Deliverable 1.3 Results of survey of technological advancements in the field

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Changes with respect to the DoA (Description of Action)

This first version of the deliverable is in line with the DoA. This deliverable will be updated as sub-groups of the think-tanks for workpackages 4,5 and 6 discuss specific technological advancements in the animal agriculture.

Table of Content

1. Summary of results

The survey for Deliverable 1.3, designed by EFFAB and UEDIN, aimed to identify technological advancements in animal agriculture. The survey saw good participation, highlighting the relevance of the subject matter within the animal breeding and academic research sectors. The responses provided valuable insights into the current state and future direction of scientific and technological developments in the animal agriculture field. Task 1.2, a critical component of Work Package 1 (WP1), involves establishing the scientific leadership of the EuroFAANG infrastructure and formation of the wider EuroFAANG consortium for the next stage of infrastructure. This task is important for developing the EuroFAANG Research Infrastructure concept as it involves identifying scientific partners and stakeholders with the necessary expertise, capabilities and facilities that are currently missing from the consortium. The completion of the survey for Deliverable 1.3 has helped to identify new potential partners to integrate within the EuroFAANG infrastructure project as it moves into the next preparatory phase. The survey covered scientific and technological developments in the field (including for example gene editing, advanced digital technology for phenotype recording, machine learning for phenotype prediction, robotics to test many thousands of potentially causal genetic variants at scale using in vitro systems). Survey participants were also asked to identify other international and national initiatives in animal agriculture, including those that are novel and beyond the state of the art. The results of the survey identified at least seven areas in which we could expand the EuroFAANG RI consortia in order to incorporate new technological advances. Looking ahead, we propose to engage the subgroups of the EuroFAANG think-tanks for WP4, 5 and 6 by sending strategic questions about new technologies in each space (genome editing, new genomic and phenotyping technologies and in vitro systems). Their expertise and insights will be very valuable in identifying promising areas for future research and investment, capabilities and provision of access. Furthermore, we plan to continuously update this deliverable based on these discussions and the rapidly evolving landscape of scientific and technological developments in animal agriculture. This iterative approach, coupled with the high level of interest shown by the survey participants, demonstrates the dedication of partners within the EuroFAANG RI project consortium to advancing the field of farmed animal science.

2. Introduction

The EU Horizon Europe research program funds the EuroFAANG Research Infrastructure (RI) project under the *HORIZON-INFRA-2022-DEV-01* funding stream. This call focuses on developing, consolidating and optimising the European research infrastructure landscape and maintaining global leadership, ultimately creating a world-leading, coherent, agile and attractive RI landscape in Europe. The EuroFAANG RI project will look at how to develop the concept for implementing and building an infrastructure for farmed animal genotype to phenotype research in Europe. Research infrastructures provide access to facilities, resources and services used by the research communities, and other stakeholders, to conduct research and foster innovation in their fields. They include major scientific equipment (or sets of instruments), knowledge-based resources such as collections, archives and scientific data, e-infrastructures, such as data and computing systems and communication networks and any other tools essential to achieve excellence in research and innovation.

The EuroFAANG RI aims to streamline interdisciplinary capabilities for Genotype-to-Phenotype research in terrestrial and aquatic farmed animals and provide transnational access to all the relevant facilities, expertise and knowledge to European stakeholders. This will address the need to bring together national facilities at the pan-European level in animal genetic resources, phenotyping and breeding, and animal health, which was identified as a gap in the infrastructure landscape by the 2021 ESFRI Roadmap. The proposal builds on the foundation of the six H2020 EuroFAANG projects, AQUA-FAANG, BovReg, GENE-SWitCH, GEroNIMO, HoloRuminant and RUMIGEN. It connects with existing infrastructures for data management and animal agriculture in the European research infrastructure landscape.

Within this framework, a specific work package (WP) will oversee the coordination of concept development for the EuroFAANG infrastructure. This WP has three main objectives:

- Forming a consortium and establishing the scientific leadership of the infrastructure by consolidating the roles of current partners and identifying new partners and areas of expertise.
- Providing a comprehensive business plan for the logistics required to establish the EuroFAANG infrastructure, including legal entities, cost breakdown, and securing political and financial support.
- Ensuring that the objectives outlined in this proposal are met, including ensuring conformity with the work plan in meeting and delivering overall progress, milestones, deliverables, and planned resources.

Work Package 1 (WP1) is the overarching framework within which all tasks and deliverables are organised. Its success is contingent upon the successful execution of its constituent tasks and the timely delivery of their corresponding deliverables.

Task 1.2, led by UEDIN with contributions from EFFAB and FBN, is a critical component of WP1. It involves establishing the scientific leadership of the EuroFAANG infrastructure and forming the consortium. This task is pivotal as it involves identifying scientific partners and stakeholders with the necessary expertise and facilities that are currently missing from the consortium. These additional partners will be invited to join the consortium at the next stage to strengthen the infrastructure and the overall EuroFAANG strategy.

The success of Task 1.2 is closely tied to Deliverable 1.3, which is the result of a survey of technological advancements in the field of animal agriculture. EFFAB and UEDIN will undertake this survey to identify new potential partners to integrate within the EuroFAANG operating infrastructure. This survey will cover scientific and technological developments in the field and other international and national initiatives in animal agriculture, including those beyond the state of the art.

In summary, the successful execution of Task 1.2 and the completion of Deliverable 1.3 are integral to the success of WP1. They ensure the formation of a robust consortium and the integration of the latest technological advancements, thereby strengthening the EuroFAANG infrastructure and strategy.

3. Core Report

4. Methodology

Survey Design

The survey for Deliverable 1.3 was designed by EFFAB and UEDIN to identify technological advancements in the field. The goal was to identify potential partners to integrate with the EuroFAANG operating infrastructure. The content included in the survey covered scientific and technological developments in the field, as well as other international and national initiatives in animal agriculture, including those beyond the state of the art. The survey design can be found in Annex 1.

Distribution

The survey was distributed to EuroFAANG partners and participants in the think-tanks for WP5 genome editing, and WP4 in vitro systems. The details of participants in the WP5 think-tank can be found in D5.5, and included academic researchers, animal breeders, social scientists and other experts in animal breeding and production. These recipients were asked to further share the survey with their colleagues, expanding the survey's reach. Out of 110 emails sent, we received 42 responses. This represents a response rate of approximately 38%.

Respondent Demographics

The respondents were a diverse group of scientists and animal breeders with varying years of experience and backgrounds. The majority of respondents had >20 years experience in animal agriculture (Figure 1). They were located across a wide range of geographic regions of Europe and beyond (Figure 2). This methodology provides a clear and concise overview of how the survey was conducted and the respondents' demographics in the context of the results obtained from the survey.

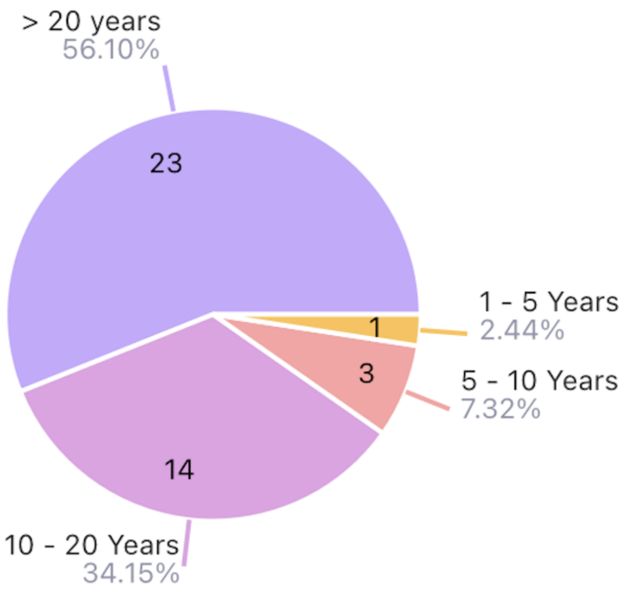

Figure 1 Years of Experience in animal agriculture

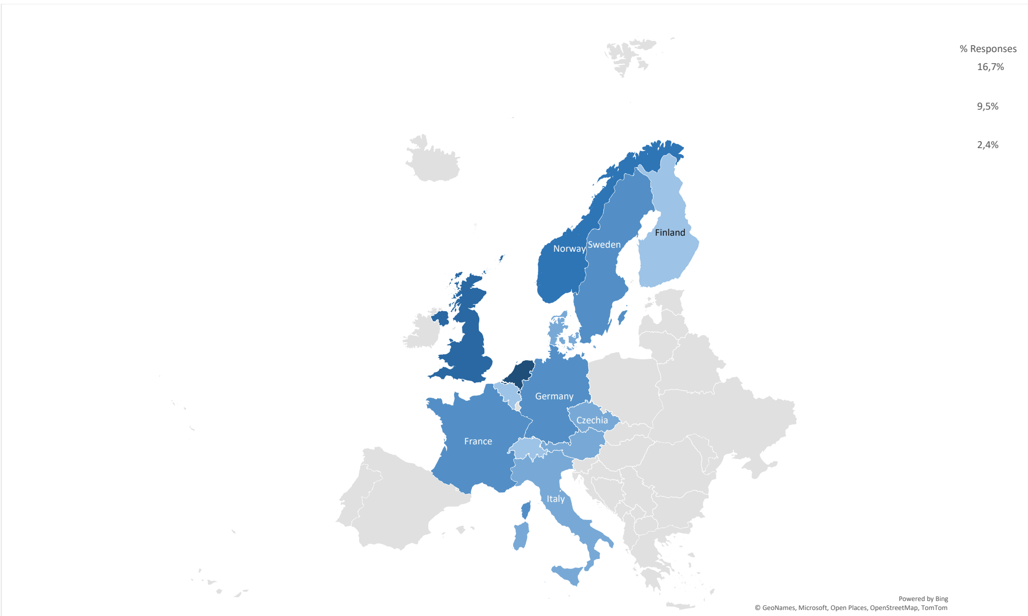

Figure 2 Geographical spread of survey respondents

5. Results

Overview of survey responses

In the field of animal agriculture, specifically farmed animal science and animal breeding, there have been several scientific and technological advancements that are particularly promising and impactful. In the following section we initially give an overview of the responses to the survey, then describe the responses to specific questions in detail, and finally provide some insight into how the results of this deliverable will influence consortium formation for the next phase of the EuroFAANG RI project.

The following technological advancements in animal agriculture were provided by the survey respondents:

- **Genomic selection** and **gene editing**, particularly with the CRISPR/Cas system, are frequently mentioned as impactful advancements with the potential to advance breeding goals . These technologies have revolutionized animal science research and breeding, and their impact is expected to increase in the future.
- The **implementation of genomics information into poultry breeding** and the development of balanced meat poultry breeding were specifically mentioned as promising. This includes overcoming the antagonism of traits through the development and implementation of new traits across a wide range of areas (welfare, robustness, environmental impact, reproduction, production) in a diversity of pedigree lines.
- Some respondents mention the realization of **leucosa type J and A free chicken via gene editing** and realization through transgenesis via Primordial Germ Cells (PGCs) transplantation into sterile cockerel acceptors.
- The use of **AI and computer science**, such as machine learning for complex trait prediction and digital phenotyping, is highlighted by some respondents.
- The potential of **biobanking for the conservation of genetic diversity and risk mitigation**. Though from a genetic diversity perspective, some respondents found that the potential positive impact of new technologies did not materialize. Quite the opposite - the decrease in diversity has continued despite the availability of techniques that could be used to avoid it.
- **Genome enabled management** with whole genome sequencing on all animals **(individualised genomes)**, or initially only high value animals, within a breeding population will provide information on which to base breeding decisions once prices are low enough to have whole breeding populations included.
- **In vitro systems**, such as enteroids and organoids, and **stem cell technologies** were mentioned as promising for research and breeding.
- Increasing **resistance to diseases** (like PRRS in pigs) in populations of farmed animals through **immunogenetics/genomics**, genomic selection and genome editing was mentioned as being important in application of the technology.
- A few respondents also mentioned the importance of **community-based breeding programs (CBBP)** and **precision livestock farming** technologies for constant phenotype collection.

- Routine **phenotype recording** will be essential for future sustainable farmed animal production and new phenotyping technologies, including **digital twins** will provide considerable impact.
- Some respondents highlighted the potential of **using functional genomic technologies for animal breeding**, such as epigenetic profiling, single-cell analyses, and other new next-generation sequencing technologies.

Responses to specific questions are described in the following sections:

New technologies for Genome Editing

In response to question 4.3, which aimed to identify the most promising new technologies for genome editing in farmed animals, participants highlighted a range of innovative approaches. These responses highlight the rapid advancements in the field and the potential for these technologies to revolutionise animal agriculture.

- **CRISPR/Cas9 and its applications** (e.g.,high throughput phenotyping CRISPR screens and multiplex editing) are frequently mentioned as promising technologies. These tools are seen as important for discovering and investigating potential alleles driving traits that are relevant for breeding (e.g., for disease resistance).
- **Single step multiplex editing.** A few respondents mentioned the importance of next-generation Cas9 systems and the potential of multiplex editing to introduce multiple mutations in a single step. This will be particularly important for polygenic traits.
- **Novel in vitro systems**, such as organoids and organ-on-a-chip, are also mentioned several times by respondents. These new cellular systems reduce the use of animals in research and allow researchers to functionally analyze specific phenotypes at the organ level in vitro using genome editing of potential causal functional variants.
- **Basic genetic surveillance techniques,** including low pass whole-genome sequencing and routine genotyping to understand the full genetic background of farmed animal species, to identify targets for genome editing was suggested as important by some respondents.
- A few respondents expressed a technology-neutral stance, in relation to genome editing, stating that their interest lies in the resulting genetic change, regardless of the technology used.
- A number of respondents either did not know, were unsure, or did not see clear scientific interest in the application of genome editing in the short term.

Question 4.4, addressed the most promising applications of genome editing in farmed animals. These responses of the participants in the survey reflect the broad potential of genome editing technologies to be transformative for animal breeding, management and production.

- **Disease resistance:** Many respondents see genome editing as a promising tool for enhancing disease resistance in farmed animals. This could potentially reduce the impact of detrimental diseases on the animal breeding industry.
- **Environmental sustainability:** Some respondents highlighted the potential of genome editing to improve environmental sustainability. This includes traits such as reduced methane emissions and improved protein digestibility.
- **Animal health and welfare:** Genome editing is seen as a promising tool for improving animal health and welfare. This could include editing for traits that cannot be

improved efficiently through current genomic selection and other breeding practices such as disease resistance.

- **Surrogate host/sire technology:** Some respondents mention the potential of surrogate host technology to preserve endangered species and small local populations or to safeguard breeding lines where disease outbreaks have been detrimental to the industry.
- **G2P research:** Genome editing is seen as a promising tool for G2P (genotype to phenotype) research. Lab-based research using functional genomics will be used to validate and discover G2P links, including causal variants in functionally enriched genomics regions and then genome editing will provide a route to application for this data.
- **Climate change adaptation:** Genome editing is seen as promising for the animals' tolerance to climate change.
- **Enhanced human nutritional quality**: Some respondents see genome editing as a tool for editing for enhanced human nutritional quality.
- **Sterility (in aquaculture):** Genome editing is seen as a promising tool for editing for sterility in aquaculture.
- **Introgression of novel phenotypes by genome editing:** Some respondents mention the potential of genome editing for the introgression of novel phenotypes caused by single loci into a population. For example, genome editing provides the potential to introduce a trait into a breeding population that would otherwise be missing e.g. adding the polledness trait to a breeding population of sheep in which the horned phenotype is dominant.

New Technologies in In-vitro systems

Question 5.3 explored the most promising new technologies in in vitro systems in farmed animals, and survey participants identified several cutting-edge techniques. These responses highlight the exciting advancements in in vitro technologies and their potential to significantly impact the field of animal breeding and production.

- **Organ-on-a-chip:** This technology is seen as promising by several respondents as it allows for the analysis of intricate complexities of host-pathogen interactions and can reduce animal use by allowing studies in vitro prior to in vivo research.
- **Enteroids:** These are seen as promising for phenotyping feed efficiency and disease resistance. They can be combined with gene editing for gene discovery.
- **High-throughput phenotyping using CRISPR screens in cellular systems:** This technology was seen as promising by several respondents and was often mentioned in combination with the need for more cell lines and organoid systems.
- **Co-cultures, 3D cell cultures, and organoids:** These are seen as promising technologies for in vitro systems in farmed animals for understanding fundamental biology and linking cell-tissue and whole animal scale knowledge.
- **Pluripotent stem cells (iPSCs)** combined with organ-on-chip and Primordial germ cells (PGCs) were seen as promising for the conservation of genetic diversity.
- **Sample collection on farm, with no need for cryo-preservation:** This was seen as a promising technology that could be helpful to improve biobanking.

Question 5.4 asked survey respondents about the most promising applications of in vitro systems in farmed animals. These responses highlight the broad scope of in vitro technologies and their potential as tools for genotype to phenotype research in farmed animals.

- **Testing gene editing targets and functional validation:** Many respondents see in vitro systems as promising for testing gene editing targets and for functional validation. This in vitro testing will be essential for genome editing technology can be applied commercially in farmed animal breeding programmes. It is also a key route to application of functional genomics information and for G2P research.
- **Understanding fundamental biology:** Some respondents highlighted the potential of in vitro systems to understand fundamental biology, including the biological background of traits difficult to improve with ‘ordinary’ selection based on BLUP-values and understanding the molecular mechanisms driving multigene effects in breeding programmes.
- **Bio-banking and conserving genetic diversity:** In vitro systems are seen as promising for bio-banking and conserving genetic diversity. This includes the bio-banking of primordial germ cells or iPSCs for the conservation of genetic diversity and to preserve breeding lines without the associated maintenance cost of keeping live birds.

- **Testing genetic combinations and screening of chemical compounds for pharmaceutical effects:** In vitro systems are seen as promising for testing genetic combinations and screening of chemical compounds for pharmaceutical effects.
- **Understanding disease resistance:** Some respondents see in vitro systems as promising for understanding disease resistance (e.g. through disease challenge experiments and validation of potentially causative functional variants identified by high-throughput CRISPR screens).

New Genomic and Phenotyping Technologies

Question 6.3 focused on the most promising new and advanced genomic and phenotyping technologies for farmed animal breeding and research, including machine learning, robotics, and individualised genomes. Participants identified a range of technologies, reflecting the transformative potential of these advancements in the field of animal farming.

- **Machine Learning/AI:** Many respondents see machine learning and AI as promising technologies for phenotype prediction and for predicting relationships between genotype and phenotype in farmed animals. This includes the use of AI for processing and interpreting data from connected sensors and imaging solutions.
- **Individualised Genomes:** Some respondents highlight the potential of individualised genomes in farmed animal breeding and research. This includes the incorporation of whole genome sequence data in genomic selection and the cataloguing of structural variants. It also includes genome enabled management where in the future high-value or focal animals in breeding populations would have their genome sequenced and decisions about their management would be based at least partially on this information.
- **Digital phenotyping for behavioural traits:** Some respondents mention the potential of digital phenotyping, including image-based phenotypes and in-cage phenotyping in aquaculture. Image analysis and sensors in combination with machine learning can facilitate phenotyping of behavioural traits.
- **Robotics:** Robotics was seen as a promising technology by some respondents for collecting phenotypes at scale. This includes the combination of robotics and sensor technology. It could also include the use of robotic technologies to perform high-throughput CRISPR screens to identify causative functional variants for complex traits at scale. High throughput phenotyping using in vitro systems and CRISPR screens is currently being explored in D5.1.
- **Sensors:** The use of sensors, including wearable sensors and GPS, bolus, and data recording chips on farmed animals, was seen as promising for real-time phenotyping of farmed animals. The use of equipment to collect important new traits like feed intake and methane emissions data was also mentioned.
- **Database of Sequences to Consequences:** Some respondents see the potential of a database of sequences, including variations and the impact on functionalities, for predicting the impact of a functional mutation or set of mutations on phenotype.
- **Deep Phenotyping:** Deep phenotyping, as much as possible automated, is seen as promising by some respondents.

Question 6.4 focused on the most promising applications of the new genomic and phenotyping technologies for farmed animal breeding and research outlined in Question

6.3. Participants in the survey identified a range of applications, reflecting on the transformative potential of these technologies in the field of animal farming.

- **Improving Sustainability:** Many respondents see the application of new genomic and phenotyping technologies as promising for improving sustainability in farmed animal production. This included improvements and new technologies for recording of phenotypes that are difficult or expensive to measure on a large scale, but relevant to sustainability, such as feed intake and methane emission.
- **Increasing the Accuracy of Genomic Selection:** Several respondents highlighted the potential of understanding more about the genome using functional genomics, and whole genome sequencing at the population scale, to increase the accuracy of genomic selection. This includes the identification of low frequency, high-impact variants in livestock populations to pre-emptively remove disease allele carriers or to fix naturally occurring, beneficial alleles.
- **Better Breeding Decisions:** Some respondents mention the potential of new technologies to lead to better breeding decisions. This includes providing new knowledge to inform the choice of selection traits and estimation of potential progress.
- **Improved Animal Welfare and Health:** Some respondents see new technologies as promising for improving animal welfare and health. This includes individualised care to improve welfare and less invasive phenotyping for disease resistance, as well as the potential to use AI/machine learning to predict welfare parameters in breeding populations.
- **Data Capture from Commercial Farms:** The ability to capture data from commercial farms, including collecting phenotypes, was seen as a promising application of new digital technologies such as sensors by many applicants.

Challenges in Adoption of Advanced Technologies

Question 7.1 sought participants' opinions on the key challenges or obstacles facing adopting advanced technologies in animal agriculture. The responses to this question shed light on the various hurdles that need to be overcome to fully realize the potential of these technologies in the field.

- **Legislation and Regulations:** Many respondents highlighted the need for appropriate legislation and regulations to be in place for the adoption of advanced technologies like gene editing and other advanced reproductive technologies in animals.
- **Public and Social Acceptance:** The acceptance of society with the practices for animal breeding and genetics (ABG) and consumer awareness of both genome editing and also more generally how animal breeding currently work and how animals are produced were seen as key challenges. This includes the perception of populations and consumers, and the influence of misinformation from the media and protest groups.
- **Communication:** Some respondents mentioned the challenge of scientists not communicating enough about the technologies being used, which leaves for misinterpretations. Interdisciplinary communication and knowledge will be even more important in the years to come.
- **Financial Aspects and Costs:** The financial aspects of implementation and the costs of using new technologies for precision livestock farming (PLF) are seen as significant challenges. Many technologies are still being refined and require more capital investment in order to see them reach a state for effective use.
- **Sustainable Breeding:** Some respondents highlight the importance of sustainable breeding and taking the right decisions. This includes the challenge of carbon footprint reduction, which is mostly feed (and feed is also costly). With more precise feeding, we can move even faster - but is that in line with animal welfare and even more important: with the development of nutrients in the feed?
- **IT Resources and Data Sharing:** The availability of IT resources and the sharing of data in a usable format are seen as key challenges. This includes the ownership of data and the willingness of companies to agree on sharing data.
- **Lack of Knowledge, Infrastructure, and Money:** On a global perspective, the lack of knowledge, infrastructure, and money is seen as a key challenge. On a biological level, conflicts between breeding goals are mentioned as a challenge.
- **Development Costs and Competence at the User Level:** The development costs and competence at the user level are seen as key challenges to uptake of new and advanced technologies. This includes tailoring new technology to different farming systems, from small labour-intensive to large high-tech farms.

Ethical Considerations in advanced technologies in farmed animal science/breeding

Question 7.2 asked participants to reflect on the ethical considerations that should be considered when implementing advanced technologies in animal agriculture. The responses to this question indicate that the ethical landscape surrounding the use of these technologies is complex, and many points will be quite specific to each technology being discussed.

- **Animal Welfare:** Many respondents highlight the need for animal welfare to have high priority when implementing advanced technologies in animal agriculture. This includes the goal to increase the welfare of farmed animals and to avoid breeding goals that increase animal suffering for productive gain.
- **Food Safety:** The fact that food safety should not be compromised by using advanced technologies is mentioned by some respondents.
- **Good Biosecurity:** Good biosecurity is seen as an important ethical consideration.
- **Benefit Distribution:** Some respondents question for whom the benefit of these technologies is. Is it for the private company, for the animal, or for society?
- **Disease Resistance:** Making an animal resistant to one disease may allow other diseases to expand and become dominant in a system.
- **Public Engagement:** Advocacy and awareness creation to educate end users, as well as open communication, are seen as important ethical considerations. In parallel to this effort, some respondents felt we will need to engage with the public to discuss improvements that are being made to continue to produce food but in a more humane fashion.
- **Consumer Acceptance:** Consumer acceptance was seen as a key ethical consideration by some respondents.
- **Active Intervention in the Genome:** Some respondents mention the need to consider the ethical considerations related to active intervention in the design of the genome.
- **Understanding and Justification:** A full understanding of each new technology is required before uptake, according to some respondents. This includes a lack of promotion and the justification of proven potential benefits over any risks.
- **Environmental Impact:** The environmental impact generated by advanced technologies was seen as an important ethical consideration.
- **Distribution of Resources:** Some respondents mention the distribution of resources as an ethical consideration. Particularly, where should the money for research and development go in order to increase our contribution to the fulfilment of UN’s Sustainable Development Goals (SDGs)?
- **Data Sharing and Reuse:** Data sharing and reuse was seen as an ethical consideration by some respondents. Currently, much of the data generated by research projects is not easily reusable or usable by all stakeholders.
- **Tech Implementation:** Tech should be implemented for a greater good, not to fulfil the ambitions of the developers/researchers, according to some respondents.

- **Monopoly Between Companies:** The concurrence and monopoly between companies is seen as an ethical consideration by some respondents.
- **Conserving and Increasing Biodiversity:** Conserving and increasing biodiversity is seen as an important ethical consideration. This includes responding to regulatory and ethical concerns regarding the use of genome editing (GE) for conservation purposes (e.g, surrogate hosts).
- **Robotization of Animals:** Where we become so good in predicting and steering animals, that they become "things" rather than living animals, was an issue of adopting the above technologies according to some respondents.

The future of advanced technologies in farmed animal science/breeding

Question 8.1 asked participants to envision the future of farmed animal science and animal breeding in terms of scientific and technological advancements over the next 5-10 years. The responses to this question provided a glimpse into the potential future of the field, highlighting the optimism and anticipation surrounding the evolution of these technologies.

- **Animal Welfare:** Many respondents see a future where there is more interest for techniques that will improve animal welfare and that are accepted by society.
- **Biotechnologies:** The potential of biotechnologies is seen as huge, particularly for the impact in the global south.
- **High Tech and Big Data:** Some respondents predict a future where high tech and big data play a significant role in farmed animal science and animal breeding.
- **Greater Use of Genomics:** Greater use of genomics is seen as a key future direction. This includes the improvement of genomic selection through weighted consideration of markers with known causal effects from functional genomics data.
- **Sensor Data and Machine Learning:** More sensor data and advanced technology in phenotyping combined with machine learning are seen as significant future trends. This includes the wider adoption of high-throughput phenotyping and individual animal biometric sensors.
- **Increased Production Efficiency and Disease Resistance:** There will be continued focus on disease resistance and increased production efficiency as climate poses more pressure on animal production.
- **Genome-enabled management:** where genome sequence information for high-value animals is used to make management and husbandry decisions.
- **Increased Use of Artificial Intelligence for Phenotyping:** Particularly for measuring welfare traits based on photographic information and also infra-red spectra for milk measurements. These technologies will also lead to more precise phenotype recording.
- **Digital Twins:** Where animals have a digital counterpart that can be manipulated using simulations and management decisions based on these simulations.
- **Better Prediction of Breeding Values through Integrated Data Analysis:** Better prediction of breeding values by combining AI, novel in vitro and in vivo phenotyping technologies, and genomic knowledge is seen as a key future direction.
- **Application of Genomic Tools to Minor and Emerging Species:** The application of genomic tools to minor species (other than cattle, pig, chicken, turkey, salmon) is seen as a significant future trend. These species include shrimp and other marine invertebrates and insects such as black soldier fly and honey bees.
- **More Focus on Precision Breeding**: More focus on precision breeding is seen as a key future direction. This is defined as utilizing cutting-edge technology and data-driven methods to enable plant and animal breeders to develop crop varieties and farmed

animals that are better adapted to changing environmental conditions and more resilient in the face of diseases and other challenges.

- **Gene Editing:** Gene editing will be applied in farmed animals to mitigate disease, health and welfare challenges, although its use in Europe may be hampered because of consumers' attitudes against gene editing.

Further insights on scientific and technological development in farmed animal science

Question 9.1 provided participants with an opportunity to share any additional comments or insights related to scientific and technological developments in animal agriculture. The responses to this question offer a wealth of perspectives, highlighting the complexity and dynamic nature of this field.

- **Communication:** Some respondents believe that there needs to be more frequent communication on livestock technological developments both across the scientific community and to stakeholders.
- **Advocacy for Livestock Science and Research:** Some respondents advocate for the need to advance livestock science and research. This includes reducing inadequate welfare pressures and demands by supermarket chains to increase the prices of animal products to increase their margins.
- **Market Considerations:** Some respondents mention that the questionnaire is essentially technology-driven and that there is a complete lack of questions regarding the market, the processors, the animal, the societal demands, and the international competitiveness between actual breeding companies and future competitors from countries with large developing economies such as China or Brazil.
- **Integration with Farm System and Food System Studies:** Animal science needs to integrate much more with farm system and food system studies, according to some respondents.
- **Role of Food Producers:** The role of food producers is indispensable and the role of animal source foods needs to be highlighted more clearly, according to some respondents.
- **Multidisciplinary Approach and Collaboration:** Some respondents stress the need to stimulate the multidisciplinary approach and collaboration among specialists (holistic approach) and to use innovative communication methods for improving the trust of society and consumers in the animal production sector.

Focus areas of investment in farmed animal research

Question 8.2 asked participants to identify specific areas within farmed animal research that they believe should receive more attention and investment soon. The responses to this question highlight the areas of research that are considered critical for the advancement of the field.

- **Animal Welfare:** Many respondents believe that more attention and investment should be directed towards improving animal welfare. This includes the need for more sustainable breeding programs based on adaptability and animal welfare.
- **Conservation and Genetic Exploration:** Some respondents highlight the need for more focus on conservation and genetic exploration of candidate genes for productivity and resilience.
- **Phenotype Collection:** More effective collection of phenotypes from commercial farms is seen as a key area deserving more attention and investment.
- **Cell and Molecular Biology:** Some respondents see the need for more cell and molecular biology work to identify molecular phenotypes that could be used to improve animal production systems or to optimize metabolic systems.
- **Resource Efficiency:** Resource efficiency is seen as a key area deserving more attention and investment.
- **Disease Resistance:** A better resistance to diseases is seen as a key area deserving more attention and investment.
- **Climate Adaptation:** Some respondents highlight the need for more focus on animals' ability to handle disturbances that become more frequent and more severe with climate changes, such as heat stress.
- **Data Infrastructure:** Data infrastructure, sustainable breeding, conservation of local breeds, G2P research, and genome editing are seen as key areas deserving more attention and investment.
- **Health Data:** Some respondents believe that health data need more attention and a good collaboration for data and sharing data.
- **Non-Invasive In Vivo Phenotyping:** Some respondents see the need to encourage non-invasive in vivo phenotyping using sensors and video.
- **Minor/Emerging Species:** (other than cattle, pig, chicken, turkey, salmon), adaptation of breeding programs to new environments (large farms, automation, climatic change, ecological efficiency), management of genetic variability are seen as key areas deserving more attention and investment for emerging farmed animal species such as marine invertebrates and insects.
- **Value of Sensors:** Maximising the value of sensors, in terms of improved management, is seen as a key area deserving more attention and investment.
- **Immunogenetics/genomics:** Immunogenetics, linking immunology and genomics is seen as a key area deserving more attention and investment.
- **Large Scale Automated Phenotyping:** Detailed large scale automated phenotyping (both in vivo with e.g. sensor technology and in developing specific in vitro systems) is seen as a key area deserving more attention and investment.
- **Sustainability of Animal Production:** Sustainability of animal production is seen as a key area deserving more attention and investment.

Expertise that will be important to include in the next phase of the EuroFAANG RI project based on the results of the survey

The technological advancements, identified by the survey currently missing or underrepresented in the EuroFAANG RI project consortium are listed in Table 1. During the EuroFAANG RI concept development project we will explore new and existing links to incorporate expertise in these technological advancements into the next phase of the EuroFAANG RI. Through the survey we also identified several projects in which participants were involved (Annex 2) that will provide valuable contact points for consortia expansion.

Table 1: New technological advancements in animal agriculture which are not currently directly represented by the expertise of partners in the EuroFAANG RI concept development project. The potential to include these in the next phase of the infrastructure will be explored in WPs 3-7.

Technological advances	**Potential to include in the next phase of the EuroFAANG RI project**
Robotics - for high-throughput phenotyping using organoids and cell lines	Potential partners with expertise in this space (such as BRIC in Denmark) will be identified in deliverable 5.1 which is focused on providing a framework for access to high-throughput CRISPR screens for functional validation of causative variants using genome editing.
Focused AI, machine learning and digital twin technology	Through planned activities in work package 6 we will identify potential partners with capacity and expertise to utilise these technologies for G2P research in farmed animals to improve health, welfare and productivity.
Large-scale automated phenotyping from sensors and other devices	In work package 7 we are building links with a new research infrastructure concept development proposal focused on farmed animal phenotyping that will provide an access framework to these technologies in Europe.
Testing genetic combinations and screening of chemical compounds for pharmaceutical effects	This was an interesting outcome of the survey that we hadn't considered previously. In vitro systems in WP4 may provide appropriate systems for this and potential partners with expertise in this space will be identified through WP4 activities.

Big data and analytics including millions of data points from large-scale phenotyping and from high throughput CRISPR screens	The potential to link up with commercial or other entities managing data at this scale will be explored in work packages 3 and 7, particularly through establishing partnerships with Elixir (D7.1) and the European Open Science Cloud (EOSC).
Advanced tools for understanding animal breeding and production in a social science context	The EuroFAANG RI project has a social scientist as a member of the advisory board but for the next stage of the project a work package specifically designed to provide access to social science expertise, including to the tools that are available for consumer dialogue and engagement in animal production, will be important to facilitate consumer uptake of these technologies.
Immunogenetics/genomics	Identifying partners with specific expertise in immunology and the genetic and genomic drivers of disease resistance (e.g., FLI in Germany and the Pirbright Institute in the UK) could be explored through work package 5, as one route to application of this information is through gene editing.

6. Conclusion and Next Steps

The survey results and the insightful responses from participants highlight the significant potential for technological advancements in the field of animal agriculture. Advancements in genomic and phenotyping technologies, machine learning, in vitro systems, and genome editing hold immense promise for improving animal health, productivity, and welfare, and for addressing key challenges related to sustainability and food security.

Despite the length of the survey and detailed responses required, the higher-than-average number of participants highlights the importance of this topic. The robust participation and depth of the responses affirm that we are on the right track in focusing on these areas and that discussion among stakeholders is the key to progress in this space.

However, the adoption of these technologies is not without its challenges. Ethical considerations, technical difficulties, regulatory issues, and economic factors were highlighted as potential obstacles. Addressing these challenges will require concerted efforts from all stakeholders in the field.

One of the main aims of this deliverable, in addition to describing technological advances in the field of animal agriculture, was to identify expertise that is currently missing from the EuroFAANG RI project in new and advanced technologies. From the results of the survey, we were able to identify seven key areas in which we could expand the expertise of the consortia for the next phase of the EuroFAANG RI project and will explore the potential to achieve this through planned activities in work packages 3-7. We can also identify potential partners with this expertise from the survey respondents and the list of projects in Annex 2.

Looking ahead, we propose to engage think-tank subgroups by sending strategic questions focused on specific new technologies in each space (e.g., the use of robotics for high throughput phenotyping in organoids and the potential for access to this technology across Europe). Their expertise and insights will be invaluable in identifying promising areas for future research and investment. Furthermore, we plan to continuously update this deliverable based on these discussions and the evolving landscape of scientific and technological developments in animal agriculture for EuroFAANG RI project duration.

This iterative approach, coupled with the high level of interest shown by the survey participants, demonstrates our dedication to advancing the field of farmed animal science and to adoption of new and advanced technologies. We look forward to continuing this important work throughout the EuroFAANG concept development phase and into the next phase of project.

7. Annex 1: National and International Initiatives identified by respondents

- **Genomic in Herds I & II**: This project aimed to improve methods for genomic prediction and had a significant impact on the reliability of genomic enhanced breeding values.
- **GenSAP (Center for quantitative genetics and genomics)**: GenSAP develops Genomic Selection (GS) methodology for managing, integrating, and extracting relevant information from massive amounts of data emerging from whole genome sequencing, functional genomics, epigenomics, and complex phenotyping technologies.
- **On-farm monitoring of methane from dairy cows**: An initiative involving AU and others.
- **MethaneOmics**: This project focuses on breeding for reduced methane emission in dairy cattle using multiomics information.
- **EC BovReg project**: A partner in this project works on the ethics of cattle genomics and advanced breeding and especially public engagement through the Democs card game.
- **EnviroCow Project at ILRI**
- **Breed4Food**: This initiative focuses on implementation in an industrial setting, rather than focusing on research alone.
- **InterBeef and Interbull**
- **US version of FAANG and farmGTex projects**
- **GeRoNIMO, EuroFaang**: EU projects
- **SLICK angus cattle, Samson heavy muscled cattle, CELTIC Holstein cattle, Landrace/ Large White/ Duroc pigs, resistant to PPRS**: These are commercialized NGT Animals.
- **AG2PI**: This initiative focuses on animals and plants in the US and is effective at building networks globally and bringing two communities together.

- **EU-LI-PHE European COST Action**: This initiative is focused on phenotyping but has a working group for linking Genotype to Phenotype (G2P).
- **Farmbank led by IRTA**: This initiative is just starting and is based on in vitro systems.
- **EuroFAANG projects (bovreg, aquafaang, geronimo, rumigen, holoruminants) and EuroFAANG infrastructure**
- **Carnot, ApisGene and ANR fundings**: These initiatives also support such research in France.
- **FAANG**
- **US FAANG and EU FAANG**
- **DairyBio (Australia)**: This initiative is focused and very effective.
- **Genome Canada**: This initiative gathered several Canadian institutes and companies, in addition to several outreach to the US community.
- **Diseases challenges and estimation of genetic parameters in fish and shellfish (European Marine Fisheries and aquaculture Fund, EMFAF : Medmax sea bass and Vibrio harveyii; FlavoControl rainbow trout and Flavobacterum psychrophilum; GeneSea sea bas and sea bream and VNN and pasteurellosis)**.
- **H2020 NewTechAqua**: This initiative focuses on Pacific oyster and resistance to conditional disease OHsV1 virus and Vibrio aestuarianus.
- **EMFAF Omega-Truite**.
- **IDDEN Initiative**: This initiative is a part of the broader efforts in the field of animal genetics and breeding.
- **Global Alliance Initiative**: This initiative is a global collaboration aimed at advancing the field of animal genetics and breeding.
- **ICAR/Interbull/Interbeef Projects (PPP Project)**: These projects are collaborative efforts involving ICAR, Interbull, and Interbeef, aimed at advancing research and development in the field of animal genetics and breeding.
- **Breeding programs of all major livestock and poultry species**: These programs focus on improving the genetic traits of major livestock and poultry species through selective breeding.

- **All Faang initiatives (Aquafaang, geneswitch, bovreg)**: These initiatives are part of the broader FAANG project and have the potential to be very effective.
- **National and international projects for systematic collection of SNP genotypes and phenotypes**: These projects focus on the collection of SNP genotypes and phenotypes, mostly health-related, of cows and young stock on selected farms.
- **The Breed4Food partnership**: This is a partnership between breeding organisations and WUR in The Netherlands.
- **FAANG and G2P (US) initiatives**: These are initiatives based in the US that focus on genomic research.
- **FarmGTEx**: This initiative is part of the broader GTEx project, which aims to create a public resource to study tissue-specific gene expression and regulation.
- **Key Welfare Indicators International Poultry Welfare Alliance**: This initiative focuses on the development of criteria for 3R-ness (robustness, reliability, repeatability) of potential Key Welfare Indicators (KWIs).

8. Annex 2: Survey

Scientific and Technological Developments in Farmed Animal Science

Thank you for participating in this survey. Your valuable input will contribute to a better understanding of the advancements and initiatives in farmed animal science for the Eurofaang Research Infrastructure and also as a base to improve the next think-tank in Spring. I want you to know that your responses will be kept confidential.

Section 1: Demographics

1.1 Name

First Name   Last Name

1.2 Affiliation/Institution

1.3 Position/Job title

1.4 Years of experience in farmed animal science and/or breeding

- < 1 year
- 1 - 5 Years
- 5 - 10 Years
- 10 - 20 Years
- > 20 years

Section 2: Scientific and Technological Developments

2.1 Please rate your awareness and involvement in the following areas on a scale of 1 (low) to 5 (high):

	1	2	3	4	5

Genetic Breeding Techniques	◯	◯	◯	◯	◯
Reproductive technologies	◯	◯	◯	◯	◯
Nutritional Advancement	◯	◯	◯	◯	◯
Disease Management	◯	◯	◯	◯	◯
Ethics & Social Sciences in Animal Breeding	◯	◯	◯	◯	◯
Precision Farming Technologies	◯	◯	◯	◯	◯
Fucunctional Genomics	◯	◯	◯	◯	◯
In-vitro Systems and biobanking	◯	◯	◯	◯	◯

2.2. Are there any specific scientific or technological breakthroughs in farmed animal science and animal breeding that you have found particularly promising or impactful? Please describe.

Section 3: International and National Initiatives

3.1. Are you aware of any international or national initiatives aimed at improving our understanding of the link between genotype and phenotype (G2P) in farmed animals? (e.g., government programs, industry collaborations)

◯ Yes ◯ No

3.2. Please provide details about any specific initiatives or programs you are aware of, and your opinion on their effectiveness.

Section 4: Cutting-Edge Methods - Genome Editing

4.1. How familiar are you with the use of genome editing for farmed animal research? (1 = Not familiar, 5 = Very familiar)

	1	2	3	4	5
Genome Editing for Farmed Animal Research	○	○	○	○	○

4.2. Have you or your organisation been involved in research or application of genome editing in farmed animals? Please describe your experiences.

4.3. What do you see as the most promising new technologies for genome editing in farmed animals? (e.g., high throughput phenotyping CRISPR screens, novel in vitro systems, multiplex editing)

4.4. What do you see as the most promising applications of genome editing in farmed animals? (e.g., editing for disease resistance, environmental sustainability, animal health and welfare, surrogate host technology to conserve genetic diversity, G2P research)

Section 5: Cutting-Edge Methods - In vitro Systems

5.1. How familiar are you with the use of in vitro systems for farmed animal research? (1 = Not familiar, 5 = Very familiar)

	1	2	3	4	5
In Vitro systems for Farmed Animal Research	○	○	○	○	○

5.2. Have you or your organisation been involved in research or application using in vitro systems for farmed animal research? e.g. using organoids, organ-on-chip or cell lines for G2P research, biobanking, functional genomics etc. Please describe your experiences.

5.3. What do you see as the most promising new technologies in in vitro systems in farmed animals? (e.g., organ-on-a-chip, high throughput phenotyping using CRISPR screens, surrogate hosts)

5.4. What do you see as the most promising applications of in vitro systems in farmed animal? (e.g., to test gene editing targets, for functional validation, linking G2P, to understand fundamental biology, bio-banking, conserving genetic diversity)

Section 6: Cutting-Edge Methods – New genomic and phenotyping technologies

6.1. How familiar are you with the use of new genomic and phenotyping technologies for farmed animal breeding? (1 = Not familiar, 5 = Very familiar)

	1	2	3	4	5
New Genomic Technologies	◯	◯	◯	◯	◯
Phenotyping Technologies	◯	◯	◯	◯	◯

6.2. Have you or your organisation been involved in research using new genomic and phenotyping technologies for farmed animal breeding and research? e.g. using GPS wearables to collect large numbers phenotypes, use of artificial intelligence/machine learning, cutting edge reproductive technologies and genomics enabled breeding. Please describe your experiences.

◯ Yes ◯ No

6.3. What do you see as the most promising new genomic and phenotyping technologies for farmed animal breeding and research? (e.g., machine learning, robotics, individualised genomes)

6.4. What do you see as the most promising applications of new genomic and phenotyping technologies for farmed animal breeding and research? (e.g., improving sustainability, increasing the accuracy of genomic selection, better breeding decisions)

Section 7: Challenges and Ethical Considerations

7.1. In your opinion, what are the key challenges or obstacles facing the adoption of advanced technologies in animal agriculture?

7.2. What ethical considerations should be considered when implementing advanced technologies

in animal agriculture?

Section 8: Future Directions

8.1. Where do you see the future of farmed animal science and animal breeding heading in terms of scientific and technological advancements over the next 5-10 years?

8.2. Are there specific areas within farmed animal research that you believe deserve more attention and investment in the near future?

Section 9: Additional Comments

9.1. Do you have any additional comments or insights that you would like to share related to scientific and technological developments in animal agriculture?

Thank You!

Thank you for taking the time to complete this survey. Your input is valuable in advancing our understanding current and future technological advancements in the field of farmed animal science. If you have any further information or resources to share, please feel free to contact us.