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Annex: Expert Group Reports
Genetics, Genomics, Reproduction, Food Quality and Safety, Diversity and Distinctiveness, Robustness, Aquaculture, Cattle, Horses, Honeybees, fur- and companion animals, Pigs, Poultry, Sheep and Goats

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Introduction

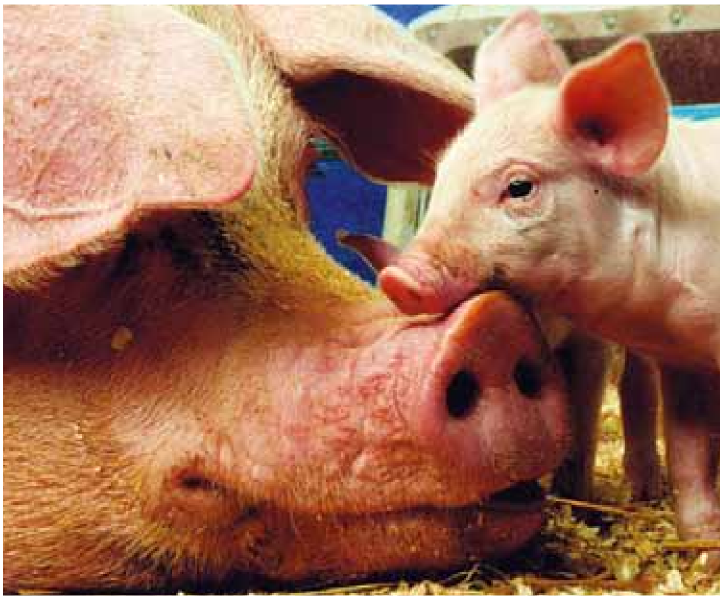
Animal farming plays an important role in European society. Optimised animal production systems 1) contribute to a safe, healthy and diverse diet, 2) help to maintain sustainable human communities in more marginal regions of Europe and, 3) offer opportunities to reduce the environmental footprint. A vibrant and effective animal breeding and reproduction industry is essential if Europe is to meet the future challenges of animal farming in a rapidly changing ecological, economic and social environment. Farm animal breeding and reproduction is a global, highly competitive and knowledge intensive sector. Currently, European breeding organisations are major players in the global market and therefore have a major influence on the genetic makeup of future animals and hence on the whole of animal production.

Research programmes on breeding and reproduction must focus on the support of breeding schemes which enable secure and sustainable food production and food safety; availability of high quality, healthy, affordable, diverse food products to consumers in and beyond Europe as real options for improving their quality of life is vital. The competitiveness of European agriculture and aquaculture and its organisations should be enhanced by enabling efficient breeding of animals for sustainable and secure food production. A more sustainable agriculture and aquaculture should be supported, including emphasis on non-food functions of animals such as for pleasure, leisure, or medical use.

The Sustainable Farm Animal Breeding and Reproduction Technology Platform (FABRE-TP) works as a contact point for the Farm Animal Breeding and Reproduction sector in Europe for organising updates on research and implementation and initiating European efforts and activities. FABRE-TP is supported by 116 organisations across Europe to enhance the sustainability of animal breeding and reproduction in (and outside) Europe. After its start as an independent initiative in 2005, the development of a Strategic Research Agenda and Implementation Plan was funded by the European Commission (FOOD-CT-2006-044228). Since 2009, FABRE-TP has been funded as a joint initiative of the European Forum of Farm Animal Breeders (EFFAB), French National Institute for Agricultural research (INRA), Biosciences Knowledge Transfer Network (BKTN), NOFIMA, and Wageningen University and Research Centre (WUR).

FABRE-TP is presenting its updated Strategic Research Agenda, highlighting the challenges and opportunities of animal breeding and reproduction to answer the great challenges. More specific information per specie, technique or theme are presented in the annex.

All extended versions of the expert group reports, country reports, the SRA from 2007, as well as a leaflet and poster are available from the web site: *http://www.fabretp.info*



Animal breeding and reproduction: A knowledge intensive sector

FABRE-TP stands for Sustainable Farm Animal Breeding & Reproduction Technology Platform. The concept of sustainability is highly elastic and therefore different for each type of organisation. In farm animal breeding, the concerns gathered under the umbrella of "sustainability" include animal welfare and health, animal integrity, biodiversity, environmental protection, consumer safety, food quality, profitability and general commercial viability. Obviously, each of these concerns is a topic in its own right. The key challenge set by sustainability is that of clarifying and balancing these concerns.

in productivity of pig, poultry and dairy cattle. The increase in productivity in these species in Western countries over the last 50 years lies around 1% per year (Van der Steen, 2005). At least half of the increase in productivity (efficiency) results from animal breeding activities.

Within animal breeding and reproduction, the aim is to influence future animals - by selecting animals that are optimally equipped to produce meat, milk, eggs, piglets, etc to produce the next generation. Although animal breeding has a long history, development of the industry as recognised today started with the widespread use of new reproductive techniques and selection methods in the mid 1900's. Since that time, the sector has become a knowledge intensive, highly competitive sector with high rates of innovation (often originating from the EU) playing an important role in allowing the sector to develop rapidly (e.g. new

A simple concept

Animal Breeding is based on the simple concept of selecting the most suitable animals as parents of the next generation. The process of determining suitability focuses on two main parts, namely developing assessments as accurately as possible of:

i) The environment in which the animals produces, and the demands of the market into which the animal products are to be sold.

ii) The animal's genetic potential in relation to these needs.

The process works by harnessing the naturally occurring genetic variation that exists between individual animals. As the benefits of selection are cumulative, continued selection for the same goals over several generations allows substantial genetic improvements to be made. The only condition is that the trait that has to be improved, has to be heritable. Through high reproductive rates (especially in males for most species) and the availability of advanced reproductive techniques, the improvements made can be disseminated widely, allowing very high economic impacts to be achieved at a company (breeding organisation) or industry (farm) level.

The expected rate of genetic gain from effective breeding programs generally lies around 1% per year (e.g. Hume et al., 2011). Genetic gains are permanent and cumulative so that the gain made in one year will give benefits over all subsequent years without further intervention. Observed changes in productivity as reflected by annual statistics result from the combined effect of genetic improvement and improvements in housing, nutrition and disease control. In the past half century, important increases have been realized

Added Value Animal Breeding in Europe (SRA 2007)

Economic gain (cumulative, permanent)	€ 1,89 billion/y
of which	
Dairy cattle	€ 430 million/y
Beef cattle	€ 70 million/y
Pigs (Europe)	€ 520 million/y
Sheep/goats (Europe)	€ 156 million/y
Broilers (Europe)	€ 610 million/y
Layers (Europe)	€ 125 million/y
Salmon/rainbow trout/seabass/seabream/turbot	€ 80 million/y

Animal Production in the EU (EuroStat 2010)

Value (EU 27, 2010)	€ 141 billion/y
Of total agricultural production	40 %

AgriFood in the EU (EuroStat 2010)

Number of farms (EU 27, 2007)	14 million
Number of jobs (EU 27, 2007)	12 million fte
Annual turnover AgriFood industry	€ 600 billion
Number of jobs	2,6 million fte

computing methods, genetics, genomics, measuring techniques). The use of some technologies (e.g. cloning or genetic modification) raises ethical considerations regarding balancing e.g. environment, health, welfare, feasibility, choice and animal integrity. Recent advances have allowed higher rates of genetic changes to be possible, and also have allowed a greater range of animal characteristics to be included in breeding programmes, especially in relation to animal health, welfare and product quality.

In the future the global consumption of animal products such as fish and meat will increase even further, especially in Asia and the Pacific, as is represented in Figures 1 and 2. Although animal production is spread all over the world, the genetic material for these animals is mostly provided by European based organisations. For example in the poultry sector both the breeding organisations for layers and turkeys have a worldwide market share of >90% and are European based. Therefore it is important that research in Europe on all aspects of sustainable animal breeding and reproduction continues.

Figure 1.
Increase in meat demand, by region between 2008/2010 and 2020 (carcass weight equivalent or ready to cook) Consumption growth of 60 Mt is projected by 2020; predominantly in Asia

Source: OECD-FAO Agricultural Outlook 2011-2020

http://dx.doi.org/10.1787/888932427094

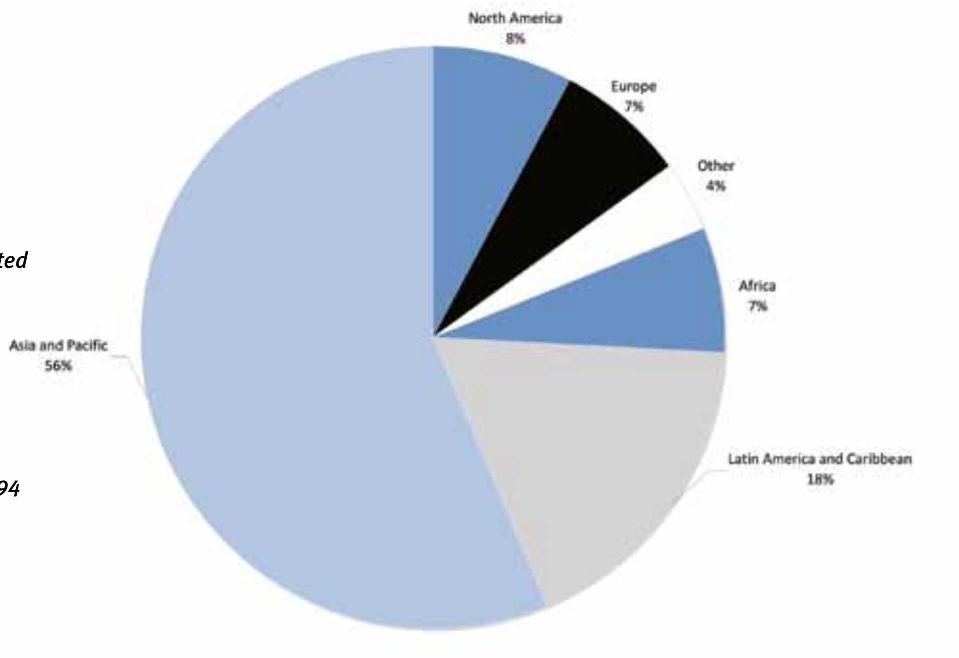
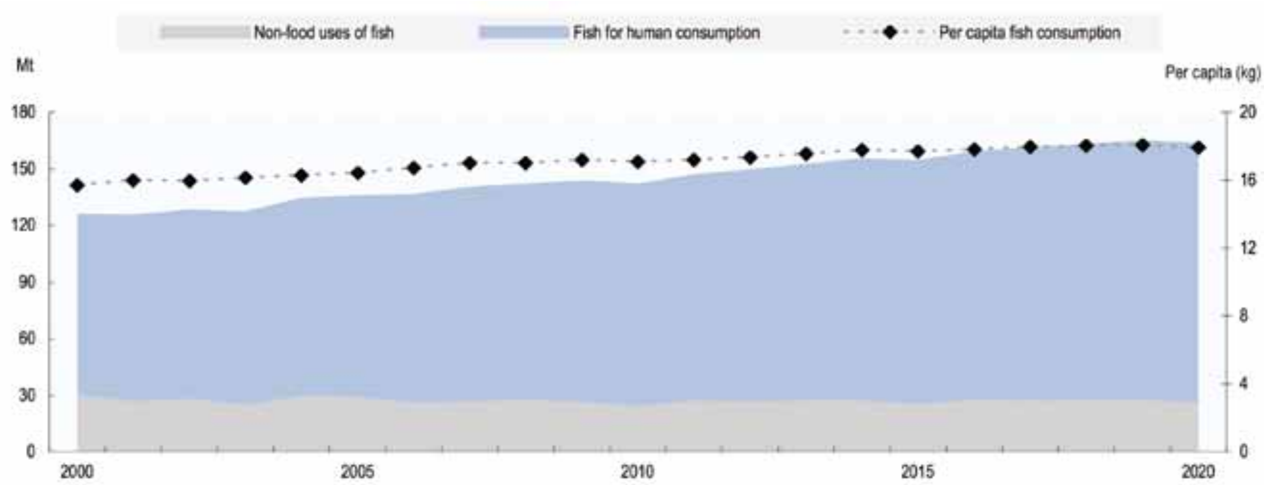


***Figure 2.** World fish utilisation and consumption projections*
Development of utilisation of world fish production and per capita fish consumption between 2000-2020



Note: Non-food uses of fish include utilisation of aquatic products for reduction to meal and oil, for feed and bait, for ornamental purposes, withdrawals from markets and any other non-food uses of fish production (e.g. fertilisers, medical uses, etc.).

Source: OECD-FAO Agricultural Outlook 2011-2020 *http://dx.doi.org/10.1787/888932427189*

Farm Animal Breeding Organisation Structures

Until the 1950s, most breeds of **ruminants** — i.e. most cattle, sheep and goats — were multi-purpose. A single breed of cattle, for example, would be kept for both beef and milk. That same breed might even be kept for draught purposes, as well. Over the last fifty years, specialisation has taken place. In general, cattle are now bred either for meat or to produce milk, and sheep bred for their milk are generally distinct from those bred for their meat (wool is mainly a co-product in Europe).

In **cattle** a small number of major breeds are used extensively around the world. Globally there are many breeds, some of which are at risk or endangered.
Many of these are geographically specialised and therefore also at risk from disease outbreaks.
Most European beef cattle breeders are individual farmers who are members of farmer cooperatives or breed societies. Dairy farmer cooperatives often provide their members with semen of several breeds of bulls.
Both breed societies and cooperatives may support research on artificial insemination (AI) and embryo technologies (ET), and undertake data registration for their members. AI is widely used in dairy breeds. For beef breeds, natural mating still is important.
In dairy cattle breeding, next to production, functional traits such as disease resistance, fertility, calving ease and longevity are taken into account. New developments of incorporating genetic marker information will assist progress further, especially for traits which are not directly measured or which have low heritability.

The organisation of **sheep** and **goat** farmers in regional and national farmer cooperatives or societies is often similar to that in cattle but with a greater number of breeders with few animals and a lower frequency of data recording and performance testing.
This is in part a result of lower margins from their sales of milk, meat and especially for wool.
Natural mating with rams is the widely used practice for reproduction. Next to production and reproduction traits, sheep and goat breeding programmes have started including traits for resistance to diseases/endoparasites.

Horses are primarily bred for sport and leisure purposes.
Breeding for meat is taking place in a few member states and horse milk has become more popular in Europe with some consumers. Breeding horses to work on the farm is of minor importance. There are many small and private breeding units (farms and hobby breeders), organised in regional or national studbook organisations especially in sport horses. Breeding of horses is characterised for many breeds by a constant process of introduction of genes from thoroughbred breeds to improve regional breeds.
Breeding goals focus on performance, conformation, and functional traits such as fertility, behaviour, and animal health.
Performance testing schemes need to overcome problems related to subjective and difficult to measure traits, small groups for data analysis (e.g. race on a track), and selection bias. Europe has a leading global position in sport horses.

European **pig** breeding organisations are organised in cooperatives and privately owned companies. They have been, and still are, world leaders in their sector.
A trend towards amalgamation exists. Purebred animals of several specialised sire and dam lines in nucleus herds form the top of the breeding pyramid, are providing the animals used for crossbreeding for the production level. The breeding goals have evolved from highly heritable traits such as growth, feed efficiency and carcass composition to now include sustainability related traits such as litter size, piglet vitality, sow longevity and meat quality.

In **poultry**, a few large-scale (about € 500–700 mln annual turnover) private companies supply breeding stocks. Most eggs today come from specialist crossbred laying hens. Broilers are also crossbred for their meat. The main selection criteria in poultry breeding are productivity, product quality, reproduction and fitness, health and welfare as well as traits enhancing the processing and marketability, such as breast meat yield and uniformity of products. Crossbreeding farm animals brings natural benefits. For example, production birds bred for meat (broiler chickens, turkeys and ducks) combine male and female lines selected to ensure a balance between growth, uniformity and reproductive performance. In the cross, hybrid vigour is also secured, and so the offspring have added vitality and productivity.

Breeding in **aquaculture** is a recent development. The oldest breeding programmes in aquaculture have been running for ten or less generations. To date it has targeted a limited number of species of freshwater fish (trout, carp and salmon) and marine species (bass, bream, cod and halibut) and none in molluscs. The degree of development of breeding programs for different species differs greatly as does the degree of business specialisation of companies. Genetic improvement is based on the development of large selective breeding programmes using genealogic performances (mostly by multinationals or big companies) and on the development of smaller scale selective breeding programmes, more adapted to Small and Medium Enterprises, using individual selection and in some cases fingerprinting to allow genealogical reproduction. The traits currently of interest relate to growth and processing yields including fat content, disease resistance, spawning season, age at maturation and body shape.

Europe is internationally leading within fur animal, honeybee, and rabbit research, breeding and production, and plays an important role globally in training of working dogs such as for police/army/customs. In **rabbits**, cross-breeding is the common breeding policy with specialised dam and sire lines similar to pigs. Selection traits are litter size and milk production in dam lines and meat % for sire lines. Farmed rabbits are genetically not far removed from rabbits in the wild - their needs and their susceptibility to disease are very similar. **Fur animal** breeding focuses on mink and foxes, concentrating to Northern Europe (high quality fur) in nationally organized schemes and in non-European countries (e.g. China) with much lower production costs.

In **honeybees** there is, next to the production of honey, a benefit from the pollination of plants. The 25 geographical honeybee races arose from natural selection. Natural honeybee populations are strongly affected by the transport of non-native races. Breeding honeybees for resistance to parasites is becoming more and more important.

Dogs are used both as companion animals and working dogs. Companion animal breeding is in the hands of private people and is largely non-commercial. Working dogs (e.g. herding and guarding, guiding, dogs for police, customs, and army, assistance dogs) are mainly a relatively new field of breeding.

Opportunity 1: Global Responsibility and Competitiveness

Scope: European farm animal breeding and reproduction organisations are market leaders in a competitive global environment. Opportunities originate from the global demand for food that is produced transparently and with respect for the environment. For this, a favourable competitive business and regulatory climate is a necessity.

A. Goal: To assure global food security and sustainability of production systems

The global population is expected to grow to 9,2 billion people in 2050 (United Nations, World Population Prospects, 2010). Even without any change in per capita consumption of food products from animal origin, the demand will grow enormously. Moreover, urban populations in all developing countries are expected to grow at an average of 2.9% per year (Delgado et al., 1999).
Per capita income will also increase and this will significantly contribute to the increasing demand for animal food products. For instance, the expected demand for poultry meat will grow from 80 million metric tonnes per year (2005) to 132 million metric tonnes per year in 2022. This will mean that there needs to be a larger grand-parents stock in the broiler industry: 46% more by 2019.
The need for balanced breeding programmes may be demonstrated by the fact that such an increase in food demands can be met with 33% extra feed instead of 46%.
The European animal breeding and reproduction sector will contribute to European and global food security and affordability of animal products by increasing the potential of animals to produce efficiently. This is done by transferring knowledge and sharing technologies and data across the European Union.

Challenges and opportunities:

- Development of more effective animal breeding and reproductive technologies
- Improvement of knowledge and technology transfer (better exchange of knowledge, technologies and skills)
- Development of more efficient and sustainable animal production systems
- Increase the value of data collected, through standardisation of recording methods and collation of data sets

B. Goal: To reduce the environmental footprint and waste

Increased emphasis on the environment will have a significant impact on the viability of animal production and the level of production in the EU. Improved biological efficiency and more specifically a reduced amount of waste per unit output will be important future breeding goals. Another opportunity is to reduce labour input, whilst maintaining or improving animal health and welfare, and product quality. Selection for improved Food Conversion Ratio (FCR) and adaptability to utilise alternative feed sources is likely to have an important effect and there is potential for this to be achieved in several more species. Possibly there is genetic variation in other important traits that have not yet been discovered.

Global ecological and geo-political factors will have an impact, particularly in the longer term. The rising costs of energy and transport may stimulate production close to consumption.
Competition for land use between subsidised energy production (e.g. bio ethanol) and animal feed has already increased feed prices.

Climate change will result in the need to more efficiently use available resources, to reduce emissions of greenhouse gases, to modify systems of animal husbandry, to develop crops that can be grown as animal feed under the new climatic conditions, and to cope with emerging pathogens and pests. The production of green house gases (GHG) will impose strong social and political pressures on all (European) industries to reduce their emissions. The livestock sector (globally) is currently responsible for 18% of total human-related GHG production (CO_2 equivalents). In the future an increased demand for animal production may increase this level even further, therefore the need for balanced breeding and efficient animals is essential.

Challenges and opportunities:

- Definition and development of pertinent traits reflecting environmental footprint for inclusion in breeding programmes
- Quantification of the real life benefits and additional opportunities for animal breeding to reduce emissions per unit of animal product

C. Goal: To address consumer demands

Consumer demands, including both product quality and safety as well as the welfare of the animals producing the product and the environment footprint of the production systems are increasingly intensifying. Such demands, but more importantly, future expected demands, must be considered when developing breeding programmes as well as ensuring the consumer that resources are being expended in generating animals suitable for future production systems without compromising the resulting product. Such initiatives can only succeed through multi-disciplinary collaboration including animal breeding and reproduction.

Challenges and opportunities:

- Improved translation of consumer and purchaser demands in breeding programme development

D. Goal: Strengthen European competitiveness

Europe has always played an important role in improving the world's major livestock and aquaculture species. European breeds are used across the world, and European farmers and breeding organisations are major players on the global market.
The European farm animal breeding and reproduction sector will thus have a great influence on, and therefore responsibility for, the future genetic makeup and characteristics of farm animal populations worldwide.

The future success of the European farm animal breeding and reproduction sector depends on its ability to remain competitive and accepted by society.
Farm animal breeding and reproduction is a knowledge-intensive sector. This means not only that it exploits knowledge to provide the world with breeding stock, but also that the knowledge developed is or can be used to meet local, niche, or cultural demands inside or outside Europe. The past success of European breeding owes much to its longstanding close ties with universities and research institutes, fostering the dissemination of knowledge to the farm and individual breeder level.

Breeding farm animals that perform optimally in economically viable production environments is a key challenge. This will require a vibrant basic research and education base, linked with effective, industrially and governmentally supported applied research and technology transfer. It is vital to enable Europe to have a real choice regarding new technologies and a solid basis for discussion of their possibilities, desirability and uncertainties.

Challenges and opportunities:

- Continuous development and investment in improved (breeding) technologies and programmes that exploit state of the art technologies and methodologies
- Development of effective structures and methods for dissemination of results through relevant industries
- Ensuring animal breeding programmes take account of changing regulatory frameworks and market needs

E. Goal: Develop responsible ownership and protection of new innovations

As the opportunities that arise from biotechnological developments increase and larger investments in research are made, the interest in and questions about intellectual property grow.
In animal breeding, there are no "Animal Breeder's Rights" equivalent to Plant Breeder's Rights. Arrangements for the transfer of ownership of improved genetic material are typically governed by contractual arrangements. Breeding animals are expensive – you pay for the animal and for the right to use it for breeding. In order to encourage investment in R&D, breeders are keen that the regulatory framework should provide a period of protection for those that invest in new technologies.

Patents are frequently written with a number of claims, which may cover genes or gene sequences. Such products are patentable, even if their structure is identical to that of natural elements present in the animal body. As long as the gene has been isolated from the animal body and the inventor has disclosed its concrete use, it is no longer considered as a discovery but as an invention. In such cases as developing a selection test based on the sequence information, utilising the gene to produce a transgenic animal or as a marker gene etc., the gene itself may be patentable. Such patents have no effect on traditional breeders: patent holders are not able to claim rights on farm animals naturally carrying this gene; they may only claim rights on the use they proposed of this gene (Noiville, in Farm Animal Breeding and Society, 1999).

Where excessively broad patent claims are being made, or patents are applied that cover already running businesses, companies can ask for re-examination with the respective patent offices. In practice, breeders exercise patent watches jointly, so as to assure that patents are granted on 'new inventions covering reasonable breadths of application'.

Challenges and opportunities:

- Ensuring a balance between protection and openness of intellectual property without suppressing industrial R&D investments

Opportunity 2: Social Responsibility

Scope: Animal breeding and reproduction has an enormous potential to improve our lifestyle and prosperity. Opportunities arise from the possibilities to simultaneously improve efficiency, animal welfare, health and product quality that ensure safe animal products. However, the links with the society are important: therefore accessible information, full transparency and constructive dialogue are necessary.

A. Goal: Produce safe animal products

Food-borne infection is a significant cause of human morbidity and even mortality. Often, infection originates from animals or their products (zoonosis). Farm animals may display different responses to many zoonotic pathogens (e.g. Salmonella, Campylobacter) because of their susceptibility. However, the relationships between hosts and their many pathogens are complex - disease resistance of the host is likely to be only one component of effective health control strategies. Moreover, new zoonotic infections can emerge, such as influenza. Opportunities may arise through genetics/genomics research to reduce the risk of recombination of non-human with human influenza virus types. Such opportunities might include genetically modified (GM) animals resistant to specific diseases. However, selection for resistance to one disease may have unwanted effects on other diseases. Thus, more scientific work needs to be done in this area of expertise.

For animal breeding organisations, the production of breeding stock that is disease-free is a necessity.

Challenges and opportunities:
- Exploit genetic variation to reduce susceptibility of farm animals to zoonotic and other diseases
- Basic GM research on zoonoses and farm animals

B. Goal: Enhance product quality and consistency

Tastier, as well as healthier, food is becoming an increasingly important demand from consumers. Some attributes in animal food products (e.g. tenderness, colour, texture of meat or albumen quality of eggs) are heritable. This means that these aspects can be improved through animal breeding. The farm animal breeding and reproduction sector needs to take such aspects into account in their selection decisions. New opportunities arise from the potential discovery of valuable bioactive compounds in animal foodstuffs. These compounds may prove valuable, especially in the form of dietary supplements for immune-suppressed individuals. However, at the same time, harmful or anti-nutritive components may also be discovered in foods of animal origin.

Challenges and opportunities:
- Exploit genetic variation to improve the quality and consistency of products of animal origin, next to selection for environmental efficiency, production level etc.
- Exploit the genetic variation in the amount of bioactive and anti-nutritive food components in different genotypes of farm animals
- Development of quality assurance schemes

C. Goal: Maintain and enhance animal welfare and health

It is important that animal welfare is identified through the use of objective criteria. For breeding purposes, only those criteria that are heritable and that can be routinely measured with a high level of repeatability are useful. The shift to selection for improved product quality and health is considered a major opportunity in all farmed animal species. Breeding programmes contain ever more traits, thus balancing production, environmental efficiency, health-welfare and fitness traits. There is a continuous search for reliable health and welfare traits that can be included in breeding programmes. Currently, the search for robust animals that can cope with variable environments, and animals that are resistant to specific diseases is a hot topic in genetics research.

There is considerable scientific opportunity to develop a better understanding of the molecular genetics of host/pathogen interactions, but there is much we need to know before this opportunity is converted into real impacts on animal health. The impact of improved health across populations is not known (herd immunity).

Commercial producers, especially of extensively farmed species, want breeding stock that continue to produce profitably in a range of different production environments. If, for example, supply of animal feed is limited, the more robust animal diverts resources to maintaining fitness at the expense of productivity, but will remain productive at a lower level.

Challenges and opportunities:
- Quantification and exploitation of genetic variation underlying sustainable animal welfare and health in different production systems
- Definition and development of pertinent traits describing animal robustness
- Develop understanding of genetic variation in responsiveness to drugs and therapeutics
- Develop effective systems for collecting animal health and welfare data

D. Goal: Achieve a balanced and transparent regulatory framework

Future policy decisions and regulatory frameworks will have a strong influence on the development of a sustainable animal breeding and reproduction sector in Europe. It is essential that decisions are made as inclusive and transparent as possible.
Due to the global environment in which animal breeding and reproduction organisations operate, it is essential that there is an effective regulatory framework which encourages business and innovation on the one hand, and which provides proper consumer information on the other. A policy environment that facilitates business and innovation, i.e. a workable, practical regulatory and legal framework and global trade rules are important for the further development of the farm animal breeding and reproduction sector in Europe. An example of past success is the development of a voluntary Code of Good Practice, Code-EFABAR® for farm animal breeding and reproduction as a result of an EU funded project. Code-EFABAR® is useful both as a guideline within the professional organisations and as an instrument for dialogue with society.

Challenges and opportunities:
- Further implementation of Code of Good Practice for farm animal breeding and reproduction: Code-EFABAR®
- Ensuring an open and transparent dialogue between different stakeholders whilst developing new regulations and industry driven research policies

E. Goal: Maintaining genetic diversity while respecting different cultural and regional needs

In recent years, the breeding and reproduction sector has significantly consolidated its enterprises. Although cooperative and national breeding programmes are likely to be more resistant to this trend, we may see increased globalisation of business there as well. At the other end, there are small and local breeding and reproduction enterprises. Both groups of enterprises contribute to maintain genetic variation within their species, and are important for the genetic diversity of the species.

Genetic diversity within a species is important to be able to provide animals that are optimally suited to marginal areas or extensive production systems, thus increasing the economic efficiency of farming in less favourable areas. Often higher market prices of recognised local food types is the only reason that production in some marginal areas can be economically sustainable.

There are considerable national and regional differences in breeding practices and in public attitudes towards them. Each country tries to identify equilibrium between local needs and global uniformity demands. Genetic diversity is also important to address future unknown changes in markets, climate, politics etc.

Challenges and opportunities:
- Achieve sustainable management of farm animal genetic resources
- Adapt selective breeding programmes to specific regional/ cultural needs and goals

F. Goal: Improve consumer understanding of the application and potential benefits from new approaches and technologies

Understanding the application and potential benefits from new scientific approaches and technologies is key to acceptance and exploitation of research. Communication with the consumer is also key to ensure transparency in the research methods and implications of the results. However, any communication must be in a suitable format for ease of understanding by the consumer and education of the communicator, which in the majority of cases are the scientists, is a necessity. Communication must be continuous and must use several media including state of the art tools like social media. Potential repercussions as well as benefits must be clearly identified including long-term consequences and risks.

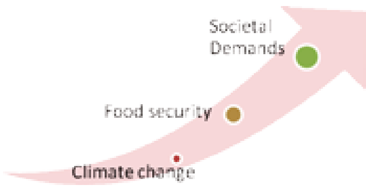
Challenges and opportunities:
- Communicate with consumers and the end-users of technologies on ongoing developments
- Education of scientists and animal breeding and reproduction organisation on communication with consumers.

Research Priorities

The expert group reports (see Annex 1) generally mention three important drivers of change. Societal demands in the European Union are changing rapidly and both citizens and consumers have an opinion about current methods of animal production. Food should be not only cheap (as otherwise competition from non-EU countries will arise), but also safe and be produced under good environmental and animal welfare conditions. Future research priorities should take their considerations into account. Moreover, the need to feed a growing world population (an estimated 9,2 billion people in 2050 (United Nations, World Population Prospects, 2010)) emphasizes the need for an efficient, though environmental-friendly, animal production industry. Last but not least, climate change may have an influence on animal production: animals will have to produce under changing weather and temperature conditions. New host-pathogen interaction patterns may lead to increased disease pressure; animals of the future have to be adapted to deal with these challenges.

In total, five different domains were defined by the expert groups, where improvements can be made (Figure 4). These improvements, which we will now call breeding challenges, vary from improvement in production traits which will improve the economic viability of the farmers to improved exchange of knowledge between different sectors (e.g. breeding and feed industries in Europe). In Figure 4 an overview of these challenges is provided.
The exploitation of the rapidly developing technologies and understanding in biology and genetics provides an opportunity to adapt to the drivers of change, generating major opportunities for effective animal breeding.

***Figure 3** Main drivers of change that direct current animal breeding*



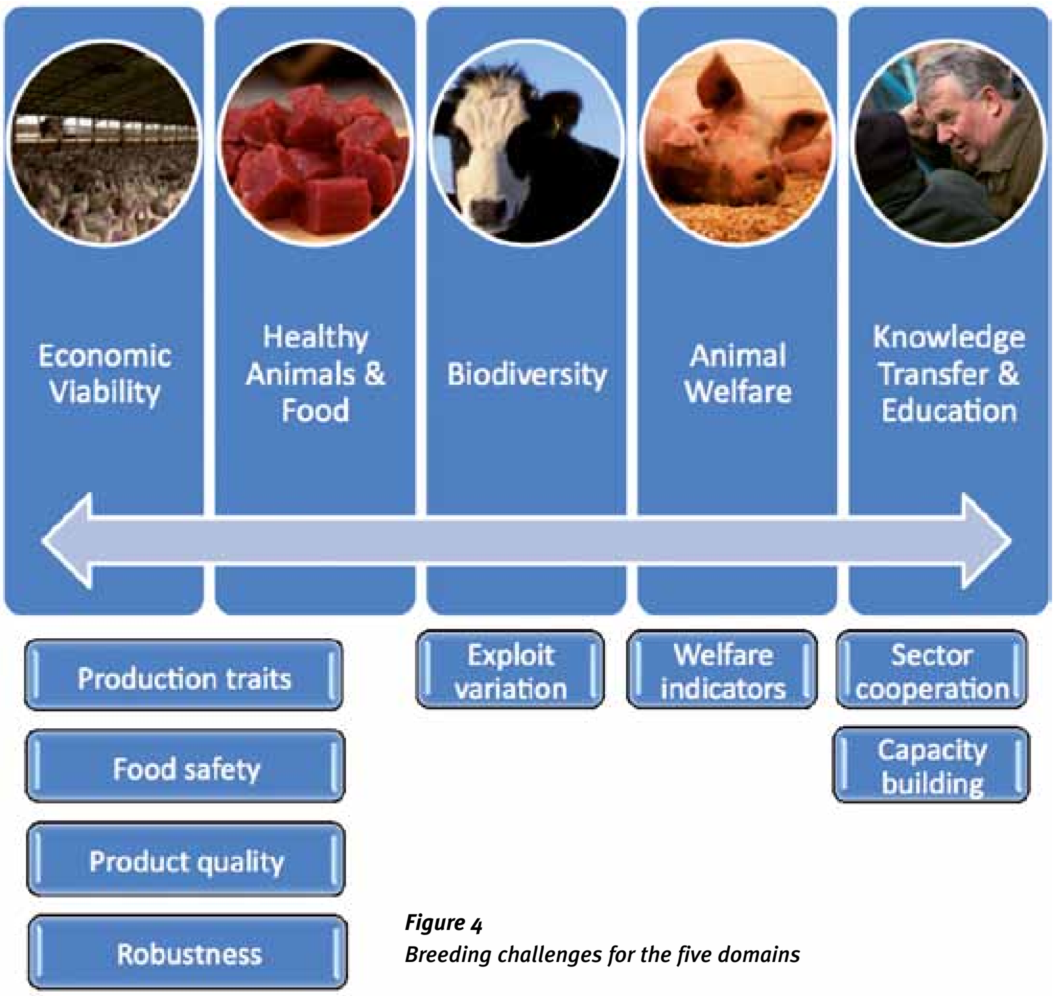


Figure 4
Breeding challenges for the five domains

Figure 5
Overview of the research priorities

These opportunities can only be realised if tools, resources and understanding that are currently missing are developed, exploited and disseminated at the appropriate level.

From the breeding challenges that are provided in Figure 4 the research priorities may be derived. These priorities are visualised in Figure 5.

The first research priority is the **redefinition** of some of the **breeding goals**. Productivity will not be the only relevant breeding goal anymore, but also environmental and welfare aspects have to be more and more included in future breeding goals, which may of course differ between the different animal production sectors.

In order to keep track of the breeding goal, it is essential to **select the right traits for breeding**. Understanding of the biology of individual traits, how they interact with each other and the environment is essential in order to be able to select the right set of breeding traits.

Then, in some parts of the animal production sector, **animal recording and data collection** is still sub-optimal. Performance recording is essential to choose the right animals as breeding stock. Cost-effective methods to collect standardised, comparable and appropriate data are a necessity for optimal functioning of breeding programmes.

Moreover, **new tools and technologies** offer huge opportunities within the animal breeding sector. New sequencing technologies that offer high throughput options, whole genome sequencing of most farmed animal species, the validation of SNP panels, the development of oligo-tiling path arrays and new bioinformatics programmes are just a couple of the current developments. These technologies offer lots of possibilities to understand how breeding works at the molecular level.

However, the need for new traits and an increase in the number of involved phenotypes (the most likely outcome of the re-definition of breeding goals) **will impact the breeding goals** because of the increased complexity that is required. The outcome of 'omics' information needs to be embedded within breeding programmes in order to improve genetic evaluation. Moreover, specific statistics and algorithms need to be developed, which are adapted to the new traits (e.g. product quality, environmental efficiency) and phenotypes. A method should be found to account for environmental variation and sensitivity, and specific techniques should be applied in order to assess low heritability traits and traits associated with health, welfare, animal physiology and product quality.
In order to secure sufficient genetic variation, the available variation should be fully exploited.
In ruminants this goes through implementation of global management in commercial breeds and systematic screening of endangered breeds. In pigs and poultry this should be done via in-house management of diversity in breeding companies.

Last but not least, breeders should show how the outcome of the breeding programmes is meeting the needs of **society**, whether the proper traits were indeed included. Moreover, knowledge about successful breeding needs to be disseminated.

In order to accomplish all of the above and to enhance the competitiveness of the European animal breeding sector, an appropriate and workable legal and regulatory framework is necessary, which stimulates both enterprises and the research infrastructure.

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Stakeholders

Aarhus Universitet	http://www.agrsci.dk
ABC (Agricultural Biotechnology Center)	http://www.abc.hu
ABI (AgroBioInstitute-Sofia)	http://www.abi.bg
ACOS (Associação de Criadores de Ovinos do Sul)	http://www.acos.pt
ADR (Arbeitsgemeinschaft Deutscher Rinderzüchter)	http://www.adr-web.de
A.I.A Associazione Italiana Allevatori	http://www.aia.it
University of Technology and Life Sciences - Bydgoszcz	http://www.utp.edu.pl/
Alta Genetics	http://www.altagenetics.nl
ANAS (Associazione Nazionale Allevatori Suini)	http://www.anas.it
ANPS (Asociación Nacional de Criadores de Ganado Porcino Selecto)	http://www.anporse.es
APEZ (Portuguese Association of Animal Science Engineering)	http://www.apez.pt
Aristotle University of Thessaloniki	http://www.auth.gr
AquaGen	http://www.aquagen.no
Aviagen	http://www.aviagen.com
BBSRC (Biotechnology and Biological Sciences Research Council)	http://www.bbsrc.ac.uk
Bio Talentum Ltd.	http://www.biotalentum.hu
BKTN	https://ktn.innovateuk.org/web/bioscienceskt n
BUT (British United Turkeys)	http://www.but.co.uk
CESTR (Czech Fleckvieh Breeders Association)	http://www.cestr.cz
CF Consulting Finanziamenti Unione Europea	http://www.cf-consulting.it
Cherry Valley	http://www.cherryvalley.co.uk
CITA / Gobierno de Aragón	http://www.aragon.es
Cobb Europe	http://www.cobb-vantress.com
CONVIS Herdbuch Service Elevage et Génétique Luxembourg	http://www.convis.lu/
COPA-COGECA	http://www.copa-cogeca.be
CRA (Consiglio per la Ricerca e la Sperimentazione in Agricoltura)	http://www.ispave.it/
CRV Holding	http://www.crvholding.nl
CECAV (Research Center of Animal and Veterinarian Sciences)	http://home.utad.pt/~cecav/prodcient.html
Danske Slagterier	http://www.lu.dk
Deutsche Reiterliche Vereinigung (German Equestrian Federation; FN)	http://www.pferd-aktuell.de
DGfZ (Deutsche Gesellschaft für Züchtungskunde)	http://www.dgfz-bonn.de
EAAP (European Association for Animal Production)	http://www.eaap.org
EAS (European Aquaculture Society)	http://www.easonline.org
EFFAB (European Forum of Farm Animal Breeders)	http://www.effab.info
Estonian Pig Breeding Association (Eesti Tousigade Aretushustu)	http://www.estpig.ee
Escuela Técnica Superior de Ingenieros Agrónomos	http://www.etsia.upm.es
Europabio	http://www.europabio.org
European Development Group Montenegro	
Animal Production Service and Health Division of FAO	http://www.fao.org
FEAP (Federation of European Aquaculture Producers)	http://www.feap.info
FIBL (Forschungsinstitut für biologischen Landbau)	http://www.fibl.org
FBN Dummerstorf	http://www.fbn-dummerstorf.de
Fugato	http:// www.fugato-forschung.de
ULg Université de Liège Gembloux Agro-Bio Tech	http://www.gxabt.be/
Gentec	http://www.gentecweb.com
Genus PIC	http://www.genusbreeding.co.uk /pic.com
Hendrix Genetics	http://www.hendrix-genetics.com
Hubbard	http://www.hubbardbreeders.com
Hungarian Society of Agricultural Sciences	http://www.mae-kozpont.hu
IAH (Institute for Animal Health)	http://www.iah.bbsrc.ac.uk
IBABSA	http://www.ibabsa.net
IBBA, Istituto di Biologia e Biotecnologia Agraria	http://www.ibba.cnr.it
IBNA (Institutul de Biologie si Nutriti Animala)	http://www.ibna.ro
ICAR (International Committee for Animal Recording)	http://www.icar.org
ICBF (Irish Cattle Breeding Federation)	http://www.icbf.com
INIA (Instituto de Investigación y Tecnolog’ia Agraria y Agroalimentaria)	http://www.inia.es
INRA (Institut National de la Recherche Agronomique)	http://www.inra.fr

Institute of Animal Science, Kostinbrod, Bulgaria	*http://iasbg.hit.bg*
Institute of Biology and Immunology of Reproduction, Bulgaria	*http://ibir.bas.bg*
Instytut Zootechniki Panstwowy Instytut Badawczy	*http://izoo.krakow.pl*
IPG, Institute for Pig Genetics	*http://www.ipg.nl*
IRTA (Institut de Recerca i Tecnologia Agroalimentàries)	*http://www.irta.es*
Isituto Sperimentale Per La Zootecnia	*http://www.isz.it/ita/index.asp*
ITP (Institut Technique du Porc)	*http://www.itp.asso.fr*
KU Leuven	*http://bio.kuleuven.be/*
King Faisal University	*http://www.kfu.edu.sa/en/pages/home.aspx*
Lohmann Tierzucht	*http://www.ltz.de*
Marine Harvest	*http://www.marineharvest.com*
Marine Institute, Foras na Mara	*http://www.marine.ie*
Merial	*http://www.merial.com*
MLC (Meat and Livestock Commission)	*http://www.mlc.org.uk*
MTT Agrifood Research Finland	*http://www.mtt.fi*
NAGREF (National Agricultural Research Foundation)	*http://www.nagref.gr*
NEIKER - Tecnalia	*http://www.neiker.net*
Parco Tecnologico Padano	*http://www.tecnoparco.org*
Nofima	*http://www.nofima.no*
Norwegian School of Veterinary Science	*http://www.veths.no*
Norsvin	*http://www.norsvin.no/*
PASEGES	*http://www.paseges.gr*
Pfizer Animal Health	*http://www.pfizerah.com*
Pig Research Centre	*http://eng.vsp.lf.dk*
Polish Academy of Sciences - Institute of Genetics and Animal Breeding	*http://www.ighz.edu.pl*
SAC (Scottish Agricultural College)	*http://www.sac.ac.uk*
Sementitaly	*http://www.sementaly.com*
SIGRA	*http://www.sigra.lv*
Slovak Agricultural Research Authority	
Slovak Agricultural University in Nitra	*http://www.spu.sk*
Slovenian Holstein Breeding Organisation	
SperiVet, Dipartimento di Scienze Sperimental Veterinarie	*http://www.sperivet.unipd.it/*
Stonebridge Breeding Ltd	*http://www..stonebridgeg.com*
Swedish Dairy Association	*http://www.svenskmjolk.se*
SUISAG	*http://www.suisag.ch*
SYSAAF (Syndicat des Sélectionneurs Avicoles et Aquacoles Francais)	*http://www.sysaaf.org/*
Teagasc	*http://www.teagasc.ie*
TOPIGS	*http://www.TOPIGS.com*
UCL - Faculté d'Ingénierie Biologique, Agronomique et Environmentale	*http://www.agro.ucl.ac.be*
ULg Université de Liége Faculté de Médecine Vétérinaire	*http://ulg.ac.be/fmv*
UNCEIA	*http://www.unceia.fr*
Universita Cattolica Piacenza	*http://www.unicat.it*
University of Milan - Veterinary Science and Technology for food safety	*http://www.vsa.unimi.it*
University of Padua - Dipartimento di Scienze Sperimentali Veterinarie	*http://www.sperivet.unipd.it*
University of Palermo - Dipartimento (S.En.Fi.Mi.Zo)	*http://www.unipa.it/*
University of Bologna	*http://www.unibo.it*
University Bonn / Institute of Animal Science	*http://www.itw.uni-bonn.de*
Universitá Degli Studi Di Teramo	*http://www.unite.it*
University of Córdoba	*http://www.uco.es*
University of Copenhagen, faculty of Life Sciences	*http://www.ku.dk/english/*
University of Bedfordshire	*http://www.beds.ac.uk*
University of Ljubljana	*http://www.uni-lj.si*
University of Newcastle	*http://www.ncl.ac.uk/afrd*
University of Perugia	*http://www.unipg.it*
University of Sevilla	*http://www.investigacion.us.es*
University of Stirling, Institute of Aquaculture	*http://www.external.stir.ac.uk*
Viking Genetics	*http://www.vikinggenetics.com/en/*
WAAP (World Association for Animal Production)	*http://www.waap.it/site/*
WCHIRZ	*http://www.wchirz.pl*
World's Poultry Science Association Federation of European Branches	*http://www.wpsa.com*
WUR (Wageningen University and Research Center)	*http://www.wur.nl*
ZDS (Zentralverband der Deutschen Schweineproduktion)	*http://www.zds-bonn.de*

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EXPERT GROUP REPORTS

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Genetics

To enhance competitiveness and sustainability of animal food production, breeding pro-grams should focus on sustainable exploitation of genetic variation between animals to:

- ***produce better-quality, healthy, affordable, diverse food offering consumers real options for improving their quality of life;***
- ***promote a more sustainable agriculture and aquaculture, in terms of producer profitability, biodiversity, environmental footprint, animal welfare, animal health, public health, food safety and food security.***
- ***include emphasis on non-food functions (pleasure, leisure, use in the medical area);***

Advances in genomic technologies and reproductive techniques require reassessment for breeding value estimation, breeding programs and germplasm dissemination strategies.

Opportunities and challenges

Key opportunities are the European strength in population and quantitative genetics, with access to a wide range of genetic resources of high value and to world-class breeding infrastructure. Europe is well positioned to rapidly transfer scientific developments to a more profitable and sustainable agriculture and aquaculture. Key challenges concern **(i)** quantification of factors contributing to genetic variation and **(ii)** development of breeding schemes that make optimal use of genetic variation while restricting loss of genetic diversity:

- Improvements in **breeding value estimation** to include developments in statistics, computer algorithms, access to phenotypes of purebreds and crossbreds in a wide range of environments, and to increasing genomic data volume. Phenotypes will increase and diversify, e.g. for disease resistance, behaviour, robustness; also developments in sensor technology. Genotypic and sequence data will soon be available for many animals in many species; ditto for transcriptomics, metabolomics, proteomics and epigenomics.

- **Breeding goals** must be re-evaluated to account for changes in consumer and societal opinion, including the ecological footprint. This includes incorporation of **(i)** traits with uncertain economic values, **(ii)** the social interactions in groups of animals that are important for proper functioning of the group, and **(iii)** exploitation of genetic differences in environmental sensitivity of animals.

- Increased interest in **cross-breeding** and combining ability requires indexes to rank animals based on predicted performance including non-additive genetic effects. Genomic information offers new possibilities to estimate and exploit such effects.

- Quantify the impact of current **breeding schemes** and for design of new ones. This must exploit developments in new biotechnologies and preserve genetic diversity.

- Building tools, infrastructure, and implementation guidelines for breeding strategies in **populations with poor infrastructure**. This applies to species with a limited market, or that are still in the process of domestication and do not currently have a breeding scheme including breeding schemes in developing countries.

Gap analysis and challenges

Some of the above challenges require increased knowledge, improved technologies and additional resources including:

- How to exploit increasing complexity in phenotypes (e.g., high nutritional value, host-pathogen interactions, longevity traits, and behavioural or social interactions among animals in groups) and increasing volume of genomic data, and efficient computer algorithms in breeding value estimation.

- The genome sequence of "minor" species such as duck, quail and aquaculture species, as well as sequence information on founder animals of large breeds.

The European breeding industry has a high technological level that ensures the value of its products and determines its leading role in the world market. The industry is well positioned to adopt novel technologies but this requires a continuous and substantial re-search investment. Access to/use of genomic information (in particular gene sequence linked to phenotypic variability) could be limited in the future, because of a perceived short-term competitive advantage of retaining ownership (particularly when genotyping cost is high relative to the value of the animal). It may be circumvented through international consortia.

Short, medium and longterm opportunities/ needs for research

First 5 years

- Breeding value estimation:
  - o Optimal incorporation of "omic" information
  - o Statistical programming adapted to new traits and new phenotypes

- Breeding goals:
  - o Finding an economically viable way to include traits of increasing consumer concern including those with uncertain economic value
  - o Tools to exploit genetics of traits influenced by social interactions.
  - o Accounting for large environmental variation and environmental sensitivity

- Breeding plans:
  - o Tools to achieve sustainable long-term genetic gain, avoid undesirable side effects, and secure sufficient genetic variation
  - o Exploitation of new developments in other technologies (e.g., reproduction)

Longer term

- Tools to improve breeding value estimation incorporating "omic" data
- Estimate and exploit non-additive genetic variation.
- Implementation of tools to select for desired degree of environmental sensitivity or specialists in different environments, and to select for combining ability
- Development of schemes incorporating largescale genotyping at the embryo level.
- Better utilise genomic information to exploit different types of DNA variation

Genomics

The growing awareness of the finite nature of the planet's resources means that changes are needed in many economic sectors, including animal production systems, to address environmental issues and more generally sustainability. The scientific strategy for sustainable animal breeding and reproduction needs to address 'animal as systems and animals in systems'. The development and testing of models lie at the heart of systems biology research. The extent to which a model is predictive determines its value in understanding the system of interest. Such models have been the foundation of quantitative genetics and genetic improvement of plants and animals for decades. Thus, adapting the 21st century vision of systems biology to the needs of sustainable animal breeding and reproduction is about ensuring that the technologies and information systems customised for the target species and systems are put in place.
In the next five years many new genomes and transcriptomes (species and individuals) will be sequenced. Significant developments in statistical and computing tools, along with improvements in capturing phenotypic data, will be required to realise the potential of genomics to deliver information that will be useful to design improvements in sustainable animal production. The key agenda items to deliver genomics-driven improvement in animal breeding and production are set out below.

Short, medium and long-term opportunities/needs for research

Five years
Genomics, sequencing and genomic variation: Sequence characterisation of the genomes, and variation therein, of economically important species, populations and individuals is critical to 21st century selective animal breeding.

- "Finished" quality genome sequences, together with massive discovery of variants, for most relevant species.
- Metagenomic sequencing microbial communities, e.g., in the gastrointestinal tract.
- Tools for genotyping DNA variants, including SNPs and CNVs at high density.characterization of epigenomics variation across a range of tissues.

Transcriptomics, proteomics and metabolomics: Knowledge of systems at the level of the transcriptome, proteome and metabolome can contribute to understanding the links between the genome and the traits of interest.

- Refine transcriptomic tools (arrays, RNA-seq) and develop proteomics technologies for high throughput analyses in farmed animal.
- Develop comprehensive immunological, metabolomic toolkits for high throughput assays of for all major farmed animal species.
- Develop systems for high throughput genetic modification, including RNAi-based gene knock-down in cell-based systems.

Phenomics – The physical and biochemical traits of organisms: As sequencing and genotyping costs continue to fall, effective capture of phenotypic information has become the bottleneck.

- Establish standard phenotypic trait ontologies for the major farmed animal species to encompass production traits and disease traits (metabolic, inherited and infectious).
- Co-ordinate and standardise the acquisition of disease surveillance data at a pan-European level Encourage the use of commercial populations for high resolution genetic analyses in farmed animal species.

Bioinformatics, statistics and computer science: Effective exploitation of the opportunities presented by 'omics technologies requires substantial developments in bioinformatics, statistics and computing.

- Support for continued annotation and maintenance of genome databases customised for farmed animal species (need for continuity requires inclusion in 15 and 25 year agendas)
- Develop data sharing policies to maximise the value to be extracted from complex data sets without compromising legitimate commercial interests.
- Exploit distributed computing technologies (GRID, Cloud) for more effective data storage, sharing, integration and analysis (cf. iPlant). Develop scalable bioinformatics tools to handle high throughput 'omics and trait data, e.g., genomic selection procedures or inference of genomewide diversity parameters.

Fifteen years

- Integration of multi-level 'omics data (genome sequence, transcriptomics, proteomics, metabolomics) for effective dissection of the link between the genome and end traits of interest.
- Use advanced technologies to acquire high quality phenotypic data for large numbers of animals (living and/or post-mortem in slaughter houses or packing plants).
- User friendly, customizable and yet sophisticated statistical tools and web based systems to make the most of genomic and phenomic information.
- Exploit latest computing and communications technologies for more effective for more effective data storage, sharing, integration and analysis.

Twenty-five years

Develop a range of stem cells from farmed animal species to facilitate cell-based in vitro functional genomics research, including genetic manipulation.
Develop systems for high throughput genetic modification, including RNAi-based gene knockdown in cell-based systems.
Develop advanced technologies for genetic manipulation in farm animal species, including the capability for precision genetic modification using homologous recombination in appropriate stem cells, use of zinc-finger nucleases and RNAi-based gene knockdown.

Reproduction

Reproduction techniques (RT) are almost indispensable and essential components of modern animal breeding.
They have been used for decades to enable safe and efficient breeding and to ensure improved efficiency in food production. Several reproduction techniques are available but their application in animal breeding schemes differs between countries and regions in Europe as well as between the different species. Relatively new is the application of RT in the area of human medicine, for example for transgenesis in relation to xeno-transplantation or for use of animal models in pharmaceutical research.

Opportunities and challenges

The rapid developments in molecular genetics, and "omic technologies" (genomics, proteomics, metabolomics) and genomic selection have provided new opportunities to reduce generation intervals and enhance fertility and breeding efficiency. Effective use of RT is important to reap the maximum benefits of genomic selection. This will enable production of more offspring (larger litter size for some species), and genetically more efficient animals to reduce costs and guarantee efficient food production. Such developments represent a major opportunity for both secure food production and for applications in human as well as veterinary medicine. There are several challenges in optimisation of existing RT especially to improve their practicality, to develop new techniques and to implement RT over multiple species for a secure, diverse and sustainable food supply for European citizens and for application in the area of veterinary as well as human medicine. Part of the challenge is to overcome lack of knowledge and circumvent the anatomical and physiological limitations in some of the species through dedicated research and development.
Interdisciplinary opportunities: Transgenic farm animals generated for use in new medical approaches as models, bioreactors or organs or tissue donors are already on the market and will grow fast in importance.
In species such as pig, sheep, goat, cattle and rabbit, efficient production of these very highly valuable animals would require improved reproductive technologies (Assisted reproductive technology (ART), nuclear transfer, gamete banking). Although transgenic farm animals are not essential for food security, the need for specific RT is high and the animal production for food security can benefit from developments and research in this area. Therefore close collaboration between teams with different areas of expertise is necessary.

Gap analysis and goal setting

IIn order to meet these opportunities and challenges there is a need to improve efficiency of RT in general, but this need may be even more important for specific local and endangered breeds or species. The gap is due to differences in anatomy and physiology among different species, a lack of coordination in the research and differences in the level of development in the field which hamper practical application of RT in different species or breeds present in EU. Therefore it is important not only to fill the gaps of knowledge and further develop practical methods in order to facilitate the use of both old and new reproductive techniques but also to invest in coordination in research and application within the EU with respect to these RT. A coherent and flexible European research agenda in animal breeding and reproduction therefore is a must to achieve the following goals:

1. Improve the efficiency of reproductive techniques (including ART) to preserve genetic diversity,
2. Identify the critical networks of genes involved in fertility through reproductive physiology and gene expression studies
3. Identify through access to "omic technologies" new phenotypic and genetic markers for fertility for multi trait selection and prevention of diseases. This aspect will be very critical to improve performance and competitiveness of the breeding industry in Europe keeping up the quality of dairy and meat products.
4. Improve reproductive techniques to lower ecological footprint
5. Increase food security in relation with global warming and global increase in human population.
6. Improve efficiency of RT to fill the gaps in human ART in relation to the use of animal models, investigation of epigenetic effects and development of new therapeutic approaches.

The problem of stasis

If no research and development takes place in the area of RT, the rate of further developments in animal breeding will be drastically reduced. This will negatively influence the evaluation and dissemination of specific genes of high importance for the improvement of animal health and welfare as well as for the changes necessary for true sustainability in agriculture and aquaculture. In the new context of genomic selection, reproductive efficiency may become a bottleneck in selection for production traits as well as functional traits and for the new traits of importance to limit environmental footprints. At the same time, selecting for a very large number of traits of interest may lead to increased inbreeding and to reduced genetic diversity. Such selection goals will require dissemination of genes from very few elite sires through innovative and efficient RT (e.g. Embryo typing prior to transfer).

The most relevant research activities as a result of the gap analysis and priority setting exercise are summarised in Table 1 (appendix). During this process, we first discussed for each research issue how much it contributed to: efficient food production, environment, animal health and welfare, sustainability and human applications. Then research issues were ranked based on their priorities within the categories sub-categories. The main categories were: RT research in general, artificial insemination (AI), embryo transfer (ET), Assisted Reproductive Technology in animals for human medicine, Nucleus / Gene transfer.

Table 1: Research activities and priorities

Research activity	Priority	Time frame (years)
Efficient semen sexing	High	5
Disease transfer through sperms / oocytes / embryos / nuclei / genes: - detection, relevance and destruction of pathogens.	High	5-15
Gamete development, maturation and embryo development including maternal interaction= epigenetics and fetal growth regulation	High	5-15
Optimization of estrus synchronization, ovulation induction, super ovulation response, minimizing the use of hormones	High	5-15
Improved in vitro embryo production	High	5-15
ART / NT / GT technology development for instance to complete functional validation of the novel candidate genes potentially affecting fertility and other economically important traits	High	5-15
Rearing of efficient breeding animals	High	5-25
Influence of physical environment and animal interaction on reproduction including feed composition.	High	5-25
(Cryo)preservation of gametes, embryos and somatic cells for gene banking purposes and reproduction	High	15-25
Improvement of imaging methods: Ultrasonography to analyze ovarian state, early detection of pregnancy and fetus abnormalities.	Medium	5-15
Evaluation of relevant breeding soundness	Medium	5-15
Development of accurate ovulation detection methods for timed insemination	Medium	5-15
Low dose insemination	Medium	5-15
Improvement of methods for processing, handling of embryo's in order to enhance survival/ quality	Medium	5-15
Investigation of the fertilization process	Medium	5-15
Development of AI techniques with improved practicality and labor efficiency for all species	Medium	5-15
Semen preservation: development of new extenders, slow release semen incl. liquid semen	Medium	5-15
Non-surgical transfer of embryos	Medium	5-15
Embryo quality: development of diagnostic tests for relevant (genetic) characterization of embryo quality	Medium	5-15
Non invasive sexing of embryos	Medium	5-15
Estrus cycle: investigation of the estrus cycle for some species or endogenous breeds	Medium	5-25
Female factors e.g. reproductive diseases associated with the decrease in fertility and pregnancy loss	Medium	5-25
Development of milk or non milk based indicators for estrus and pregnancy	Medium	5-25
Improvement of efficiency and safety of gene transfer methods	Low	5-15
Development of transgenic animal models for new applications in the medical area	Low	5-15
Farm animal production for animal models	Low	5-25
Development of advanced NT protocols	Low	5-15
Establishment of cellular differentiation and transplantation methods	Low	5-15
Farm animal production for biomedical application	Low	5-25
Development of methods for derivation and maintenance of livestock embryonic and adult stem cells	Low	5-25
Risk assessment / research communication	Low	5-25

Food Quality and Safety

Priority problems and opportunities.

Consumer and retailers expectations for nutrition sourced from livestock in Europe are changing very quickly and more and more information on the provenance, quality and safety of the food is required. The animal breeding sector needs to be able to adjust selection goals consistently to meet these expectations and to provide new product/market opportunities through selection. There are significant opportunities to improve safety, quality and consistency of product through; a) development of better tools to measure/predict phenotypes and b) genomics research to develop molecular genetic selection tools. Food Safety: We need to better understand and exploit genetic variation in resistance to infection by (current and emergent) zoonotic organisms as one of several technologies needed to ensure food safety.

Product quality: The safe dissemination of genetic improvement also has a role to play in ensuring food safety and quality.

Nutritional quality: The nutritional value of foods of animal origin is driven by macro and micro composition. There is an opportunity to improve general nutritional value and maintain and further develop niche products, through better understanding of the genetics and genomics of product composition.

Gap Analysis

The main gaps are: a) the need to identify the DNA polymorphisms (and their mode of action, SNP, CNV, etc.), their interactions with each other and the environment controlling the heritable component of relevant traits; b) the need for the development of better, cheaper and less invasive tools for measuring (deep) phenotypes as a basis for breeding value estimation and payment systems and c) the integration of a) and b) to add genomic selection for novel traits related to food quality and safety to genetic improvement programmes. New 'gaps' in relation to safety may be created by legislative changes (e.g. antibiotic ban). Also, changes in future distribution of livestock production, spatial and temporal and considering scale and type (e.g., free range vs intensive indoors), is likely to have an impact on the "risks" to food safety, but could also provide opportunities.

The problem of stasis

Without relevant research on product safety and quality within Europe we will not be able to satisfy the increasing demand of consumers for diverse foods of high safety and quality produced in a transparent and traceable way. We risk that animal breeders elsewhere in the world gain in market share, and also miss out on the opportunity to develop differentiated value-added products to help European farmers compete with lower-cost imports.

RESEARCH NEEDS

First 5 years

Animal breeding can help to support antibiotic reduction policy by improving selection for genetic resistance and better understanding of immune system especially the non-specific part of it. Having in mind that the use of antibiotics in livestock production will be decreased in the future, those genotypes that require less administration of pharmaceutics will become the preferred ones, preferred by producers and consumers. The priorities are: Campylobacter

infection of poultry meat, Mycobacterium avium subspecies paratuberculosis (MAP) in bovines, MRSA and ESBL producing bacteria in intensive production systems and relevance for human health, Salmonella infection of poultry and pig meat and eggs, Listeria monocytogenes in Ready-To-Eat foods, innate immunity, general animal "fitness", identified taints of foods (especially boar taints), tenderness of beef and pork, shell quality of eggs, lipid/antioxidant content and composition of all animal foods, storage stability of fish and milk. Understanding the role that genetics plays in the response of animals to vaccines will help to identify animals that respond best to vaccines, current and those under development. We need to develop tools to routinely phenotype animals for these traits and progress from QTL to identified polymorphisms. These are requisites for integrating food safety and quality related traits in future genomic selection programmes. We need to develop tools to aid in the collection, collation and quality assurance of relevant data in the food chain and across borders. The provision of interoperability of different databases and to enable easy data-exchanges shall be a research task, as well.

15 years

Continued work on the traits listed under 5-years together with increasing attention to other zoonoses (especially VTEC, Staphylococcus in milk and viral infections of shellfish), food flavour characteristics, protein quality variation, processing characteristics (we expect important developments in processing in this timescale), micronutrient composition and consistency of the desired food/processing quality attributes.

By 15 years we should have sufficient knowledge of important genes for quality and safety traits and the priority will be to research the interactions of these major effects in relation to the sustainability of specific livestock products and systems. Advances will also be needed in genetic evaluation systems that combine novel phenotypes, multiple genetic markers and/or complete genomes to inform selection decisions and product differentiation. Also, food quality is likely to expand to include functional attributes of the product rather than sensory attributes alone. As highlighted this will be a trait that animal breeders will chase but food research is likely to develop animal feeds (or additives) which will convey the desired functional attribute in the animal product (i.e., functional feeds leading to functional food). With the combination of tools available it will be important to understand the genotype * diet interaction for the desired attributes. As a result of global change competition for resources may change the composition of livestock diets (e.g., availability of grain for animal feed, use of new protein resources) which could impact on animal performance, product quality and consistency. Animal breeders may need to explore future genotype * future diet (and system) interactions for traits of interest.

25 Years

In this timescale priority should be given to animal fitness and adaptation to global change as a component of perceived quality. The knowledge of the functional genetic elements related to food safety and quality traits will have grown significantly and research will be driven by predictive biological approaches that seek to model the interactions of genes and production systems to meet specific market needs. From improved understanding of the genomics of host-pathogen interactions, research should include novel approaches to safety, including improved vaccines and possibly GM approaches to resistance.

Diversity and Distinctiveness

Introduction: exploitation and conservation of genetic diversity

Farm animal genetic resources are sources of genetic variation of fundamental importance to ensure future genetic improvement, to satisfy possible future changes in the markets and in the production environment, and to safeguard against disasters that give an acute loss of genetic resources. In many areas, local breeds adapted to harsh conditions are unique sources of income for the rural communities. The link between local breeds and the environment where they were developed makes them key components for the management and conservation of the European agro-ecosystems diversity, and important elements of cultural diversity, as they reflect a history of symbiosis of relatively long periods with mankind. Diversity of breeds and their farming systems highly contribute to European food products quality and diversity. Then, farm animal genetic resources are opportunities to maintain a vital countryside. European breeding organisations are strong players in the global competition. It is crucial for Europe that the breeding sector maintains and further develops its leading role. At this respect, sustainable utilisation and conservation of the European breed (and production system) diversity can play an important role.

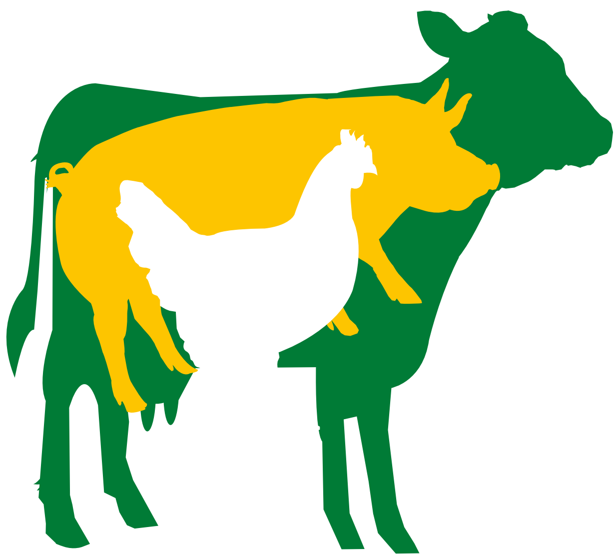
1. Challenges, opportunities, gaps

1.1 Challenges

- To maintain within the production systems a large variety of breeds economically competitive. This includes developing sustainable local breeds.
- To develop methods and strategies to further exploit available genetic variation in livestock and at the same time implement and further develop methods/strategies to maintain farm animal genetic diversity.
- To achieve a wider participation of the stakeholders on the issues of animal genetic resources sustainable use and conservation, including the industry.
- To achieve a better incorporation of AnGR criteria in policies.
- To develop low cost strategies for animal genetic resources inventories, conservation and development.
- To develop and implement strategies for a common management of the genetic variation of worldwide distributed commercial breeds, in order to avoid losses due to the use of too narrow genetic basis.
- To minimize the negative impact of improved selection processes such as genomic selection on the genetic diversity of breeds.
- With EU enlargement, number of farms has more than doubled. In this process new breed diversity has also entered in EU. Across all Europe, still existing diversity is at risk of being exposed to the erosion process that generally accompanies intensification of production systems.

1.2 Key opportunities

- Breed diversity is often thought just as source of genetic variation to ensure future genetic improvement. However, it is also valuable for food product diversification and quality, for maintenance of diversity of natural agro-ecosystems and rural culture and for new roles upraise for domestic animals, including sport, leisure, tourism, companion, hobby.
- Awareness for farm animal genetic resources has been raised in the last two decades within EU.
- Genomic research is making possible to localise and characterise genes and their functions. Breeds with extreme phenotypes are proving to be particularly useful at this respect. Then, breed diversity offers high



opportunities for understanding genome structure and function of farm animals, and development opportunities.

- Breeds with seemingly limited competitive benefit may harbour single genes (e.g. disease resistance) of potential high value with respect to economics and animal welfare, which can be transferred through traditional breeding strategies or transgenic techniques in high efficiency breeds.
- European research leadership in the farm animal genetic resources issue can provide useful expertise for other parts of the world.

1.3 Gap analysis

Basic technology to meet existing challenges and opportunities is already available, but needs further development in particular in the following areas:

- systematic screening of potential unique genetic structures in (endangered) breeds, based on farm animal sequences, high throughput genotyping and comparative genomics;
- reproductive technologies for commercial and conservation (ex situ) purposes;
- strategies for keeping a vital countryside, including the characteristic animal production systems and associated breeds. Strategies should be based on a total economic value of breeds.
- Strategies for minimizing genetic loss (inbreeding) under improved selection processes (e.g. genomic selection).

2. The problem of stasis: what will happen if no research or development occurs

- Loss of farm animal genetic diversity and of opportunities for future development of farm animal populations.
- Loss of opportunities for keeping a vital countryside.

3. Short, medium and long-term needs for research

3.1 Five years horizon

- To develop strategies at the country and European level to halt erosion of farm animal diversity, within and between breeds.
- To develop models and strategies, at the European and global levels, for the management of genetic diversity when breeding is not centralised in order to avoid the risk that a too narrow genetic basis will be used.
- To develop enhanced reproduction, molecular genetic and statistic tools for preserving genetic diversity.
- To increase efficiency and profitability of less intensive or small-scale animal farming, often associated to local endangered breeds.
- To develop strategies to balance improved selection processes (genomic selection) with minimizing the loss of genetic diversity.

3.2 Fifteen years horizon

- To study efficiency of strategies to halt erosion of farm animal genetic resources.
- To understand and experiment the role of animal farming agriculture including the associated local breeds in sustainable rural economies and environments.
- To develop mechanisms in order to have markets recognising the non-market services of farming, including the environmental and cultural roles.
- To implement knowledge on differences in the genetic structures of breeds.
- To develop techniques for the regeneration of individuals from cryoconserved diploid cells in oviparous species

3.3. Twenty-five years horizon

- To develop models using breed diversity to understand genome structure and functions.

Robustness

Robustness comprises many components but in general is the way animal can cope with its environment and potential changes in this environment. Climate change is one of these potential changes and can have large effect on disease challenge, in fodder and water availability, and land degradation. Given the current evolution of the European agriculture and the demand for environmental friendly production systems; adapted breeding for low input and industrial production systems will be needed. Environments will become less "optimised" due to welfare consideration (e.g, extensification, open air, more diverse feedstuff), genetic characteristics need to be adapted in order to avoid decrease in fitness and therefore efficiency. This should be considered also in relation to the climate change, as extensive systems maybe more susceptible to some negative effects of climate change. Shift to selection for increased product quality, healthy and safe products is considered a major challenge in all species from poultry to buffalos. To achieve such goals, all methods to develop adequate multiple trait selection tools in breeding strategies should be encouraged. More automatic on-farm performance recording (e.g., milk ingredients and hygienic status), interaction between recording protocols and modelling of genetic and non-genetic goals are key opportunities and challenges.

Problem of stasis

Experts identified that stasis in the fields of "Health, Welfare, and Performance" (Robustness) will increase the gap between available and needed animals in the future, as well as the gap between technological possibilities and adequate use of them. Impact on the industry and EU citizens will be very substantial. Industry will be unable to adapt and face challenges from competitors and EU citizens will not find the quality of products and production circumstances they aspire to. Given already known and probably generalised negative genetic correlations between production and health traits, lack of research in this area will lead to continued deteriorating functionality of animals and the decrease of animal welfare because of the lack of adaptation to production circumstances.

Short, medium and long-term opportunities and needs for research

5 year time horizon by group of topics:

- Improved performance, environmental impact, health and welfare recording for diverse commercially and socially important traits including:
  - o Sustainable performance recording (e.g., useful information, genetic and non-genetic, going back quickly to farmers stimulating and maintaining interest) linked to genotypic data.
  - o Biological efficiency and environmental sustainability (e.g., waste, diets, greenhouse gases).
  - o Animal health (e. g., recording covering all animals, not only diseased).
  - o Animal welfare (e.g., indication of welfare aspects of traits in breeding programmes, developing and recording of objective (heritable) welfare indicators, welfare being the balance of the various aspects in breeding programme, and appropriate management).
  - o Linking of existing databases, easier data exchange, on a herd-level, regionally, nationally and EU wide together with public-private cooperation in this field.
  - o Obtaining data in environments closer to commercial use in all species and for all traits.
- Improved genetic evaluations for performance, health and welfare traits including:
  - o Development of routine combined genetic evaluation of animals based on phenotypic and genomic information, sustaining research towards genomic selection.
  - o Advanced genetic evaluations using optimally existing data bases on a herd, regional,

national and EU wide level, taking into account genotype-environment interactions.
- o Strengthening research on genetic evaluation methodology, in particular for novel traits as product quality and animal fitness and robustness.
- o Development of EU wide cooperation on common breeding animal comparisons.

- Improved breeding programmes for performance, environmental impact, product quality, health and welfare:
  - o Breeding for improved products and improved production circumstances will affect current breeding programmes.
  - o Importance of health, environmental impact, and welfare traits and reproduction will increase with broadening of breeding objectives.
  - o Social considerations will enter breeding programmes.

15 year time horizon:

- o New ways of getting traits of animals, which are closer to the genes and physiology of the animal - biological / physiological knowledge of the animal will be used to get better phenotypes and breeding programmes.
- o Selection for alternative product quality and animal robustness traits will be widespread.
- o Advanced modelling for new and potentially massive data (e.g., longitudinal data recorded on-farm automatically) will be needed.
- o Integration of GxE interaction in routine genetic evaluations, selecting animals for an environment, not creating proper environments for the animals. This will be especially important in less optimised production systems and for developing countries.
- o Interaction, data exchange, distributed computing and expert-systems will be developed on a herd, regional, national and EU wide level.
- o Major research in development of genetic solutions to diseases, leading to development of generalised immunity. This will be accompanied by investigations of the molecular or polygenic genetic mechanisms specific to individual diseases.
- o Molecular genetics could play a major role including the use of laboratory species (e.g., mouse) to identify disease resistance candidate genes.

25 year time horizon

Developments of technologies have the potential to change radically the direction of animal breeding for performance, health and welfare, most influential should be increased capabilities:

- Monitor biological processes to gain new inside into animals
- Acquire molecular, gene-expression and other novel types of data
- Analyze data and to predict genetic merit and non-genetic management related values

Aquaculture

Aquaculture is an important food sector in the EU, which provides healthy, nutritional products of high quality. It is strategically important for Europe, especially in view of our heavy reliance on imports of seafood. The EU-27 total fisheries capture in 2007 was 31 % less than in 1995, while aquaculture production increased by 10.5 % to 2.142.600 metric tonnes (EuroStat Fishery statistics 2009).

Aquaculture production systems and technology will have to address climate change and contribute to sustainable food security. The EU Commission requested, in communication (SEC(2009) 453 and 454) to the EU parliament and EU Council, an increased focus on aquaculture and to acknowledge the importance of sustainability in this regard. Selective breeding and reproduction are important knowledge areas for further development of the industry in a sustainable and ethical manner, where research is needed for the industry to be able to develop and to meet market demands and need for fish products in Europe.

Challenges and opportunities for breeding in aquaculture

Reducing the environmental impact

- **Feed source:** many aquaculture species are carnivorous but are more and more fed with fat and protein of plant origin to substitute for this from wild fish origin. Selective breeding has the potential to accelerate this development considerably.
- **Production efficiency:** There is significant genetic potential for improvements in production efficiency traits: growth rate, feed efficiency, nutrient retention, processing yield, sexual maturity and survival. Producing more fish with fewer inputs and less waste will reduce the environmental footprint and increase competitiveness of the industry. Greater challenges are arising for these traits as a result of climate change.
- **Escapees:** Escapees from aquaculture stocks continue to pose a major limitation to aquaculture production in open environments, mostly because of the unknown genetic impact of escaped fish from genetically improved strains on wild stocks. Quantification of the impact of escapees on the genetic structure of wild populations is urgently needed. Novel techniques are needed to control puberty and maturation and methods to incorporate these into breeding practices.

Improving fish health and welfare

- **Robustness:** Robustness can be simply defined as the ability of animals or strains to continue to perform under challenging or changing conditions.
  Aquaculture is in close relation to the environment in terms of temperature, oxygen, feed and pathogens. Climate change will emphasize the challenge as rearing environments are becoming more variable and extreme. The technological gap is to define robustness traits, that can be included in breeding schemes, and to develop methods to select for these. Their relation to production traits must be established under different rearing systems.
- **Disease resistance:** Existing and new diseases erode productivity and hence profitability and development of the industry. Prevention and treatment rely on vaccination (where feasible) and use of drugs and chemicals. The latter have a negative impact on the environment and the public image of aquaculture. Animals with better resistance to specific diseases for each species are needed to ensure a healthy and more sustainable industry. Breeding for better resistance to infectious diseases have been implemented in several breeding programs, mainly in salmonids. Further research in other species and pathogens should be encouraged.
- **Product quality:** Aquaculture products represent a large and increasing part of the EU aquatic product consumption Therefore, it is of paramount importance that European aquaculture products sustain the highest quality level for appearance, organoleptic and nutritional value. Important product quality traits are; processing traits, skin and meat colour, texture, fat content and distribution, nutritional profile (especially health promoting fatty acids), ability for conservation, smoking or cooking and flesh flavour and taste.
  The scientific basis for including product quality in breeding programs is scarce.

- **New aquaculture products:** European aquaculture production is dominated by a limited number of species farmed regionally using improved juveniles (salmon, trout, sea bream, sea bass, carp). Initiation of rational domestication and breeding programs is needed for other species for the long term and sustainable development of these productions, with special attention to herbivorous/omnivorous species. For description of state of farming development for each species see www.aquabreeding.eu.

Generic topics

- **Genomics:** Today, there is a growing amount of genomic information available (genetic markers, genetic maps, QTL, transcriptome and genome sequence data, etc), but there are large differences between species. This information should be expanded and methods have to be developed to include them in the breeding programmes.
- **Knowledge transfer:** Very little knowledge on genetics and breeding is being transferred to the aquaculture industry and to developing countries. This is particularly true for marker assisted and genomic selection. It is important to facilitate education of students and industry representatives in the area of breeding and genetics.
- **Crossbreeding and exploitation of heterosis:** Crossbreeding is an accepted methodology for the protection of genetically improved strains, by exploring hybrid vigour. In many aquaculture species, hybridisation between related species is possible, producing sterile or monosex offspring. Thus, more knowledge is needed on the use of crossbreeding for breeding programs and for preventing genetic pollution.
- **Reproduction technologies and sex determination:** Efficient reproduction technologies are important for breeding programmes, as they facilitate directed matings of parents. Cryopreservation can be an essential tool to secure and manage efficient breeding programmes. In parallel, in many fish species, sex determination is a mixture of genetic and environmental factors, leading to unbalanced sex-ratios in aquaculture stocks (e.g. sea bass, sole). Knowledge about such factors is needed for many species (rainbow trout, cod, sea bass, halibut and molluscs) as they have the potential to improve production efficiency and product quality through breeding of mono-sex populations, possibly without the use of hormonal treatments.

Cattle and Buffalo

Key opportunities and challenges - The role of research and development

In most European countries, efforts undertaken in the past using animal breeding technologies have focused on increased output per animal. Recently, breeding programmes have been modified to increasingly focus on profitability and to include functionality and product quality traits. However, Europe's cattle production is increasingly becoming a global market with two aspects: the threat caused by imports of cheaper products from South America (mainly beef) but also the opportunities of emerging countries increasing dairy and beef consumption (Asia). There is a need to improve efficiency of production (rather than productivity) but also the opportunity to export high value genetics to new markets as well as high value animal products (e.g. dairy products). Furthermore, across country genetic evaluations provide increasing access to diverse genetics. Additionally, tools and algorithms are constantly improving to exploit the rapid advances in genomic technologies. Consumer interest in environmental footprint and food safety and quality, including nutritional and organoleptic quality, and improved animal health and welfare, are intensifying. National breeding programmes of the future must readjust to reflect these international trends.

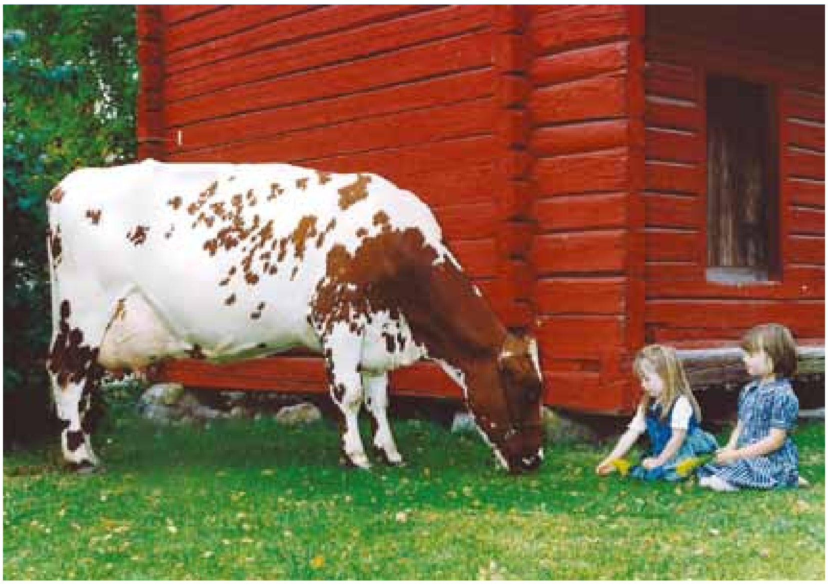
Gaps to be filled

The fields of future research can be divided into three categories: I) trait-orientated research; II) optimal exploitation of developing technologies in cattle; and III) other issues including genetic diversity.

I. In trait-orientated research, one main focus should be the development of cost-effective protocols for the recording of traits especially associated with health, welfare, animal functionality and product quality. This trait orientated research is especially important for the exploitation of genomic selection for these traits.

II. '-omic' technologies are developing rapidly and whole genome sequence (mainly through imputation) available on all animals will soon be the norm. The optimal exploitation of this information in genetic evaluation and breeding programs is currently not known.

III. Simulation studies clearly show that genetic gain is expected to rapidly increase with the application of genomic selection to breeding programs. This may have serious implications for genetic trend of selected population (changes in breeding goals) and genetic diversity both within breed but also across breed. Niche markets helped by localised breeds may vanish as breeds for which accurate genomic predictions are available take over.



The problem of stasis

With stasis firstly, cattle farming in Europe will lose its international competitiveness as other countries develop and exploit new technologies. In some parts of Europe the occupation of land is closely linked to livestock production and in this situation a loss of competitiveness will have a very strong negative societal impact. Secondly, this situation will eventually lead to a drastic increase in imports of livestock products and create longer term dependencies. Thirdly, since animal breeding already is a global business, scenarios in which only very few breeding organizations take over the entire market, as is already the case in poultry breeding, may be envisaged. Finally,

new technologies, be it biotechnology, or molecular approaches, or others, bear the ultimate chance for increased quality of production (cattle and buffalo products), food safety and welfare of animals.

Short, medium and long-term opportunities/ needs for research

5-year horizon

a) Trait-orientated research

- Improvements for the recording of health, functionality, and product quality traits with integration of molecular approaches like metabolomics and proteomics;
- Management of phenotypic and genomic data for best use (i.e., comparative phenomics and genomics across species).

b) Technology

- More research on the optimal implementation of genomic data into genetic evaluations
- Improvements in reproductive technologies like semen sexing and embryo technologies and how they can be exploited in cattle breeding
- Embryonic selection
- Development of tools for managing SNP and sequencing data for individual genomic selection (data transfer, database structure, cloud computing)
- Evaluation of whole genome sequence data as a source of information in dairy and beef cattle breeding programs
- International genomic evaluations
- Implementation of concepts for maintaining genetic diversity including genomic information

c) Other issues

- Economical assessment of new technologies and their associated risks

15-year horizon

a) Trait-orientated research

- Mechanisms of disease resistance
- Physiological traits as alternative indicators; metabolomics

b) Technology

- Genotype x Environment interaction and epigenetics including genomic information

c) Other issues

- Local breeds and specific regions issues

25-year horizon

For this horizon, it may be very difficult to speculate about future research needs, some topics could be:

- Efficient prediction and capturing from gene x gene and gene x environment interactions
- Expert systems for on-farm as well as networked genetic evaluations
- Designer food (milk, beef) from transgenic animals
- Use of stem cell technology for reproduction

Horses

The economic impact of the horse industry in the EU has been estimated at 100 billion euro per year providing 400 000 full time jobs. It plays a leading role internationally. The horse sector is very diverse and horses fulfill a wide range of functions to serve mankind. This has resulted in a diversity of horse breeds and related activities. Importantly, horses have a very positive image towards society.

The diversity of the sector in itself is a challenge and requires efforts to raise standards of education of breeders and owners to the same level within all EU-member states. Knowledge and technology transfer between EU countries should be extended. Traditionally, there is a tight relationship between equine science and horse breeding organisations. This facilitates a quick and efficient adoption of new knowledge into horse breeding programs.

Gap analysis and goal setting

If no research or development occurs in Europe, it is expected that the EU will loose its international leadership in sport horse breeding and competition, will loose breeds and will be confronted with shrinkage of the horse breeding industry, especially in CEE countries. Reduced animal welfare, less contribution of horses to sustainable farming and socio-cultural life and economic losses in breeding industry are to be expected

Research in equines is needed to improve performance (such as gaits, jumping ability, velocity, endurance), functional traits (e.g. longevity, fundamental stability) and to investigate the potential of disease resistance.
Furthermore, research on fertility, behavior (e.g. temperament) and hereditary diseases is needed.
The sector should preserve its positive image by anticipating on signals of negative effects of selection on health and character.

Short, medium and long term opportunities and needs for research

Short term

- Identification and parentage control using new tools integrated in a European identification system;
- Development and use of DNA-tests to select against diseases
- Recording more precise phenotypes using conventional and modern tools;
- Defining reliable breeding objectives focused on performance, behavior and health resistance, evaluated with modern technical and biological data and then implemented genetic analysis;
- Analysis of interactions between genotype and environment and between horse and human;
- Developing statistical models that can handle typical horse data (ranks or competition results);
- Improving information on horse genome;
- Identify genes for the main genetic (hereditary) diseases;
- Strategies to cope with limited size reference population in

genomic selection programs;
- Control of effective population size of the horse breeds;
- Building a horse breed inventory, estimation and management of biodiversity of
- Study sub-fertility of stallions and mares due to their usage as sport horse;
- Knowledge of stallion and mare reproductive physiology;
- Study of environmental factors (pesticides) with effects on fertility and development of tools for diagnosis and therapy of fertility problems;

Long term
- develop tools for selection which combine genomic testing (on multiple loci) and phenotypic data for many traits simultaneously such as performance (gaits, jumping ability), temperament, fertility, growth development;
- Identify of genes which play a role in the main genetic (hereditary) diseases;
- Develop early and reliable predictors for longevity;
- Develop basic knowledge in the main biological functions to decipher muscle, skeleton and nerve development and physiology;
- Develop bioinformatics pipelines to answer scientific questions and implement traceability;
- Study genetic aspects of quality of horse milk and meat;
- Develop breeding systems including new traits: biomechanics, performance, temperament, growth and fertility ability, and the effects of training, welfare and horse judging systems;
- Study genetic variation of horse behavior and implement knowledge in breeding;
- Improve reproduction efficiency (animal and breeders' welfare), predict fertility of stallions per ejaculate (frozen or chilled);
- Improve efficiency of oocyte freezing techniques;
- Investigate factors during gestation and neonatally to minimize bone disorders and neonatal diseases;
- Identify genes for fertility traits;
- Improve knowledge and understanding of technologies for semen sexing and cloning.

Honeybees, fur- and companion animals

The species dogs, fur animals, honeybees, and rabbits - were chosen for their organized breeding and/or extensive European economic revenues. An additional report was produced for each species that contains further details.

Key challenges and opportunities and problem of stasis

Europe is leading within fur animal, honeybee, and rabbit research, breeding and production, and plays globally an important role in breeding of dogs for police/army/customs. Despite the leading role for each of the four species, it is a challenge to increase or even maintain the present European production and market share. The already insufficient numbers of high quality working dogs is expected to increase further resulting in high prices and lower quality. Stasis will give others the opportunity to further develop their professional breeding programs, making import of the genetically better dogs from Europe redundant. In fur animals and rabbits, stasis will give other countries, such as China, the opportunity to increase the market share at the expense of Europe. This threatens the European production characterized by high quality and safety of animal products and high animal welfare. In honeybees, there are very large losses due to diseases. A serious consequence is the loss of pollination of agricultural crops and wild flora. Unintended crossing of imported breeds to indigenous honeybee races results in a loss of biodiversity and more aggressive hybrid colonies. Furthermore, the indigenous races constitute an important export product to countries outside Europe.

Gap analysis

Research is required in order to maintain Europe's leading role. This can be divided into two main areas: 1) study of traits and the techniques required to do so, and 2) development of efficient breeding schemes. Table 1 shows gaps in knowledge and technology in the species. Specification is made with respect to overall gaps or gaps in some countries/breeds.

Table 1. Gaps in technology and knowledge in dogs, fur animals, honeybees, and rabbits

	Species							
	Dogs		Fur animals		Honeybees		Rabbits	
	A	B	A	B	A	B	A	B
Technology								
Application of DNA technology	X		X		X		X	
Genetic evaluation	X			X		X		X
Artificial insemination		X		X		X		
Cryoconservation		X	X		X		X	
In vitro cultivation of somatic cells					X			
Knowledge								
Education of breeders	X		X			X		
Reproductionbiology, Embryo Mortality, fertility		X	X				X	
Genotype.xEnvironment Interaction	X		X		X		X	
Selection criteria	X			X		X	X	
Epigenetics			X		X		X	
Genetic parameters	X			X		X	X	
Efficient breeding programs	X			X		X	X	
Transparency about new technologies to the public	X		X		X		X	

An x indicates a gap in that field. *A = gap in general; B= gap in some countries/breeds;

Needs for research

5 years:

- **Practical issues:** dogs: improve the recording system and set up organized breeding programs; honeybees, rabbits: develop techniques for cryo-conservation of semen and improve reproductive technologies
- **Genomics:** fur animals: construct a genome map and sequence the genome; rabbits: improve the assembly and annotation of the rabbit genome; dogs, fur animals, honeybees, rabbits: SNP analysis and genomic selection
- **"-Omics":** dogs, fur animals, honeybees, rabbits: develop "–omics" tools
- **Health:** dogs, fur animals, honeybees, rabbits: investigate the genetic background of health related problems and develop selection strategies to improve resistance to the most important parasites and improve disease resistance; rabbits: improve quality of available vaccines using recombinant marker technologies ;
- **Epigenetics:** dogs, honeybees: study of epigenetic contribution to the variability of production and disease traits, behavior and mortality
- **Performance:** dogs: develop objective measures of behavior; dogs, fur animals, honeybees, rabbits: estimation of breeding values for new traits
- **Biodiversity:** honeybees: conservation of genetic diversity, develop techniques for maintaining pure races; fur animals: cryo-conserve semen (alopex-types), live populations (mink)
- **Ethics:** fur animals: public transparency of the production; dogs: investigate ethical aspects of breed specific traits
- **Education of breeders for all species:** Show the importance of recording systems and agreement on the breeding goals

15 years:

- **Technologies:** honeybees: develop technologies for in vitro cultivation of somatic cells for functional genetics in breeding for resistance; rabbits: in vitro cell technology and cryo-banking of embryos and female gametes
- **"-Omics":** dogs, fur animals, honeybees, rabbits: use oftranscriptomics, proteomics and phenomics (e.g. metabolomics, etc.) approaches and other technologies to understand the biology of the traits to understand the consequences of selection
- **Epigenetics:** fur animals, rabbits: study of epigenetic contribution to the variability of production and disease traits, behavior and mortality; dogs, honeybees: application of the results of the research on epigenetics
- **Health:** honeybees: develop selection strategies to improve resistance for parasites; rabbits: investigate the genetic components for resistance to important diseases; dogs, fur animals: investigate the genetic background of health related problems
- **Ethics:** honeybees: investigate the risk of use of genetically modified honeybees; dogs: investigate ethical aspects of use of dogs for new tasks
- **Education of breeders:** dogs: prioritization of selection criteria and genetic evaluation

25 years:

- **Genomics:** fur animals: genomic studies of biology of reproduction, sexual maturity and moulting; rabbits: develop tools for managing genomic information
- **Performance:** dogs, honeybees, fur animals, rabbits: selection for adaptation to changing climatic conditions; honeybees: breeding honeybees for pollination in greenhouses

Pigs

1. Context - opportunities and challenges

Pork is the most widely consumed meat in the world and will steadily increase over the next decades, mainly in developing countries, while meat consumption in Europe and North America will tend to slowly decrease. All elements of the pig carcass are valued in some form, creating a very wide range of products. Traders value uniformity within and between individual sales packages of a specific product. In most cases, European pork chains will necessarily trade on a worldwide basis to create maximum value of the individual elements of the pig carcass. Within Europe or any other production region the pig should adapt as good as possible to the local environment in terms of climate, housing system, health and availability of nutrients.
European pig breeding organisations are SMEs. A trend is visible of concentration, with currently about 10 global players and a significant number of smaller local breeders. A limited number of purebred animals of specialised sire and dam lines in nucleus herds are the basis for cross-breeding for the production level. Yet, the available genetic variation is still immense with each breeding organisations owning several purebred lines, each of them with (mostly) 50+ effectively unrelated animals. The breeding goals have evolved from highly heritable traits such as growth, feed efficiency and carcass composition to sustainability related traits such as litter size, piglet vitality, sow longevity and meat quality. Breeding has become more and more technology intensive, with an increasing use of computer and information technologies for real-time treatment of large amounts of information.
Research in genetics and breeding has been revolutionized by the eruption of molecular technologies. Sequencing of the porcine genome was virtually finished in 2010, allowing to move forward to genomic selection. Finally, increasing research efforts have been devoted to the characterisation and an improved management of genetic diversity.
Research on reproduction has also been very active, with significant progress on fresh and frozen semen technologies, the development of embryo freezing and somatic cell cloning.
Breeding objectives will further evolve, with the need for animals that are robust, are easy to manage in less constrained housing systems, with as few interventions (treatments, assistance) as possible, and have a good adaptability, i.e. remain productive and healthy in a wide range of production environments. Pig feed is now more in competition with human food, therefore more focus should be put on suboptimal diets made of by products, like DDG's.

Need for research to remain competitive (problem of stasis)

The knowledge-intensive animal breeding sector increasingly depends on new technologies / improvements of existing technologies directly stemming from research that require more and more investments as well as skilled people with a strong scientific background to understand and make an efficient use of new technologies. If no research or development occurs in Europe, only very few globally acting breeding organisations will survive and the SME in pig breeding will disappear and as a consequence diversity of breeds/genotypes suited to various environments and local market needs will be lost. The challenge is to stimulate cooperation across fields without loosing efficiency in the own SME's.

3. Short, medium and long-term opportunities/needs for research

Targets on a 5 year horizon:

1 Definition of the production environment, what is allowed and needed

- Thorough definition of welfare indicators.
- Ban of boar castration in all European countries, declaration of Brussels
- Insight in environment sensitivity traits and genotype x environment interactions;

2 Technology

- Availability of a high quality annotated genome sequence of the pig, of high density SNP panels, whole genome linkage disequilibrium maps and full genome expression arrays;
- Use of marker assisted selection based on linkage disequilibrium, genotype assisted selection and genomic selection in pig breeding; use of markers for the maintenance of genetic variability;

3 Traits

- Cooperation between feed experts and breeding experts -> use of by-products, gut health
- Cooperation between human medicine, veterinarians and geneticists; one world, one health
- Improved knowledge on the genetic variability of immune competence / disease resistance;
- Genetic evaluation for sow longevity, piglet survival/mothering ability; studies on sow reserve mobilization;

Targets on a 15 year horizon:

- Fully annotated genome of the pig including a catalogue of all functional elements;
- Identification of large numbers of causative polymorphisms; identification and modelling of gene x gene and gene x environment interactions ;
- Extensive use of genomic information at the different levels of the breeding pyramid to exploit additive and non additive genetic variation, with resistance to disease, robustness and behaviour as major target traits
- Exploitation of gene x environment interactions (e.g. by variation of the feed) for producing varying product qualities or producing under varying environmental conditions with one genotype of animals;
- Use of genomic tools (e.g. herd sanitary status evaluation) and complex models to optimise herd management;
- Large scale development of semen sexing;
- Development of models for the co-evolution of hosts and pathogens.
- Increased use of pigs as a model in human medicine (e.g. polyfactorial diseases, tumor therapy).

Targets on a 25 year horizon:

- Identification of complex regulatory networks and epigenomic mechanisms at the whole-genome level;
- A near complete catalogue of diagnostics for currently known inherited diseases;
- Progress towards modelling the likely impact of new mutations;
- Utilisation of complete genome sequence from all breeding animals;
- Full understanding of the implementation, impact and consequences of genetic modification;
- Development of a genetic identity card for each animal.

Poultry

The major part of the poultry industry is at a significantly more mature stage than those of other species both in terms of production systems and specific knowledge in respect of breeding. In part this is a result of basic research carried out in Europe over the last 40 years which also explains a significant concentration of the world commercial poultry breeders in Europe. These companies and industries are significant wealth creators and must be supported to maintain their European bases. There will be significant spin-off for minor breeds and other species from fundamental work carried out on chickens. For these reasons the approach and needs of the poultry sector may be viewed differently from the other species.

Species Groups

Several distinct species of poultry are farmed in Europe and whilst there are several synergies in research there are also a number of species specific issues. This sector is driven by the chicken about which there is most existing data and which is massively more important in economic terms than any of the other species. For clarification the groups are as follows: Broiler chickens, Layer chickens, Turkeys, Waterfowl: Ducks (Pekin ducks, Muscovy ducks, Mule ducks) and Geese, Other poultry: Guinea fowl and Quail, Game birds: Pheasants, Partridge and Wild Ducks. Currently there are reference sequences for the whole genomes of chicken and turkey, genome analyses for duck and quail are under development. Extensive knowledge on the genome variation (in particular SNPs) in chicken populations is/will be available and the same techniques can be applied to these other species. Similarly developments in high throughput genotyping have enabled this information to be translated into practical genotyping tools, at first at low density and recently at high density to the whole genome. Again the genotyping, mathematical and computational tools need to be applied to these other species.

A: Issues

In addition to controlling animal disease and maintaining welfare, the environmental impact and sustainability of poultry systems will be the major issues in poultry, with an increasing focus on genetic solutions which must be identified and understood. At the same time economic efficiency of production systems must be maintained.

1.1. Animal disease: in addition to traditional diseases there are re-emerging diseases as a consequence for example of the ban on the use of antibiotic growth promoters and limitations of current vaccines. A better understanding of the relationship between host and its microbiota and its contribution to gut health is required.

1.2. Animal welfare and behaviour: Within the EU improvements in Animal welfare remain high priorities: beak trimming; skeleton and leg strength of broilers and turkeys, food restriction especially of broiler breeders; broodiness in turkeys; research in order not to kill animals of one sex at birth such as male roosters of laying strains and female mule ducks

1.3. Food quality and safety: this is a critical issue and the basis for retaining animal production within the EU. It involves both mandatory food quality (laboratory inspection) and the market quality (consumers, retailers, etc). Novel ingredients (co-products) that enter the food chain will need to ensure that they meet these requirements.

1.4. Sustainable production: focus on management of genetic variability and genetic diversity, use of local resources (strains, raw materials) within the context of food security, economic viability (market costs and prices structure acceptability)

1.5. Environmental Impact: the environmental impact and recourse use associated with poultry systems will require a fundamental review and would solutions to reduce these. Consistent and holistic methodologies that assess these impacts are required.

B: Research priorities

1. Scientific research for application in poultry breeding programs:

- Use of genomics tools including next generation sequencing in breeding programs
  - o Improvements in access to cost-effective high throughput genome sequencing and high performance parallel computing will increase our knowledge of the genome variation (SNPs, CNV and other structural variants) in chicken populations; this new knowledge will underpin high throughput tools for cost-effective genotyping 1000's of animals for 1,000-1,000,000 SNPs; genotypes based on whole genomes will be exploited in both genome wide association analysis (GWAS) of the contribution of specific genes controlling specific traits and the development of genome wide selection (GWS) strategies of traits;
- Development of methods to increase bird robustness
- Development of methods to increase general disease resistance
- Development of breeding methods to improve animal welfare (this includes definition of appropriate phenotypes related to animal welfare)
- Development of breeding methods to improve metabolic and digestive efficiencies

2. Impact of genetics on sustainability of poultry production and food security:

- Assessment of environmental impact and resource use
- Raw materials and novel ingredient usage
- Biodiversity
- Tuning of balanced breeding objectives

3. Development of new knowledge and tools:

- Advanced methods to predict phenotypes from genotypes
  - o Advanced genomics tools will require the development of new computational and statistical methods.
  - o Advances in systems biology.
- Reproductive biotechnologies including transgenics
- Novel phenotyping methods
  - o Phenotyping methods and data acquisition in new production systems (electronic ID of animals) are important in itself but will also be the major opportunity in all future GWAS and GWS strategies.
- Holistic tools to assess environmental impact of poultry systems including life cycle analysis
  - o A major challenge will be to predict the impact of genetic selection strategies, this will include new methods in Life cycle assessment (LCA) to provide a holistic view of impacts on the livestock, the environment, the climate, social and economic impacts, in addition the impacts of these on the genetic potential of livestock.

Sheep and Goats

Sheep and goats are among the most extensively farmed livestock species in Europe that often utilise marginal areas which are not suitable for other forms of agricultural production providing the main source of income for these rural populations. The worrying decline in sheep numbers in the EU in recent years has had knock-on effects for the supporting infrastructure of the industry such as availability of sheep shearers, livestock hauliers and regional abattoirs. This decline impacts upon the social structure and industry in the remote and harshest land areas of the EU. Failure to address the decline in livestock numbers will increase Europe's dependency on imports of meat and milk products from third countries.

Sheep and goats are generally less efficient than other livestock species in the production of meat and milk because of their small size, low reproductive rate and lower yields. With declining subsidies, and in order to stay competitive, sheep and goat producers have sought to create special markets for quality products and to increase their efficiency of production. However, this approach as a means to increase profitability of sheep and goat enterprises is not having the expected impact, hence focussing on improving the efficiency of production is critical for a sustainable industry. In the absence of research and development and given decreasing subsidies, if the efficiency of production is not improved these industries will quickly lose out on price and quality to the competition to imports from third countries or to alternative domestic species, thereby furthering the existing decline in the demand for lamb meat.

Problems, knowledge gaps and opportunities

Many questions exist for small ruminants essentially due to the high cost of technologies in relation to the value of the animal.
There is a lack of good recording systems along the chain which feed back to the producer. If this would be set up, e.g. product quality could be improved. Also the better collection of phenotypes will take advantage of opportunities to tackle major diseases through quantitative and molecular breeding. Knowledge of genetic properties of disease and their correlations with production traits, either should prevent any deterioration from happening, or may control health problems if they are incorporated into sustainable sheep and goat breeding programmes. Increased economic and biological efficiency is crucial in most production systems to decrease the costs of production to ensure the future viability of small ruminant production in situations of declining or static consumption for their produce.
Direct and indirect measures of emissions are required to generate knowledge of the impact of sheep and goat production to the environment but also for the impact of a changing environment to the production. Quantifying the impact of having a diverse population of sheep and goats is needed to establish a common system of evaluation that includes both market and non-market ('public good') benefits of keeping small or declining populations of genetically distinct sheep and goat breeds.

Problem of the status quo

In the absence of research and development in the sheep and goat sectors in Europe and given decreasing subsidies, and if productive efficiency is not improved, these industries will quickly lose out to the competition (imports and domestic alternatives) on price and quality. Sheep and goats will be disproportionately affected by regulations aimed at limiting green house gas emissions. Loss of significant parts of the sheep and goat industries will lead to neglect of traditional landscapes and loss of income for the rural population in less-favoured areas, whilst biodiversity will suffer as a result of survival of only a few highly selected breeds. European consumers will depend on imports, which may not necessarily correspond to their requirements and may not be sustainable. Foreign research will only address these issues to a limited extent.

Short and long-term opportunities and needs for research

Short term horizon
High priority
- Research on new traits contri
- Improve fertility (AI efficiency, a-seasonal breeding) and prolificacy while maintaining functional abilities

Medium priority
- Research on routine measures and genetic components of meat and milk quality for human nutrition
- Finish sheep & goat genome sequencing and improve gene annotation
- Develop and improve tools (genetics, sustainable management) to cope with internal parasites
- Increase collaborative approach of new molecular technology use
- Implementation of more efficient traceability and disease monitoring systems, using EID and DNA technologies
- How to overcome biological and environmental trade-offs (antagonistic breeding goals, environmental benefits and breeding goals, others)

Low priority
- Development of methods and tools for conservation of rare breeds and genetic variability
- Development of databases on animal diseases and link with selection programs and gene discovery research

Long term horizon
High priority
- Genetic solutions to diseases
- Favour European sheep and goat production in order to limit importations and sustain our farming systems
- Genotype x Environment Interaction, including production and functional traits

Medium priority
- Research in reproductive and embryo technology
- Development of sheep and goat products adapted to specific human genomes

Low priority
- Methods to improve quality of wool or create shedding or hair sheep
- Adapt or mitigate sheep and goats and systems to changing climates. Develop strategy so that breeds keep pace with global warming
- Development of specific drugs targeted to different sheep and goat genotypes
- Official animal identification through molecular information

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