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SHORT, MEDIUM AND LONG-TERM OPPORTUNITIES AND NEEDS FOR RESEARCH FOR SUSTAINABLE FARM ANIMAL BREEDING AND REPRODUCTION TECHNOLOGY IN EU

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Invitation paper

SUMMARY

The European landscape is characterised by a range of diverse farming systems. These relate not only to varied geographical environments, but also to different social and cultural environments for farming and food production. This diversity is unique to Europe and underlines the importance of European agriculture. Animal breeding is a knowledge intensive sector, and for the future competitiveness of animal breeding and animal production, high level European research is indispensable. The preparation of Strategic Research Agenda were in a full process: opportunities and problems, gaps, short, medium and long term opportunities and needs for research. Each country experts from different group have opportunity to help define his country dimension of animal breeding in its regional and country context, and also in relation to European and global developments. The Farm Animal Breeding and Reproduction European Technology Platform, brings together a wide range of interested parties to produce a vision of how livestock breeding might develop in the next 20 years, and constitutes the first step in achieving that vision.

Key-words: research, animal, breeding, reproduction, priorities

INTRODUCTION

Animal Breeding aims at exploiting in a sustainable manner genetic variation within and between breeds in genetic improvement programmes to enhance competitive and sustainability of EU animal food production. Estimation of breeding values plays a central role in most improvement programmes. These procedures need to be improved to capitalise on the increased understanding of the underlying genetic mechanisms on one hand and the increased range of characteristics on the other. Reproduction techniques have an important influence on the optimal design of improvement and dissemination programmes that yield the desired genetic improvement while restricting the degree of inbreeding. Animal improvement programmes should focus on safe exploitation of genetic variation between animals to:

- produce better-quality, healthy, affordable, diverse food products offering consumers in and beyond Europe real options for improving their quality of life;
- . promote a more sustainable agriculture and aquaculture, including emphasis on non-food functions of animals such as pleasure, leisure, or use in the medical area;
- enhance the competitiveness of European agriculture and aquaculture and its organisations;
- build the basis for implementing high-quality and sustainable breeding strategies in developing countries.

Challenges lie in the development of a cost-effective application of the technologies for use by farmers and breeding organizations. The role of the European research community will be leading the way in this process by providing the tools, knowledge, and skills needed by the animal breeding sector to make effective use of these new technologies.

Notice: the present paper is abbreviation of FABRE TP **Strategic Research Agenda Sustainable Farm Animal Breeding and Reproduction Technology Platform (Annex I to SRA 1 Version 22 March 2007)**

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This will involve basic research, largely connected with other research activities in the field of life sciences, as well as applied research. The importance of applied research originates from two sources: Firstly, from the need of validation and verification of results from basic research in the field, and secondly, from the need to developing methodologies which can be applied in the field of livestock breeding on a routine basis.

THE PROBLEM OF STASIS

If no research or development occurs in the fields mentioned above, the impact will be severe in a number of fields. Firstly, livestock farming in Europe will loose its competitiveness compared to other regions in the world where advantages due to low costs of production already exist. In some parts of Europe, especially in Slovenia, 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. Given that it is desirable to have multiple genotypes of animals, suited to various environments and product demands. It is highly questionable whether a few breeding organizations would be willing to supply these genotypes or to take care of long-term goals like maintaining biodiversity. A future scenario as described above may only be dealt with using public funds to increase research activities which will be to the benefit of many regions and conditions within the European states. Finally, new technologies, be it biotechnology, or molecular approaches, or others, bear the ultimate chance for increased quality of production (especially from ruminants), food safety and welfare of animals. This opportunity should not be overlooked.
The fields of future research can be divided into three categories:

i) trait-orientated research;
ii) the development and evaluation of new technologies; and
iii) other issues including biodiversity and economic analyses.

In trait-orientated research, one of main focuses should be the development of cost-effective schemes for the recording of traits associated with health, animal function and product quality on large numbers of cattle. This trait-orientated research is especially important as the major breakthrough of molecular approaches like genomic selection has yet to occur and will rely heavily on accurate phenotypes to be matched with genomic information. Cost effective trait measurement can also facilitate the incorporation of a broader range of traits in cattle breeding schemes using existing technologies.
With respect to molecular genetic technologies, there is a need for better integration into breeding programmes. The focus needs to move from a focus on single QTL approaches to take the genome as an entity including all interactions between genes as well as the interactions of genes with the environment. This is important in cattle breeding due to their limited female reproductive capacity and thus an industry structure in which commercial animals are an integral part of breeding schemes. The commercial cattle even in the future will be managed and housed in a variety of environments. Reproductive technologies could have substantially beneficial impacts for the production process itself and also for meeting the large variability of demands of the consumers across Europe related to culture and alimentary habits and traditions. At present, little is known of the limits of cloning technology as further developments have to deal with the complex field of epigenetics.
Decisions on the application of new technologies to produce more rapid gains must consider the economic impact on all sectors and the impact on longer term gains. It is imperative that research on these aspects accompany all technology developments.

PROBLEMS AND OPPORTUNITIES

The ***key opportunities*** underlying our action are the world wide recognition of the European strength in the field population and quantitative genetics, the availability of a wide range of genetic resources of high value, the high quality of the breeding organisation, including reproduction biotechnology centres and performance recording networks. Europe is, therefore, well positioned to rapidly transfer developments in science to a more profitable and sustainable agriculture and aquaculture.

The ***key challenges*** concern both is increasing our understanding of factors contributing to genetic variation and the development of schemes that make optimal use of genetic variation while restricting the degree of inbreeding, especially in some breeds.

- The very fast progresses coming from animal genomics, with the short term availability of high density SNP filters, offer new fascinating opportunities for the genetic dissection of traits (QTL and gene detection through linkage disequilibrium and direct associations) as well as the selection programmes of animal (genome wide EBV and selection). Useable software tools need to be developed and made available.
- There is a need to develop novel methodologies for evaluation of the effects of on-going breeding-schemes and for design of new schemes that incorporate developments in fields like biotechnology (e.g. reproduction techniques and embryo genotyping), animal genomics (QTL information), and informatics (tracking and tracing) to improve efficient and to respond to demands from society (increased emphasis on quality of animal products and on animal welfare). There is a need to predict the consequences of developments in these areas on the (creation of) genetic progress and its dissemination from the top of the breeding pyramid to the production level.
- Improvement in the genetic analysis are needed to build on developments in field of statistics and of computer algorithms in order to deal with increasing complexity of (phenotypic) information due to multiple traits being measured in multiple environments and traits being measured on different types of animals (purebred and crossbreds). Incorporating traits such as disease resistance, longevity, and robustness requires novel methods (e.g. Markov chain Monte Carlo) to solve the complexity due to the large number of parameters relative to the amount of data, and due to the correlation of parameters. There is a need to explore other computational and numerical methods that have been successful applied outside animal breeding.
- Given the strong negative impact of inbreeding on reproductive and health traits, we need to find breeding schemes that generate genetic progress while maintaining appropriate genetic diversity (restricting inbreeding rate). Improved methods are needed for the design of breeding programmes, which involve predicting the consequences of alternative schemes on the phenotypic performance of a population and on the level of genetic diversity. Secondly, improved tools are needed to implement these concepts in selection procedures that aim at generating genetic progress while restricting the rate of inbreeding.
- In many species, selection for the most important economic traits has led to a reduction of fitness traits. Increased understanding of the biological background of antagonistic relationships between fitness traits and production traits is expected to enable the formulation of breeding strategies that achieve a balanced gain in multiple traits, i.e. prevent a reduction of fitness traits.
- The traits included in the breeding objectives of livestock species is expected to increase in response to consumer and social requirements and due to the introduction of new traits. Their underlying genetic variability must be evaluated, using classical approaches or new statistical techniques when they display specific distributions. This includes development of methodology that incorporates the social interactions in groups of animals associated with behavioural repertoires that are important for animal welfare and for proper functioning of the group.
- The environmental sensitivity (also referred to as phenotypic plasticity) of genotypes constrains the variability of phenotypic expression which depends on nutritional, climatic, infectious, and social environment. Increasing our understanding of environmental sensitivity is essential to take into account the dynamics of the environment in which future breeding animals will have to produce. Research should focus on defining, through population biology, which will be the most efficient genotypes for predictable environments
- Recording of phenotypes of animals will remain vital for breeding programmes. Given the high cost of phenotyping animals, research is needed to better define the most efficient method and design to record phenotypes. This research will be important not only to improve the application of research findings, but also to conduct appropriate research in the definition of the role of genes, especially in the product quality and welfare traits. This research requires strong interaction with scientists in other disciplines such as electronic animal identification and nanotechnology.
- The application of crossbreeding has to pass from the simple estimation of level of heterosis created by crossing two breeds to the level of heterosis created by crossing two individual animals.

- Disease transmission is a crucial population-level issue which involves two players: the host and pathogen. These two players interact through infection (pathogen to host) and immunity (host to pathogen), and the pathways involved in both processes are under genetic control. Future research must focus on increasing our understanding of how variation in a population affects the overall performance of groups of animals and how changes in biodiversity are likely to influence the control of infectious disease.

The fields of future research can be divided into these categories:

i) trait-orientated research and food quality and safety research area;

ii) the development and evaluation of new technologies, with connection on welfare, disease resistance and sustainable breeding and selection

iii) animal breeding and genetics, reproduction, biodiversity, interaction on genotype-environment, socio-economic analyses.

In trait-orientated research, one of main focuses should be the development of cost-effective schemes for the recording of traits associated with health, animal function and product quality on large numbers of cattle. This trait-orientated research is especially important as the major breakthrough of molecular approaches like genomic selection has yet to occur and will rely heavily on accurate phenotypes to be matched with genomic information. Cost effective trait measurement can also facilitate the incorporation of a broader range of traits in cattle breeding schemes using existing technologies.

With respect to molecular genetic technologies, there is a need for better integration into breeding programmes. The focus needs to move from a focus on single QTL approaches to take the genome as an entity including all interactions between genes as well as the interactions of genes with the environment. This is important in cattle breeding due to their limited female reproductive capacity and thus an industry structure in which commercial animals are an integral part of breeding schemes. The commercial cattle even in the future will be managed and housed in a variety of environments. Reproductive technologies could have substantially beneficial impacts for the production process itself and also for meeting the large variability of demands of the consumers across Europe related to culture and alimentary habits and traditions. At present, little is known of the limits of cloning technology as further developments have to deal with the complex field of epigenetics.

Decisions on the application of new technologies to produce more rapid gains must consider the economic impact on all sectors and the impact on longer term gains. It is imperative that research on these aspects accompany all technology developments.

SHORT, MEDIUM AND LONG-TERM OPPORTUNITIES/NEEDS FOR RESEARCH

Future necessity in animal breeding and reproduction research

✓ continuously better integrated European research (Network of Excellence on biosystems, epigenetics and genetics/genomics, ERANET in reproduction and breeding),

✓ the need for data gathering internationally comparable data collection systems health, sustainability and production,

✓ transfer of knowledge between large and small institutes/organisations/countries (Marie Curie programme, technology transfer network), and

✓ socio-economic projects (e.g. how cloning would work out for the several animal species), we have identified, from the 13 expert group 2 page reports as

5-year horizon

a) Trait-orientated research

- Improvements for the recording of health and functional traits (in nucleus herds, contract herds, in the field); with integration into molecular approaches like metabolomics
- New and better traits for beef and milk quality
- Recording of welfare and health traits, docility (human x animal interaction)
- Reduced cost of data (trait and identification) recording at farm level

b) Technology

- Full integration of estimation procedures with molecular approaches including SNP data
- Improvements in reproductive technologies like semen sexing and cloning, and reproduction tools such as oestrus detection or synchronisation (substitutes of hormones)
- IT-solutions for integrated data-bases from farm to central/distributed computing

c) Other issues
- Improvements of concepts for maintaining genetic diversity
- 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
- International genetic evaluations using genomic information
- Genotype x Environment interaction including massive genomic information
- Further research on cloning

c) Other issues
- Implementation of concepts for maintaining genetic diversity including genomic information
- 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, meat) from transgenic animals
- Embryonic selection; use of stem cell technology for reproduction

SHORT, MEDIUM AND LONG-TERM OPPORTUNITIES AND NEEDS FOR RESEARCH (IN SHEEP AND GOATS)

5 year time horizon, in order of priority

1. Research into the definition, understanding and estimation of genetic components (both quantitative and molecular) of new traits contributing to sustainable production, especially those related to global warming and other environmental aspects, animal health and welfare at low labour input (lambing ease, lamb survival, disease resistance). The cattle genome can serve as a basis in many aspects, but specific small ruminant work will still be required. There is a need to validate genetic markers developed elsewhere in European breeds and environments. (Europe – Specific -but certain traits and genome is similar to cattle).
2. Research and development of more cost-efficient animal recording and selection technology, including DNA collection and (in collaboration with other species) software that integrates molecular information in existing evaluations (Marker Assisted BLUP). Global – general [simple and cheap DNA technology is useful to everyone, and may be even more so in developed countries]
3. Development of new tools and optimise existing tools to manage sheep and goats cope better with internal parasites, this should include host-genetics and sustainable management tools. Global – Specific.
4. Research to develop objective measures of milk and meat quality for routine use in breeding stock and having relevance to eating quality and human nutrition, including their genetic components. Developed countries – General.
5. Research into the improvement of fertility of sheep and goats, especially efficiency of AI, a-seasonal breeding and opportunities for females to deliver and rear larger litters. Developed Countries - Specific.
6. Government and industry databases on for example animal diseases need to be developed and linked to selection programmes and gene discovery research. Global – General.
7. Development of decision support tools for conservation of rare breeds, methods of *in situ* and *ex situ* conservation and genetic variation within a selection programme. This should be based on a better understanding of functional biodiversity Global – General.
8. The effect of scrapie on human health (if any) needs to be established. Europe – Specific.

15 year time horizon

- Sequencing of the sheep and goat genome Global – Specific.

- Major research in development of genetic solutions to diseases, leading to development of generalised immunity Global – General.
- Development of breeds or lines that perform well in specific lamb exporting countries (e.g. tropical) but adhere to all requirements of European consumers. Developed – Specific [this is European breeders exporting breeding stock, while European market declines]
- Adapt sheep and goat to changing climates as a result of global warming. Develop a strategy so that breed development keeps pace with global warming. Global – General
- Research in reproductive and embryo technologies to increase efficiency of breeding programmes. Developed - General
- Effective methods to either improve quality of wool or create shedding or hair sheep as part of a selection programme for milk or meat. Developed - Specific

25 year time horizon

- Development of sheep and goat products adapted to specific human genomes. Developed - Specific

Sheep and goat breeders tend to be more traditional and operate on a much smaller scale than breeding companies in other species as a result they would find it difficult to develop and apply scientific results for their own enterprise. It is therefore important that breeder representatives participate in research at an early stage and implementation will be an essential part of most projects.

SOME PROPOSALS FOR A STRATEGIC RESEARCH AGENDA IN PIGS

Targets on a 5 year horizon:

- 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;
- Identification of an increased number of causative polymorphisms;
- Use of LD-MAS and of GAS in pig breeding;
- Genetic evaluation for sow longevity and piglet survival / mothering ability;
- Ban of boar castration in some countries; implementation of programmes for fine mapping of QTL associated with components of boar taint in commercial populations; studies on the detrimental effects of selection for low fat androstenone levels on reproductive efficiency;
- Insight in environment sensitivity traits and genotype x environment interactions;
- Improved pork quality by utilizing new knowledge on underlying genetic mechanisms
- Development of automatic recording systems
- Improved knowledge on the genetic variability of immune competence / disease resistance;
- Thorough definition of welfare indicators

Targets on a 15 year horizon:

- Generalized use of MAS / GAS;
- Identification of large numbers of causative polymorphisms and investigations on their interactions with environment;
- Identification and modelling of complex gene interactions;
- 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 complex models to optimise herd management;
- Large scale development of semen sexing
- Development of models for the co-evolution of hosts and pathogens

Targets on a 25 year horizon:

- *Exploiting absolute or near absolute barriers to disease such that key pathogen species might be eradicated from farmed populations*
- *Improved definitions of animal welfare and wellbeing such that rational information can contribute to ethical debates, such as the desirability or otherwise of changing animal behaviour or sentience via selection*
- *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*

DRAFT R&D PRIORITIES FOR POULTRY IN EUROPE

Introduction

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's 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:
Layer chickens
Broiler chickens and Turkeys
Waterfowl: Ducks (Peking ducks, Muscovy ducks, Mule ducks) and Geese
Other poultry: Guinea fowl and Quail
Game birds: Pheasants, Partridge and Wild Ducks
Grouping is based on economic relevance and current knowledge. Chickens are split into layers and broilers, due to differences in breeding practices. Whereas broilers and turkeys have much in common as far as breeding practices, in terms of genomic tools available, they can't match and turkeys are thus closer to the other poultry. One underlying issue for all other species will be to either improve the usability of the tools developed in chicken or develop specific ones.

DRAFT R & D PRIORITIES FOR HORSES IN EUROPE

Introduction

Problems- Key opportunities – Issues: Horses are becoming more popular in the **growing industry** of sports and leisure, and 'hobby' farming whereas racing industry is still flourishing. Furthermore, horses are used in therapy or tourism, and there are niche markets for horse milk for people having allergies and for meat in only few member states. There are no major ethical objections against horse breeding. In some (west) European countries **maintaining rural landscape is taken over by horses**. As herbivores equine compete with ruminants as well as with plant production for natural resources and territories. Different demands of the public on horse breeding cause **the development of a diversity of horses which fit the needs of many groups of people** who potentially would like to work with or enjoy horses. **Insufficient standards of education of breeders and owners** requests to be urgently improved to meet the same standards as in other farm animals industry. **Knowledge and technology transfer between EU countries should be extended** as well throughout a European network for Equines.

Challenges, Knowledge gaps and opportunities

- Performance, Health and Welfare: Breed athletes and leisure horses requires to define traits and breeding goals especially with regard to performance (gaits, jumping, velocity and endurance), health and behavioural (temperament) traits as well as to determine the interaction between genotype and environment (husbandry systems, riding systems and nutrition)

- Phenomics: phenotypes have to be more accurately recorded. This requires objective systems for judging and breeding as well as the development of traits to improve performance, disease resistance and behaviour of the horses
- Genomics: The Improved annotation of the horse genome sequence and new functional genomic information and associations with traits under selection will contribute to the identification of genes associated with performance, health, behaviour and other functional traits (national/European/ Global)
- Breeding and Selection: The development of statistical evaluation methods should be continued to improve performance, health, welfare, behaviour and functional traits by genetic selection. A further step will be the development of well defined breeding schemes that can also include molecular information
- Biodiversity: the diversity of and within breeds, region and states should be maintained or/and managed either in small endangered populations or large populations where inbreeding is increasing
- Reproduction: Improvement of payable and safe application of reproductive technologies such as AI, ET or sexing may help to solve fertility problems. This requires more reliable indicators of fertility as well as maternal and foetal well being during pregnancy and per partum
- The technologies for long term freezing of semen and embryos need to be improved and will also play a central role in strategies to preserve biodiversity
- Technology and knowledge transfer: the renew of breeding industry and research in CEE states is requested at regional and national level. The Improvement of education of users, breeders and extension officers and the cooperation between scientists and horse users should be organised in most of the European countries and definitely coordinated at European level.

For equines the following opportunities/needs for research are foreseen in the short- medium and long term to improve **performance** (such as gaits, jumping ability, velocity, endurance), **functional traits** (e.g. longevity, fundamental stability), disease resistance (e.g. Equine influenza, Rhinopneumonia), fertility, behaviour (e.g. temperament), and a to reduce hereditary diseases (such as OCD, myopathy, roaring).

Research needs for the 5 year horizon:

Breeding and genomics

- Identification and parentage control
- Record more precise phenotypes
- Define reliable objective traits
- Analysis of genotype-environment (nutrition-husbandry systems-health) interactions
- Improve information on horse genome (improved genome assembly, full-length cDNAs, annotation)
- Create or adapt linkage and association methodologies to the horse
- Create, develop and maintain public genome databases
- Identify genes for the main genetic (hereditary) diseases,
- Identify underlying biological mechanisms and genes of disease resistance
- Estimation and management of biodiversity of equines
- Genetic analysis of behavioural traits and welfare
- Estimate welfare through genetics and physiological data

Reproduction

- Improvement of chilled transported sperm (use for larger number of stallions) and of frozen sperm
- Better knowledge of stallion physiology (sperm production, nutrition and environmental factors, aetiology and inheritance of some reproductive disorders, techniques allowing sub-fertile stallions to be bred with more efficiency)
- Better knowledge of mare physiology (oestrus detection, ovulation time, pregnancy, foetal and neonatal losses, nutrition and environmental factors)
- Tools for diagnosis and therapy of fertility problems.

Research needs for the 15 year horizon

Breeding and genomics

- Identification of genes, which are responsible for differences in performance (gaits, jumping ability)

- Identify genes for the main genetic (hereditary) diseases
- Development of early and reliable predictors for longevity
- Development of basic knowledge in the main biological functions
- Decipher muscle, skeleton and nerve development and physiology
- Identify bottlenecks in metabolic pathways
- EU production and use of equine microarrays
- Develop proteomic methodologies
- Develop bioinformatic pipelines to answer scientific questions and Implement traceability
- Genetic analysis of quality of horse milk and meat
- Effect of training, welfare of training, biomechanics, evaluation of horse judging systems
- Genetics of biomechanics, development of breeding systems *including new traits*

Reproduction

- Fertility prediction of a stallion per ejaculate (frozen or chilled) as soon as correlations between in vitro sperm parameters and fertility will be understood
- Improvement of efficiency of oocyte freezing techniques
- Increase of research in pregnancy and neonatal period
- Identify genes for fertility traits
- Improvement of reproduction efficiency (animal and breeders' welfare!)
- Improved knowledge and understanding of technologies for semen sexing and cloning

25 year horizon

- Produce horses devoid of genetic diseases
- Include molecular information in horse selection
- Genetic monitoring of horse breeding at the stud and breed levels
- Integration of epigenomics in equine genetics.