

ENHANCING THE SUSTAINABILITY OF RABBIT PRODUCTION FROM THE PERSPECTIVE OF ANIMAL GENETICS

Juan Pablo Sánchez 

Programa de Genética y Mejora Animal, IRTA, 08140, CALDES DE MONTBUI, Spain.

Abstract: The concept of sustainability, originating from the late 1980s, emphasises the ability to maintain processes over time without compromising future generations' needs. It encompasses social, environmental and economic dimensions, although controversies persist regarding the latter's inclusion. In the case of rabbit production, the economic dimension is paramount to ensure the future sustainability of the sector, given the large number of threats, mainly economic, it is facing. The major challenge when considering social and environmental sustainability plans in breeding programmes is how to properly include these dimensions in the functions defining the relevance of the different traits to be considered during the development of specialised lines. Note however that the key drivers of the current economic sustainability of the sector: prolificacy, feed efficiency and some functional traits such as resilience and survivability, are also the most likely levers of the environmental and social components of sustainability. In this context, the development of specialised lines is the most valuable contribution to sustainability by animal geneticists, the maternal lines specialised in producing large amounts of healthy weaned kits and the terminal sire lines specialised in efficiently transforming feed into meat. Regarding feed efficiency, important milestones have been achieved in recent years, many of them related to the fact that kits are raised in collective cages, and under these rearing conditions, tools have been developed to measure feed intake at the individual level, as well as to explore the role that one individual imposes on their cage-mates. Despite the fact that genomic tools have been developed and used to explore the role of genomic regions of different traits of interest, this information is still far from being used in applied breeding programmes. In the near future, we could predict that breeding programmes for enhanced sustainability will still mainly rely on pedigree records and phenotypic information for prolificacy and feed efficiency; but enriching the list of available phenotypes with additional traits, most likely obtained under automatic recording systems, to explicitly account for the social and environmental sustainability plans. In this framework, *omic* tools will perform a valuable role for further investigation of the biological basis controlling the major drivers of rabbit production sustainability, and hopefully in the future this information could be directly incorporated into breeding programmes.

Key Words: feed efficiency, genetic selection, animal breeding, new phenotypes, *omic* tools, rabbit.

WHAT DOES SUSTAINABILITY MEAN?

The concept of sustainability might refer to the ability to maintain or support a process continuously over time. This idea is strongly linked to the concept of sustainable development, defined in the late eighties of the last century in "Our Common Future" (World Commission on Environment and Development, 1987), the foundational document of sustainable development. The document stated that sustainable development means "to satisfy the needs of the present generation without compromising the chance for future generations to satisfy them". In this context, it was proposed that three dimensions were relevant to grant the sustainability of any system: social, environment and

Correspondence: J.P. Sánchez, juanpablo.sanchez@uco.es. Received October 2024 - Accepted March 2025.
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economic. These three plans are however not free of controversy (Purvis *et al.*, 2019), since many experts consider that the economic dimension should not be included, as it is rapidly associated with “economic growth”, which in turn has been associated with many cases of environmental and social deterioration. Nonetheless, in “Our Common Future”, the role of the economic dimension was fully recognised, since it calls for “a new era of economic growth that is forceful and at the same time socially and environmentally sustainable” (Purvis *et al.*, 2019). In general, we could affirm that proper definitions of sustainability are far from being rigorous, as they are based not only on scientific evidence but also on what people find valuable, and this latter component includes largely intangible elements difficult to systematise.

Beyond this attempt to formalise the sustainability concept, what seems evident and has already been demonstrated, is the impact of livestock production on the environment (Xu *et al.*, 2021). It has been quantified that the impact of producing one Kg of protein from rabbit meat is 51.4 Kg of CO₂_{eq} and 0.5 Kg of N_{eq} (Cesari *et al.*, 2018). These values are higher than those of poultry production, similar to the figures from swine production and much lower than those of beef production.

Thus, we could say that the environmental dimension would be a priority when analysing the elements of rabbit production to enhance its sustainability. However, if we consider the economic threats surrounding the rabbit sector, the economic factor is in our opinion the most critical dimension for rabbit production sustainability in the short and even in the long term. So, in the case of rabbit production, the above statement could be rephrased as: “a new era of economic survival must be pursued while granting a social and environmental sustainability around it”.

In this context, an appealing strategy for increasing economic efficiency/profitability of any production system consists of maximising the number of output units obtained per input unit provided. But the rabbit production sector has the handicap of being a minority sector strongly influenced by other market estates, which might distort the actual relevance of the different components of the system.

Of course, this discussion about the need of developing a sustainable rabbit production relies on the fact that this sector produces something relevant to society. If this point were to be questioned, i.e. the production of rabbit meat does not merit the associated environmental impact, all arguments below are completely irrelevant and we had better stop rabbit farming.

The aim of this revision is to describe the research initiatives, mainly in the field of animal genetics, that have been conducted in the last few years to enhance the sustainability of the rabbit production sector. We will review the most relevant traits to improve sector sustainability and how these traits can be identified. We can anticipate that one of these traits is the efficiency of converting feed into meat, and we devote a few sections to review important features of these efficiency traits, such as the fact that it is necessary to record the individual feed intake and that kits are raised in groups. Then we review how up-to-date genomic and other *omic* tools are being used for the study of traits directly or indirectly linked to the concept of sustainability. The revision finishes with a reflection on the characteristics of future breeding programmes to further enhance rabbit production sustainability.

RELEVANT TRAITS FOR ENHANCING RABBIT PRODUCTION SUSTAINABILITY

Fortun-Lamothe *et al.* (2010) published an assessment of the contribution of intense rabbit production to the sustainable development of our society. They used a semi-quantitative scale applied to nine indicators and concluded that for some indicators (use of antibiotics, animal biodiversity or animal welfare) the contribution of intensive rabbit production system penalises an overall sustainable development, while for other indicators (living and working conditions, quality of products or economic profitability) the contribution of intensive rabbit production is positive. Beyond these semi-quantitative results, what is important about the study by Fortun-Lamothe *et al.* (2010) is that they classify indicators into the three pillars of sustainability. This helps to organise the contribution of the different traits and features of rabbit production. In this regard, the indicators assigned to the economic sustainability plan encompass the economic profit of the activity and issues related to this profitability, such as economic specialisation or the need for strong investments in facilities. The indicators assigned to the environmental dimension basically include those linked to the impact the activity might have on ecosystems, which in the case of rabbit farms is strongly linked to the use of energy, the use of antibiotics and the biodiversity of the populations considered for production.

Finally, the indicators assigned to the social dimension of sustainability are somewhat more diverse, in the sense that they might conceal either the perception society has about rabbit production and what we get from it. Paradigmatic examples include society's concern about animal welfare or the worry about the quality of the products the system is generating. But this dimension also covers issues related to the contribution of the activity to our social development, reviewing to what extent the labour conditions are favourable or assessing whether the activity generates inclusive labour opportunities. In the following sections, the different indicators listed above are treated in a rather loose manner, and in many cases, they are openly ignored, the traits we discuss being directly assigned to contribute to the different sustainability plans in an implicit way. For our arguments, this informal treatment of the different sustainability indicators is not a relevant limitation because one particular trait might contribute in different ways to the different sustainability plans.

The most relevant traits defining the profitability of any production sector could be determined by analyses like those used to compute the economic weights when defining selection indexes in breeding programmes (Brascamp *et al.*, 1985). This is traditionally done by deriving an economic revenue function with respect to the different traits considered when defining the function. The challenge would be to turn the social and environment sustainability plans into economic units. Some people might perceive that these two dimensions might lose their identity by following this procedure, but this is not so. Social and environmental dimensions of sustainability would become much more evident, as they involve economic units that everyone clearly understands, i.e. Euros. So, the point might not necessarily be the development of new traits to explicitly consider environmental or social dimensions of sustainability, but to redefine the rank of already recorded traits to economically account for these sustainability dimensions.

In other species like pigs and cattle there are already examples of derivations of economic weights accounting specifically for the environmental impact expressed as economic units within reviewed revenue functions. Methodologically, they can either rely on complex bio-economic models and stochastic simulations (Ali *et al.*, 2018), or on traditional revenue functions applied to both economic units and emission units, which are subsequently weighted at the time of deriving the final economic values (Amer *et al.*, 2018; Alfonso, 2019). Regardless of the method, the point is that the environmental dimension of sustainability must be expressed in economic units.

The calculation of economic weights conducted so far in rabbit production (Cartuche *et al.*, 2014), scarce anyhow, did not directly consider the societal or environmental penalties or bonuses for these nuances associated with the different traits. The challenge, as stated above, is that it is difficult to express many of the societal or environmental concerns behind the traits' marginal increases in monetary units.

Exclusively from an economic standpoint, it seems that the most relevant traits are the prolificacy of does and efficiency in the use of feed by both does and growing kits (Cartuche *et al.*, 2014). Note however that this exclusively economic criteria could sometimes be aligned with aspects of the societal and environmental dimensions of rabbit production. In this regard, a significant improvement in feed efficiency will have direct and tangible economic benefits for the rabbitries, as feeding costs represent up to 70% total costs, but will also help to minimise the use of resources for production. This fact will directly contribute to mitigating the environmental impact of production and improving the perception that society might have of our sector, positioning us as a sector concerned with optimised use of resources. Thus, acting on efficiency in feed use, we will address the three dimensions of sustainability. Another example could be the survivability of the kits, which is a major component of farm-level efficiency (Gidenne *et al.*, 2017), and is also strongly linked with animals' welfare, a major component of the societal dimension of livestock production. These intuitive arguments can be supported by derivations of economic weights accounting for environmental impact in the swine industry, which also point out that the most relevant traits from a strictly economic point of view are also still the most relevant ones when the environmental component is considered (Alfonso, 2019; Ali *et al.*, 2018).

Thus, we could affirm that considering feed efficiency and prolificacy as target traits to be improved is an adequate strategy to enhance rabbit production sustainability. Note, however, that these concepts (feed efficiency and prolificacy), when they are treated as farm-level technical indexes, should be broad enough to cover a wide range of additional elements of the production. For instance, prolificacy at weaning can be improved by reducing mortality during lactation. Similarly, an improvement in feed efficiency during fattening can be achieved through reducing post-weaning mortality. These examples on the consideration of mortality to expand the biological concepts of prolificacy and feed efficiency to technical production indexes is a way to give room to other animal traits in the sustainability

definition. These traits are designated functional traits (García *et al.*, 2021) and they are characteristics linked with health, fertility and longevity that reflect concepts such as resistance to diseases, resilience, robustness, rusticity or plasticity. Many of these concepts directly reflect the capability of the animal to maintain performance even in harsh or simply diverse environments. In the case of rabbit production, three examples of functional traits are the doe's functional longevity (Sánchez *et al.*, 2008, Larzul *et al.*, 2014), the across-parities environmental variability in prolificacy (Blasco *et al.*, 2017; Argente *et al.*, 2019) or the within-litter environmental variability in birth weight (Garreau *et al.*, 2008) and the resistance to different diseases and syndromes (Garreau *et al.*, 2021). Keeping these functional traits at an appropriate level has an enormous impact on production sustainability, since it will not only aid the improvement of the economic revenue of the activity, but it will also help to keep high levels of animal welfare, since all of them are strongly correlated with animals' survivability and different forms of robustness and resilience. Of course, the ways to enhance all these traits with the final aim to improve rabbit production sustainability are as numerous as disciplines within animal science: Nutrition, Reproduction, Pathology and Genetics.

In the current revision we will set the focus on one of the pillars for sustainability, feed efficiency, reviewing aspects directly linked to its genetic determinism, and more particularly to issues and procedures related to the genetic improvement of this type of trait.

FEED EFFICIENCY IN RABBIT PRODUCTION FARMS: EFFICIENT PRODUCTION OF WEANED KIT AND EFFICIENT USE OF FEED FOR GROWTH

Feed efficiency in rabbit production at farm level could be defined as the ratio between input and output units. In this context, we could distinguish between factors that modify the ratio by either maintaining or even reducing the inputs, while keeping the outputs constant or increasing them, and factors promoting an increase of both inputs and outputs, but the increase in outputs being proportionally larger than that in inputs. The broader the level of definition, the larger the number of traits that would determine the efficiency. At whole-farm level, efficiency would depend on both reproductive and post-weaning performance, while efficiency in the fattening sections would only depend on the post-weaning performance. The traditional three way cross (Baselga *et al.*, 2021) used in European countries for rabbit production aims to enhance efficiency at farm level: specialised maternal lines are responsible for enabling efficient production of weaned kits, while terminal sire lines would allow for the kits to grow quickly with a low feed conversion ratio and acceptable carcass quality.

To the best of our knowledge, the efficiency in producing weaned kits has never been explicitly considered in rabbit breeding programmes of maternal lines. The strategy has been to increase litter size at weaning, to increase prolificacy while reducing mortality or just to increase survivability, but never explicitly accounting for the input units needed to sustain the production. It was assumed that the marginal cost of producing an extra kit at weaning would be much lower than the benefit of having such an increase in weaned kits. These strategies to enhance the efficiency at farm level could be understood as scale factors, since the units produced are not generated in a more efficient way. On the contrary, the enhanced efficiency would simply be a consequence of the fixed costs being divided by a larger number of output units.

The case of the paternal lines is slightly different, as there have been selection processes, directly considering efficiency criteria, using different functions balancing inputs (e.g. feed intake) and output (e.g. growth) units. Note however that the traditional way to improve feed efficiency in terminal sire lines was indirect selection for either post-weaning growth or final weight; the main argument supporting this strategy was the medium-high genetic correlation between growth and feed conversion ratio. In addition, fast growing animals would entail a shorter fattening interval to reach the final weight, which would mean a reduced overall intake and the additional advantage of concentrating post-weaning growth at lower ages, on which better feed conversion efficiency has been documented (Larzul and Rochambeau, 2004; Ramón *et al.*, 2015).

Blasco *et al.* (2021), in their review of genetic parameters for growth and feed efficiency in terminal sire lines, concluded that both heritability of growth and its genetic correlation with feed conversion ratio in rabbits seem to be lower than those reported in other species. These authors argued that these parameter estimates hardly justify considering indirect selection procedures as an efficient way to improve feed efficacy. What is more, the

experimentally reported response pointed out generational changes even lower than those expected given the genetic parameter estimates. There is no evident explanation of the low genetic variation or the low heritability values in rabbits for traits showing much higher parameter values in other species. Perhaps evolutionary studies coupled with up-to-date genomic tools could aid in elucidating this situation, which seems to be peculiar to our species and could be aligned with the rabbit's tolerance of high levels of inbreeding. In this context, ideas like those proposed by the INRAe team in the FeedSeq (Gilbert, 2023) project on using Translational Genomics concepts to study rabbits and other species together would help shed some light on the above-described biological limitations in many rabbit traits.

SELECTING FEED EFFICIENCY IN GROUP-RAISED ANIMALS

Growing rabbits are usually raised in group cages, where it is not evident how to record the individual intake. Precisely the difficulty of obtaining these individual intake records is another important reason not to consider feed efficiency as a direct selection criterion for the improvement of terminal sire lines. Nonetheless, some experimental processes of selection for feed efficiency have been conducted by raising animals in individual cages; the most recent was the one by Drouilhet *et al.* (2016). In this experiment, two lines were selected, one to reduce residual feed intake (RFI) (ConsoResidual line) and the other to increase growth under restriction (ADGrestrict line). Near perfect results were reported: ConsoResidual line reduced the intake without penalising growth and ADGrestrict line improved the growth without increasing the intake. In subsequent reports of the ConsoResidual line (Garreau *et al.*, 2019), slightly different results were presented; the reduction in the feed conversion ratio of the ConsoResidual line (-0.035 units per generation) was accompanied by a reduction in the daily growth rate (-0.277 g/d per generation). This result is compatible with the reported genetic correlations in these lines (Drouilhet *et al.* 2013), and this antagonistic relationship has also been observed in other species (swine, poultry, etc).

Garreau *et al.*, (2019) also studied the interaction between rearing conditions (individual vs group cages) and the genetic response, discarding the hypothesis of a strong genotype by rearing condition interaction, despite showing some non-significant scale changes in the responses for growth and intake depending on whether they were obtained in group or individual cages.

Several projects focusing on feed efficiency have been conducted at IRTA since 2012. We considered that efficiency should be evaluated and improved in conditions close to commercial ones, so we conducted selection processes with animals raised in collective cages. A first, tentative approach to using records from animals raised in collective cages for breeding purposes was made by handling cage-average feed intake records (Piles and Sánchez, 2019) jointly with individual growth information to estimate genetic parameters and to predict breeding values for individual feed efficiency. Genetic parameters estimates were in the range of estimates previously reported by Drouilhet *et al.* (2013) from records of animals raised in individual cages. Two important finds by Piles and Sánchez (2019) were the limited genetic determinism for feed efficiency when animals were raised under feed restriction, and the negative genetic correlation between growth and residual feed intake, i.e. feed intake beyond the expected needs of the batch. When the RFI was corrected for the genetic expected needs, the unfavourable genetic correlation with growth disappeared, but the resulting feed efficiency trait had a nearly null heritability. In parallel to this study, we worked on the design and manufacture of a feeding device allowing us to record individual feed intake of animals raised in group cages. This electronic feeding device acts as a sensor recording the amount of feed available at all times for the animals and retrieving the identification of the animals when entering the feeder (Sánchez *et al.* 2024).

This system has been used to genetically improve the feed efficiency of one line selected to reduce the RFI line and to hourly (from 6am to 6pm) restrict the animals' access to feed in another line selected for increasing daily growth under restriction (ADGR line). This selection experiment was completed with a third line selected to reduce the cage-average RFI (GRP line). Preliminary results on the response attained in these selection processes are presented in a communication presented to this conference. Very briefly, the RFI line was the one with the clearest response on reducing FCR, and a trend was also observed in the GRP line; both responses on FCR were accompanied by an unfavourable response on daily growth. The ADGR line did not show any response to the selection for growth under feed restriction. To a certain extent, these results were expected, given the previously estimated genetic parameters (Piles and Sánchez, 2019; Drouilhet *et al.* 2013).

The applied selection processes fully considered the fact that animals are raised in collective cages, where social interactions between cage-mates might play an important role in the determinisms of the feed efficiency and other performance traits. In the case of the GRP line, the selection unit is the whole group of animals being raised in the same cage, i.e. we are selecting the combination of genes between cage-mates that maximise the cage-average RFI. Thus, we were not only selecting direct genes promoting individual RFI but also genes favourably affecting the RFI of cage-mates. In the case of the RFI and ADGR lines the role of the social interactions is also implicitly considered. Cage-mates are close relatives, i.e. full or half sibs; and with this within-cage family structure, breeding value predictions from an animal model are predictions of the total breeding value (Muir *et al.*, 2013; Bijma *et al.*, 2011). This is a breeding value that optimally weights the effect of genes affecting the performance of animal itself, and the effects of genes affecting the performance of its cage-mates.

This concern about the role of social interaction effects on growth and feed efficiency has been a common element in the line of projects conducted by our team in the last few years. We have demonstrated that genetic social interaction effects are a major determinant of the growth of rabbits raised under feed restrictions (Piles *et al.*, 2017), while not being so relevant for the case of animals fed *ad libitum*. This could be a factor explaining the strong genotype by feeding regimen interactions we have estimated (Piles and Sánchez, 2019). Information provided by the electronic feeders (Piles *et al.*, 2024) as well as by other technological tools such as computer vision systems (Sánchez *et al.*, 2022) for remotely monitoring the growing rabbits is also allowing us to better understand the role that the interactions between cage-mates might play on determining traits of paramount relevance for sustainable rabbit production.

GENOMIC TOOLS FOR THE STUDY OF KEY SUSTAINABILITY TRAITS

From an animal breeding perspective, the possibility to densely type the genome of the selection candidates has revolutionised animal breeding schemes in all major livestock species. Since approximately 2018, the rabbit has had a specific genome-wide panel for genotyping which includes 200 000 Single Nucleotide Polymorphisms (SNPs). This panel was developed after research on the domestication process of the species (Carneiro *et al.*, 2014); the whole-genome sequence material generated was proposed for use by Affymetrix for developing a commercial genotype panel. This development was promoted and dynamised through RGB-Net COST action (Garreau *et al.*, 2012) that pooled the interest of several research disciplines using or studying the rabbit species: evolutionary and biomedical sciences, and animal production. Since its launch, a number of studies have been conducted using the rabbit 200K SNP panel. Only one study has assessed the value of simulated SNPs panels in applied breeding programmes (Mancin *et al.*, 2021). In this study, the most convenient scenario seems to be that genotyping the candidates with a low-density panel (600 SNPs) and then imputing their genotypes to high-density (200K SNPs), keeping sires and grand-sires genotyped with the high-density panel, and dams genotyped with a medium-density panel (6K SNPs). Under this scenario, the additional response, with respect to a selection based on a pedigree based BLUP prediction, was just 0.011 kits per generation and the need for genotyping investment was expected to be between 10 000 and 15 000 € per year. Beyond this being the most convenient scenario, we believe it is still far from being practically applicable, since such a high investment would hardly be supported by the limited gain in prolificacy obtained.

Most studies considering genomic information were focused on identifying genes and genomic regions underlying traits of interest for the rabbit production sector, among them the major determinants of rabbit production sustainability: feed efficiency and prolificacy. Sánchez *et al.*, (2020) performed a genome-wide association study (GWAS) in rabbits aiming to identify chromosomal regions associated with growth and feed efficiency. Despite the limited power of their design, based on cage-average feed efficiency measurements, interesting associations for feed efficiency were declared in chromosome 16, but no candidate genes were identified. In the case of growth, QTL regions were declared in chromosomes 3 and 5, harbouring genes already described as being associated with growth, such as FTO and NDUF6. Garreau *et al.* (2023) have also reported QTL regions for feed efficiency traits measured in individual cages. They declared one region in chromosome 18 associated to RFI; this region harbours the gene GOT1, a clear candidate because it is involved in the metabolism of amino acids and urea. They also declared one region in chromosome 7 associated with FCR, but this region lacks any biologically relevant annotated gene. To the best of our knowledge, the only genome-wide association study conducted so far for prolificacy traits is the study by Sosa-Madrid *et al.* (2020b), which reported regions on chromosome 17 associated with several prolificacy traits, such as

total liveborn, number born alive, implanted embryo and ovulation rate. There are several genes in this region that could be considered as candidates for explaining the variation on the prolificacy traits: BMP4, PTDGR, PTGER2, STYX and CDKN3. For total liveborn, this region could be said to have a major effect, since it explains up to 38% of the genetic variance. The animal material used in this study comprises two lines divergently selected for uterine capacity (Santacreu *et al.*, 2005) and a control unselected population formed from vitrified embryos from the base population common to both selected lines. In addition to this recent GWAS study for prolificacy traits, previous attempts to identify genes controlling these types of traits were also conducted following the candidate gene approach, by comparing polymorphisms and expression levels of certain genes of interest between the same lines divergently selected for uterine capacity (Peiró *et al.*, 2008; Merchán *et al.*, 2009; Argente *et al.*, 2010; Ballester *et al.*, 2013).

As already indicated, another important set of factors in the definition of rabbit production sustainability are the functional traits. In relation to these traits, and within the framework of the divergent selection experiment for environmental variability of prolificacy (Blasco *et al.*, 2017) several genomic studies have been conducted to bring light to the biological pathways involved in the control of such a complex trait, and those correlated with it, i.e. resilience traits. Casto-Rebollo *et al.* (2020), using both commercial genome-wide SNP panels and whole-genome sequences of animals divergently selected, reported that genes (e.g. DOCK2, HDAC9, ITGB8, and HUNK) and pathways involved in the immune-system play a key role in the determinism of environmental variability, sustaining the strong link between environmental variability, resilience and stress tolerance.

One important conclusion from all the studies on the identification of genes or genomic regions involved in the control of feed efficiency, prolificacy and other functional traits is that the majority of the genes or loci that are involved in the control of such traits do not seem to have a major effect. Thus, selection methods incorporating specific information about the segregation status of single (or few) genes or loci do not seem to be the most sensible approach to conducting efficient selection programmes. There are more suitable models assuming the existence of multiple genes with small effect, as is the case of the traditional infinitesimal model or genomic selection procedures which, regardless of the effect of the markers, just consider the genomic information to refine the expected relationship between relatives into actually observed percentage of genome sharing. One exception to this statement could be the region on chromosome 17 affecting total liveborn. It has been hypothesised that the fixation of this region is the reason why half of the response in divergent selection process was achieved in the first two out of ten generations of selection for uterine capacity (Blasco *et al.*, 2005).

Beyond the genomic studies on the major components of the sustainability reviewed above, significant efforts have been made to identify genomic regions involved in the control of other traits of interest to the rabbit industry or to the rabbit research community. One example is intramuscular fat (Sosa-Madrid *et al.*, 2020a, 2020c); for this trait, QTL regions have been declared in chromosomes 1, 3, 6, 7, 8, 13, 16 and 17, and in some of these regions, functional candidate genes are mapped. The experimental design of these studies provided higher statistical power than studies with homogeneous populations, since they were conducted with animals divergently selected for intramuscular fat.

Similar to the use of genomic tools for the assessment of genomic regions involved in the control of traits directly or indirectly involved in the determination of rabbit production sustainability, in the last five-seven years several studies have been conducted to clarify the role played by gut microbiota in defining traits linked to sustainability. These activities, in the majority of cases, are not strictly genetic studies, since their aim is to identify microbial taxa involved in the control of traits of interest. Nevertheless, as most of these activities have been conducted within the framework of different genetic selection programmes, and technically they rely on different forms of genomic sequencing (of the bacteria genome), many times they are clustered as within the animal genetic domain. Zeng *et al.* (2015), Drouilhet *et al.* (2016), Fang *et al.* (2020) and Velasco-Galilea *et al.* (2021) have explored the role of gut microbiota in feed efficiency and growth traits. Similarly, for functional traits, the Polytechnic University of Valencia and Miguel Hernández University teams have reported evidence of the role of gut microbiota in across-parity environmental variation of prolificacy (Casto-Rebollo *et al.*, 2023) and on longevity or resilience (Biada *et al.*, 2022). The influence of gut microbiota on intramuscular fat content has also been reported (Martínez-Álvaro *et al.* 2021). Studies on functional traits and on intramuscular fat content rely on comparisons between populations divergently selected for the traits of interest or with extreme phenotypes. Thus, as in the case of genomic studies, optimal designs were considered. An overall result of these studies is that gut microbiota plays a significant role in most of the traits studied, but the effects tend to be a consequence of the participation of many species. From a traditional animal breeding perspective, a

common element around the study of the gut microbiota has been the estimation of the heritabilities of the different taxa present in the different populations, as well as the genetic correlations with different performance traits (Mora *et al.*, 202). The values of these parameters range from nearly null to moderate-high. To date, it is not evident how to take advantage of the biological knowledge of the role of gut microbiota on the traits of interest to speed up the rate of response in breeding programmes, in spite of the fact that some of the taxa clearly show inherited variability.

THE FUTURE OF BREEDING PROGRAMMES FOR ENHANCING RABBIT PRODUCTION SUSTAINABILITY

The first element that must be addressed to optimise future breeding programmes for enhancing rabbit production sustainability is the proper economic evaluation of social and environmental dimensions of sustainability within the profit functions that are used to derive economic weights to be considered in selection indexes. To do this, multidisciplinary collaboration will be mandatory, requesting the intervention of social science and economy researchers, life cycle analysis experts, scientists on biosystem environmental sustainability and obviously geneticists. The initial output of this revision of the profit functions would be the recalculation of the monetary coefficients, accounting for social and environmental dimensions of sustainability. This might generate an alternative ranking of the traditional traits considered so far in the breeding programmes. Another point of revision around the profit functions will be the consideration of new traits to explain the benefits of rabbitries. These new traits will be those explicitly accounting for specific dimensions of sustainability. One example, in a scenario where important costs might be associated with manure handling, a penalty associated with this handling could be introduced in the profit function, and at the time of deriving the economic weight this new “manure production” trait will be ranked jointly with the traits considered so far. The point is how to generate new phenotype records for these new traits to be included in the profit functions, where the cooperation of experts from different fields will again be mandatory: Nutritionists, Physiologists, Ethologists, Pathologists and Clinical Veterinarians. These experts must bring biological knowledge about the new processes to be considered in future breeding programmes, but this expertise will have to be weighed by a major need of any breeding programme: phenotypic records must be recorded at individual level in the largest number of animals possible. Thus, the intervention of (bio)-technological experts allowing the development of tools for massively recording phenotypes correlated with the new biological processes to track is also needed. In the rabbit production sector, there are already examples under development of such technological tools, for example electronic feeders to individually record feed intake in cage-raised animals (Sánchez *et al.*, 2024), computer vision systems to monitor activity, behaviour or health and stress status (Jaén-Téllez *et al.*, 2020; Sánchez *et al.*, 2022), the use of NIR prediction equations to generate phenotypes informing on the chemical composition of the body or of the meat (Zomeño *et al.*, 2011), the use of wearable sensors to monitor activity (Piles *et al.*, 2023) or the use of electrical bioimpedance techniques also to predict body chemical composition (Nicodemus *et al.*, 2009). These types of tools can be said to be still under development and a much stronger commitment by researchers and the sector as a whole would be needed to further develop and improve them, as well as to bring new ideas and tools to our sector. There are other examples of technical developments in other sectors that could easily be adapted to rabbit breeding programmes: individual NIR-based digestibility assessments in pigs (Derau *et al.*, 2021), individual Nitrogen and Phosphorus excretion (pigs: Saes *et al.*, 2005, poultry: Chen *et al.*, 2009). These techniques have the added value of being non-invasive, thus enhancing the welfare of the animal at the time of data recording.

Beyond the generation of new phenotypes and a proper evaluation of the social and environmental dimensions of sustainability, we will most likely see how *omics* tools will continue their application within breeding programmes. Most likely, as is currently done, to explore the genetic and non-genetic control of the traits of interest; but hopefully, in the near future, also to help to improve the accuracy when making selection decisions. Nowadays, this is certainly not the case, as genotyping costs are much higher than the gain in responses that can be achieved. Note however that biotechnological tools and platforms for genotyping and sequencing are evolving very rapidly. Thus, it may happen that in the future we will have genotyping or sequencing platforms that would be economically affordable and easy to use even on the farm, and they could be useful for the improvement of characteristics that may continue to be very difficult to measure, as may be the case with carcass traits.

CONCLUSIONS

Sustainability is a broad and complex concept linked to three dimensions: social, environmental and economic. Unfortunately, only the last of these has clearly defined and easy-to-understand units. Efforts must be made to translate the social and environmental dimensions of sustainability to tangible and measurable elements, or alternatively to fully integrate them into the economic dimension, i.e. directly charging Euros per unit of environmental impact. Despite the certain lack of definition of some sustainability plans, we can affirm that prolificacy and feed efficiency seem to be the most relevant traits influencing rabbit production sustainability, but other functional traits, related to resilience and robustness, may also play an important role in the sustainability of rabbit production. Nevertheless, an updated assessment of their impact on economic, social and environmental sustainability is worth doing. In any case, elements determining sustainability may act either as scale factors or as direct elements of actual production efficacy. The direct consequence of feed efficiency being a pillar of sustainability is confirmed by the fact that breeding programmes develop specialised lines with enhanced capabilities to extract and use resources from the feed. To this end, traditional selection procedures relying on phenotypic data and pedigree relationships seem to be the way to go. But we cannot fail to consider the opportunities opened by omic tools and up-to-date technologies for automatic data recording to enrich both breeding programmes and biological studies of traditional and yet-to-be-developed phenotypes.

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Authors contribution: Sánchez J.P.: conceptualization, methodology, software, formal analysis, investigation, writing – original draft, writing – review & editing, supervision, project administration and funding acquisition.

Current affiliation: Departamento de Genética, Universidad de Córdoba, Edif. C5, Campus de Rabanales, 14014, Córdoba. Spain.

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