDIAN	MIN	MAX
Unbalanced body conformation	Pain from breast blisters	25.00	18.73	31.29
Wet litter	Pain from hock burn	25.00	18.30	31.72
High temperatures and humidity	Hyperthermia/heat stress	20.95	16.83	25.10
High light intensity (incl. Natural lighting)	Scratches from other birds	20.83	14.56	27.13
Wet litter	Atmospheric ammonia irritating the respiratory tract	13.33	10.91	15.78
Wet litter	Atmospheric ammonia irritating the eyes	13.33	10.91	15.78
Fast growth rate	Ascites	13.33	10.90	15.78
Poor ventilation	Increased exposure to endotoxins (inflammatory response in mucous membranes), dust, atmospheric ammonia irritating the respiratory tract	13.33	10.79	15.90
Poor ventilation	Hyperthermia (temperature and relative humidity)	13.33	10.70	15.99
High stocking density	Movement restriction	13.33	10.69	16.00
Wet litter	Pain from footpad dermatitis	13.33	10.69	16.00
High stocking density	Heat stress	13.33	10.62	16.07
Fast growth rate	High body mass	13.33	10.62	16.07
Barren environments	Frustration	13.33	8.88	17.79
High stocking density	Reduced behavioural repertoire	10.00	7.37	12.65
Wet litter	Pain from breast burn	10.00	7.30	12.72
High stocking density	Injury through contact with other birds	6.67	4.15	9.21
High stocking density	Injury through contact with physical structures	1.67	0.00	3.35

Table 8: Welfare impact of the welfare consequences of hazards associated with the genetics of broilers, ranked by highest to lowest relative scores.

HAZARD	Consequence	WELFARE IMPACT MEDIAN	MIN	MAX
Fast growth rate	Inactivity (long periods of time in contact with litter)	41.67	34.51	42.25
Fast growth rate	Reduced behavioural repertoire	25.00	18.50	31.66
Unbalanced body conformation	Lameness	23.33	18.82	28.00
Reduced mobility	Reduced ability to perform normal behavioural repertoire	21.33	16.74	26.09
Reduced mobility	Increased time spent in contact with litter	21.33	16.73	26.11
Unbalanced body conformation	High body mass	17.50	15.29	19.78
High stocking density	Reduced litter quality (increased chance of FPD, etc)	17.33	13.78	21.03

		WELFARE IMPACT		
HAZARD	**Consequence**	**MEDIAN**	**MIN**	**MAX**
High stocking density	Reduced air quality (irritation of respiratory tract and eyes etc)	14.67	11.62	17.86
Reduced mobility	Birds experiencing pain	13.33	10.77	16.04
Reduced mobility	Reduced ability to reach feed/water when motivated	13.33	10.42	16.40
Barren environments	Boredom	12.92	9.55	16.37
Unbalanced body conformation	Pain from FPD	10.67	8.42	13.06
Inappropriate diet	Pain from footpad dermatitis, hock burn etc (see wet litter)	10.67	8.37	13.10
Low light intensity	Increased time spent in contact with litter	10.67	8.20	13.29
Low light intensity	Reduced activity	10.67	8.20	13.30
High stocking density	Disturbed rest periods	10.00	7.29	12.85
Inappropriate diet	Diet-related bone problems	10.00	7.28	12.87
Inappropriate diet	Cleanliness of plumage	9.33	7.08	11.72
Low light intensity	Reduced perception ability of the bird	8.67	6.75	10.72
Fast growth rate	Leg weakness	8.67	6.71	10.78
Fast growth rate	High body mass	8.33	6.55	10.17
Low light intensity	Reduced behavioural repertoire	8.00	5.64	10.53
High stocking density	Increased transmission of infectious diseases	7.80	6.50	9.10
Inappropriate diet	Digestive problems	7.00	5.31	8.79
Fast growth rate	Skeletal disorders	6.00	4.55	7.61
Wet litter	Pain from hock burn	5.38	3.80	7.06
High stocking density	Movement restriction	5.33	4.19	6.52
Light cycle (long photoperiod)	Disturbed rest	4.50	3.15	6.01
Wet litter	Pain from footpad dermatitis	4.33	3.39	5.32
Fast growth rate	Muscle disorders	4.20	3.02	5.53
High stocking density	Reduced behavioural repertoire	4.00	2.89	5.15
Barren environments	Reduced normal behavioural repertoire	3.75	2.34	5.32
High stocking density	Heat stress	3.33	2.57	4.15
High temperatures and humidity	Hyperthermia/heat stress	3.14	2.40	3.94
Wet litter	Atmospheric ammonia irritating the respiratory tract	2.67	2.11	3.26
Wet litter	Atmospheric ammonia irritating the eyes	2.67	2.11	3.26
Barren environments	Frustration	2.00	1.30	2.73
Unbalanced body conformation	Pain from breast blisters	1.88	1.31	2.50
Crusted litter	Pain from breast blisters	1.70	1.11	2.39

		WELFARE IMPACT		
HAZARD	**Consequence**	**MEDIAN**	**MIN**	**MAX**
Poor ventilation	Increased exposure to endotoxins (inflammatory response in mucous membranes), dust, atmospheric ammonia irritating the respiratory tract	1.50	1.14	1.89
Poor ventilation	Hyperthermia (temperature and relative humidity)	1.50	1.12	1.92
Fast growth rate	Sudden death syndrome	1.33	0.95	1.53
Wet litter	Pain from breast burn	1.30	0.89	1.75
High light intensity (incl. Natural lighting)	Scratches from other birds	1.09	0.66	1.63
Fast growth rate	Ascites	0.40	0.24	0.60
High stocking density	Injury through contact with other birds	0.35	0.19	0.55
High stocking density	Injury through contact with physical structures	0.07	0.00	0.17

Table 9: Susceptibility and resistance of broilers to the consequences of hazards.
Table shows median, minimum and maximum scores given by experts. Minimum and maximum susceptibility scores reflect the level of uncertainty in the scores. Code: -1 Susceptible; -0.5 Some susceptibility; 0 No effect; 0.5 Some resistance; 1 Resistant.

			SUSCEPTIBILITY		
HAZARDS	**Consequences**	**Genetic trait type**	**MEDIAN**	**MIN**	**MAX**
High temperatures and humidity	Hyperthermia/heat stress	Health and welfare traits	-0.25	-1.00	-1.00
		Reproduction traits	-0.50	-1.00	-1.00
		Production traits	-1.00	-1.00	-1.00
High stocking density	Movement restriction	Health and welfare traits	0.00	-0.75	-0.75
		Reproduction traits	0.00	-0.71	-0.71
		Production traits	-0.50	-1.00	-1.00
	Reduced behavioural repertoire	Health and welfare traits	0.00	-0.67	-0.67
		Reproduction traits	0.00	-0.71	-0.71
		Production traits	-0.50	-1.00	-1.00
	Heat stress	Health and welfare traits	0.00	-0.80	-0.80
		Reproduction traits	0.00	-0.71	-0.71
		Production traits	-0.75	-1.00	-1.00
	Injury through contact with other birds	Health and welfare traits	-0.25	-1.00	-1.00
		Reproduction traits	0.00	-0.67	-0.67
		Production traits	0.00	-0.75	-0.75

HAZARDS	Consequences	Genetic trait type	SUSCEPTIBILITY MEDIAN	MIN	MAX
		Health and welfare traits	0.00	-0.75	-0.75
	Injury through contact with physical structures	Reproduction traits	0.00	-0.67	-0.67
		Production traits	0.00	-0.75	-0.75
		Health and welfare traits	-0.25	-0.92	-0.92
	Disturbed rest periods	Reproduction traits	0.00	-0.67	-0.67
		Production traits	0.00	-0.67	-0.67
		Health and welfare traits	0.00	-0.33	-0.33
	Increased transmission of infectious diseases	Reproduction traits	0.00	-0.33	-0.33
		Production traits	0.00	-0.33	-0.33
		Health and welfare traits	0.00	-0.50	-0.50
	Reduced litter quality (increased chance of I, etc...)	Reproduction traits	0.00	-0.33	-0.33
		Production traits	-0.25	-0.75	-0.75
		Health and welfare traits	0.00	-0.50	-0.50
	Reduced air quality (irritation of respiratory tract and eyes etc)	Reproduction traits	0.00	-0.33	-0.33
		Production traits	-0.25	-0.75	-0.75
Barren environments	Reduced normal behavioural repertoire	Health and welfare traits	0.00	-0.67	-0.67
		Reproduction traits	0.00	-0.67	-0.67
		Production traits	0.00	-0.67	-0.67
		Health and welfare traits	0.00	0.00	0.00
	Boredom	Reproduction traits	0.00	0.00	0.00
		Production traits	0.00	0.00	0.00
		Health and welfare traits	0.00	0.00	0.00
	Frustration	Reproduction traits	0.00	0.00	0.00
		Production traits	0.00	0.00	0.00
Wet litter	Atmospheric ammonia irritating the respiratory tract	Health and welfare traits	0.00	-0.67	-0.67
		Reproduction traits	-0.25	-1.00	-1.00
		Production traits	-0.50	-1.00	-1.00
		Health and welfare traits	0.00	-0.67	-0.67
	Atmospheric	Reproduction traits	-0.25	-1.00	-1.00

HAZARDS	Consequences	Genetic trait type	SUSCEPTIBILITY MEDIAN	MIN	MAX
	ammonia irritating the eyes	Production traits	-0.50	-1.00	-1.00
		Health and welfare traits	0.00	-0.67	-0.67
	Pain from hock burn	Reproduction traits	-0.50	-1.00	-1.00
		Production traits	-1.00	-1.00	-1.00
		Health and welfare traits	0.25	-0.55	-0.55
	Pain from footpad dermatitis	Reproduction traits	-0.50	-1.00	-1.00
		Production traits	-1.00	-1.00	-1.00
		Health and welfare traits	0.00	-0.67	-0.67
	Pain from breast burn	Reproduction traits	-0.50	-1.00	-1.00
		Production traits	-1.00	-1.00	-1.00
Poor ventilation	Increased exposure to endotoxins (inflammatory response in mucous membranes), dust, atmospheric ammonia irritating the respiratory tract	Health and welfare traits	0.00	-0.78	-0.78
		Reproduction traits	-0.25	-1.00	-1.00
		Production traits	-0.50	-1.00	-1.00
		Health and welfare traits	0.00	-0.80	-0.80
	Hyperthermia (temperature and relative humidity)	Reproduction traits	-0.25	-1.00	-1.00
		Production traits	-1.00	-1.00	-1.00
Low light intensity	Reduced behavioural repertoire	Health and welfare traits	0.00	-0.71	-0.71
		Reproduction traits	0.00	-0.80	-0.80
		Production traits	0.00	-0.71	-0.71
		Health and welfare traits	0.00	-0.71	-0.71
	Reduced activity	Reproduction traits	0.00	-0.80	-0.80
		Production traits	-0.50	-1.00	-1.00
		Health and welfare traits	0.00	-0.71	-0.71
	Increased time spent in contact with litter	Reproduction traits	0.00	-0.80	-0.80
		Production traits	-0.50	-1.00	-1.00
		Health and welfare traits	0.00	-0.71	-0.71
	Reduced perception ability of the bird	Reproduction traits	0.00	-0.80	-0.80
		Production traits	0.00	-0.71	-0.71

HAZARDS	Consequences	Genetic trait type	SUSCEPTIBILITY MEDIAN	MIN	MAX
High light intensity (incl. Natural lighting)	Scratches from other birds	Health and welfare traits	0.00	-0.78	-0.78
		Reproduction traits	0.00	-0.75	-0.75
		Production traits	0.50	-0.28	-0.28
Light cycle (long photoperiod)	Disturbed rest	Health and welfare traits	0.00	-0.71	-0.71
		Reproduction traits	-0.25	-1.00	-1.00
		Production traits	0.00	-0.71	-0.71
Reduced mobility	Reduced ability to perform normal behavioural repertoire	Health and welfare traits	-0.25	-0.92	-0.92
		Reproduction traits	0.00	-0.75	-0.75
		Production traits	-0.50	-1.00	-1.00
		Health and welfare traits	-0.25	-1.00	-1.00
	Reduced ability to reach feed/water when motivated	Reproduction traits	0.00	-0.78	-0.78
		Production traits	-0.50	-1.00	-1.00
		Health and welfare traits	0.00	-0.80	-0.80
	Birds experiencing pain	Reproduction traits	-0.25	-1.00	-1.00
		Production traits	-0.50	-1.00	-1.00
		Health and welfare traits	-0.25	-1.00	-1.00
	Increased time spent in contact with litter	Reproduction traits	0.00	-0.75	-0.75
		Production traits	-0.50	-1.00	-1.00
Inappropriate diet	Digestive problems	Health and welfare traits	0.00	-0.60	-0.60
		Reproduction traits	-0.25	-0.92	-0.92
		Production traits	-0.50	-1.00	-1.00
		Health and welfare traits	-0.50	-1.00	-1.00
	Diet-related bone problems	Reproduction traits	0.00	-0.78	-0.78
		Production traits	-0.50	-1.00	-1.00
		Health and welfare traits	0.00	-0.50	-0.50
	Cleanliness of plumage	Reproduction traits	0.00	-0.67	-0.67
		Production traits	-0.25	-0.92	-0.92
		Health and welfare traits	0.25	-0.42	-0.42
	Pain footpad dermatitis , hock burn etc (see wet litter)	Reproduction traits	0.00	-0.67	-0.67
		Production traits	-0.25	-0.92	-0.92

HAZARDS	Consequences	Genetic trait type	SUSCEPTIBILITY MEDIAN	MIN	MAX
Unbalanced body conformation	High body mass	Health and welfare traits	-0.25	-1.00	-1.00
		Reproduction traits	-0.50	-1.00	-1.00
		Production traits	-1.00	-1.00	-1.00
	Pain from FPD	Health and welfare traits	0.00	-0.75	-0.75
		Reproduction traits	-0.50	-1.00	-1.00
		Production traits	-0.50	-1.00	-1.00
	Pain from breast blisters	Health and welfare traits	-0.25	-1.00	-1.00
		Reproduction traits	0.00	-0.67	-0.67
		Production traits	-0.50	-1.00	-1.00
	Lameness	Health and welfare traits	0.00	-0.75	-0.75
		Reproduction traits	-0.25	-1.00	-1.00
		Production traits	-0.50	-1.00	-1.00
Fast growth rate	Ascites	Health and welfare traits	0.50	-0.30	-0.30
		Reproduction traits	-0.25	-1.00	-1.00
		Production traits	-0.50	-1.00	-1.00
	Leg weakness	Health and welfare traits	0.50	-0.30	-0.30
		Reproduction traits	-0.25	-1.00	-1.00
		Production traits	-0.50	-1.00	-1.00
	Sudden death syndrome	Health and welfare traits	0.00	-0.80	-0.80
		Reproduction traits	-0.25	-0.96	-0.96
		Production traits	-0.50	-1.00	-1.00
	Skeletal disorders	Health and welfare traits	-0.50	-1.00	-1.00
		Reproduction traits	-0.50	-1.00	-1.00
		Production traits	-0.50	-1.00	-1.00
	Muscle disorders	Health and welfare traits	0.00	-0.80	-0.80
		Reproduction traits	0.00	-0.67	-0.67
		Production traits	-0.75	-1.00	-1.00
	High body mass	Health and welfare traits	0.00	-0.80	-0.80
		Reproduction traits	-0.25	-0.92	-0.92
		Production traits	-1.00	-1.00	-1.00

HAZARDS	Consequences	Genetic trait type	SUSCEPTIBILITY MEDIAN	MIN	MAX
		Health and welfare traits	0.00	-0.80	-0.80
	Reduced behavioural repertoire	Reproduction traits	-0.25	-0.92	-0.92
		Production traits	-0.50	-1.00	-1.00
		Health and welfare traits	0.00	-0.80	-0.80
	Inactivity (long periods of time in contact with litter)	Reproduction traits	-0.25	-0.92	-0.92
		Production traits	-0.50	-1.00	-1.00
Crusted litter	Pain from breast blisters	Health and welfare traits	0.00	-0.78	-0.78
		Reproduction traits	-0.50	-1.00	-1.00
		Production traits	-0.50	-1.00	-1.00

Glossary and abbreviations

Artificial insemination	Collecting semen from a male and depositing this into the female genital tract.
Balanced breeding	Breeding for a combination of characteristics traits, concerning animal biology, animal health, efficiency, environment production, animal welfare and economy.
Beak trimming (de-beaking)	Removal of part of the upper (and sometimes also lower) mandible of the beak.
Best Linear Unbiased Prediction (BLUP)	A statistical method that gives the estimation of a Breeding Value of an individual for a specific trait.
Breeding value	The additive genetic value of an individual defined by the additive inheritable effects of all the genes an individual transmits to its offspring
Broiler	A type of chicken *(Gallus gallus domesticus)* bred for meat production
Broiler breeder	Birds of the parent (P) or grandparent (GP) generation in the system of producing broilers, i.e. chickens kept for meat production. Broiler breeders are sometimes also referred to as “multipliers”.
Cervical dislocation	A method of killing by swift twisting and stretching of the vertebral column so that the spinal cord is torn apart and the blood vessels of the neck are ruptured.
Collective nest	Nest where several hens can lay their eggs simultaneously. Sometimes the expression “colony nest” is also used for these types of nests.
Correlation	A measure of how two traits relate to each other manifested by the way changes in one are accompanied by changes in the other. Correlation coefficients are expressed in the range –1.00 to +1.00.
Cross environment interaction	Correlation between the same trait measured in two environments. Used in connection with G x E interaction.
Culling	The killing of birds that are: non- or low-producing, excess in number in relation to the production need, or sick or injured.
Detoeing	Removal of the dew (and sometimes also pivot) claw from the feet of breeder males to prevent damage to females during natural mating.
Despurring	Removal of the spur bud on the back of the male chick’s leg

Dubbing	Removal of all, or part, of the male comb.
Dwarf gene	Sex-linked, recessive gene that causes reduced weight and height
Elite lines	See pedigree lines
Environment	External factors that affect an animal
Estimated Breeding Value	An estimate of an animal's additive genetic value for a particular trait.
Feather sexing	Day-old chicks are sexed by visual inspection of the primary feathers
Genetic Correlation	Relationships between traits that arise because some of the same genes affect both traits or genes affecting two traits are closely linked. It reflects the way genetic values for the two traits co-vary.
Genetic diversity	High variety of alleles of genes within a population.
Genetic Progress	An increase in the average genetic merit of a population from one generation to the next for a particular trait as a result of selective breeding.
Genomic selection	Selection of animals to be used as parents of the next generation based on information provided directly from their genome.
Genotype	The actual genetic make-up of an individual as determined by its genes, may refer to a particular trait or the genome as a whole.
Genotype × Environment Interaction	If various genotypes has a different ranking in different environments
Grand-parent stock	Broiler breeders two generations above the production (broiler) level. Offspring of Great Grandparent stock (GGP), which are the offspring of pedigree stock.
Half-sibs	Individuals who have the same sire or dam (i.e. half brothers and half sisters)
Heritability	Is the ratio of the genetic over phenotypic variance and reflects the proportion of a measured or observed trait that is transmitted to the offspring by genes that act in an additive manner.
Hybrid	Progeny produced by crossing two or more lines or breeds.
Lameness	An abnormal gait may or may not involve pain
Layer	A type of chicken (*Gallus gallus domesticus*) bred for efficient egg production
Leg weakness	A condition where the legs (including joints, bones, muscles, tendons etc) are affected and may predispose to lameness
Letal	Inherited gene that causes death

Lixiscope	Portable, handheld low-intensity X-ray apparatus giving a real-time imagine. Used among other for examination of bone fracture in small farm animals.
Marker assisted selection (MAS)	Selection using genomic/molecular markers with major effects for a particular trait.
Multiple Trait Selection	Selection for more than one trait.
Parent stock	Broiler breeders one generation above the production (broiler) level. Offspring of Grandparent stock (GP).
Peak production	The period in time when production (in this case the number of fertile eggs produced) is at its maximum.
Pedigree (Elite) stock	Birds used for breeding great grand-parent (GGP) stock and the generations prior to these.
Phenotype	The observed or measured expression of a trait for an individual. Phenotype is equal to genotype plus environment effects.
Polydipsia	Overdrinking
Progeny Testing	The evaluation of an individual's genotype and breeding value estimation using the performance records of its progeny.
Quantitative Trait Loci	The locus of a gene with a major effect on a quantitative trait.
Reaction Norm	In an extended G × E interaction situation with several genotypes and several environments a genotype may be more or less sensible to a given differences across environments than other genotypes. One speak of the "reaction norms" of the genotype.
Selection	The process of deciding which animals will be parents of the next generation based on some pre-determined criterion.
Spiking	A procedure aiming at sustaining good fertility levels in broiler breeder flocks. At approx. 40 weeks of age inactive males in poor condition are removed and replaced by younger mature males.
Spiking mortality syndrome	A disease condition of the heart that leads to occasional peaks of death during the first 2 weeks of rearing
Spot-brooding	Young chicks are reared in small enclosures under a heat source during the first days-week of life, instead of immediately given access to the entire area of the rearing house. Sometimes also referred to as zonal brooding.
Sudden death syndrome	Birds (broiler chickens) that die suddenly with no other obvious pathology.
Toe clipping	Removal of a specific toe at the first knuckle, for identification purposes.
Trait	Any measurable or observable characteristic of an animal.

Variation	The amount of difference observed or measured for a trait in a group of animals; may refer to phenotypic or genetic differences.
Vent-sexing	Day-old chicks are sexed by visual inspection of the cloacal area.

Abbreviations

ACRBC	Athens-Canadian Random Bred Control
AI	Artificial Insemination
AIAO	All in/all out systems
AET	Apparent Equivalent Temperature
APEC	Avian Pathogenic E. coli
BB	Broiler breeder
BGSS	Bristol Gait Scoring System
BLUP	Best Linear Unbiased Prediction
EE	Environmental enrichment
FCR	Food Conversion Rate
FPD	Food Pad Dermatitis
GGP	Great Grand-Parent
GP	Grand-Parent
GR	Growth Rate
HACCP	Hazard Analysis and Critical Control Points
H/L ratio	Heterophil / Lymphocyte ratio
MAS	Marker Assisted Selection
QTL	Quantitative Trait Loci
RSPCA	The Royal Society for the Prevention of Cruelty to Animals
SCAHAW	Scientific Committee on Animal Health and Animal Welfare
SDS	Sudden Death Syndrome
TD	Tibial dyschondroplasia