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Abstract. In France, dairy sheep and goats have developed efficient breeding schemes, whose annual genetic gain ranges from 0.10 to 0.27 genetic standard deviation of the total merit index, according to the breeds. From 2015 to 2020, the 5 dairy sheep breeds and 2 main dairy goat breeds have shifted to full genomic programs, based on reference population constituted of AI progeny-tested males. Currently, the breeding goals are similar for almost all the selected breeds and may be *per se* qualified as balanced, since they include efficiency criteria (milk yield and content), resilience criteria (udder health, resistance to scrapie), and adaptation to mechanic milking in order to mitigate the workload of the farmer in the milking parlour (udder morphology). There are increasing expectations for improving sustainability, robustness and resilience while still increasing efficiency. These new objectives are emphasized by the different stakeholders: the farmers, the industry, but also the consumers, the citizens. Opportunities occur to cope with these requests: a larger efficiency of selection offered by genomic programs allowing to consider new traits to select, new technologies and methods to limit the phenotyping costs (eg. use of MIR spectra), awareness and consent of all stakeholders to bring new challenges at the agenda (climate change, growing resistance to antibiotics or anthelmintics). Various recent or on-going projects (eg. iSAGE, RUSTIC, ARDI, SMARTER) are addressing the topics of adaptation, sustainability, resilience in small ruminants. Through the French dairy sheep and goat illustration, we propose to explore the following ways, that are the core objectives of the on-going SMARTER project: breeding for new efficiency and resilience traits in a context of more agro-ecological systems and pursuit of self-sufficiency in the feeding systems; benefiting from international harmonization and cooperation; tackling the genotype x environment interactions; sharing the ideas and solutions across the wider range of stakeholders.

Keywords. Dairy sheep – Goat – Word – Adaptation – Resilience – Selection.

Enseignements de projets récents ou en cours sur l'adaptation et la résilience des brebis et chèvres laitières en France

Résumé. *En France, les brebis et chèvres laitières bénéficient de schémas de sélection efficaces, dont le progrès génétique annuel varie, selon la race, entre 0.10 et 0.27 écart-type génétique. De 2015 à 2020, les 5 races ovines laitières et les 2 races caprines en sélection ont basculé vers des schémas de sélection génomiques, basés sur des populations de référence constituées de mâles d'IA testés sur descendance. Actuellement, les objectifs de sélection, assez similaires d'une race à l'autre, peuvent être qualifiés d'équilibrés, car ils incluent des critères de production et d'efficience (quantité et richesse du lait), des critères de résilience (santé de la mamelle, résistance à la tremblante) et d'adaptation à la traite mécanique (morphologie de la mamelle). Des attentes, soutenues par l'ensemble des acteurs des filières, sont fortes pour améliorer la durabilité, la robustesse, la résilience tout en améliorant l'efficience des animaux. Des opportunités existent pour traiter ces demandes : plus grande efficacité de la sélection offerte par la génomique, nouvelles technologies ou méthodes, prise de conscience et consentement des acteurs pour mettre en avant ces nouveaux challenges (changement climatique, résistance aux antibiotiques et aux anthelminthiques). Plusieurs projets, récents ou en cours (ex. iSAGE, RUSTIC, ARDI, SMARTER), abordent les questions d'adaptation, de durabilité et de résilience en petits ruminants. Au travers de l'exemple des chèvres et brebis laitières françaises, nous proposons de baliser*

les thèmes suivants, qui sont au cœur du projet SMARTER: la sélection de nouveaux caractères d'efficience et de résilience dans une contexte d'intérêt croissant pour des systèmes plus agro-écologiques, recherchant plus d'autonomie alimentaire; l'intérêt de l'harmonisation et de la coopération internationale; les interactions génotypes x milieu ; la partage des idées et des solutions par un large réseau d'acteurs et d'utilisateurs de la génétique et de la production de petits ruminants.

Mots-clés. *Ovin lait – Chèvre – Adaptation – Résilience – Sélection.*

I – Dairy sheep and goats breeding programs in France

In 2020, the populations of dairy small ruminants in France reached 885,000 dairy goats and 1,660,000 dairy sheep (Idele, 2020). Two dairy goat breeds and 5 dairy sheep breeds are under selection and benefit from breeding schemes: Alpine and Saanen in goats; Lacaune, Corse, Basco-Béarnaise, Blond-Faced and Black-Faced Manech in sheep.

1. Breeds under selection and main features of the breeding programs of French dairy small ruminants

The Table 1 gives a summary of the main features of the breeds under selection. The population size of the breeds ranges from 80,000 ewes in Basco-Béarnaise to 1,130,000 ewes in Lacaune. The percentage of females involved in the breeding programs varies from 12% on the Black-Faced Manech to 30% in the Basco-Béarnaise breed. The number of new males put in AI each year depends on both the rate of AI and the size of the population in selection. These programs are efficient and allow an annual genetic gain comprised between 0.10 to 0.23 genetic standard deviation of the total merit index.

Table 1. Main features of the breeds under selection in France. G: dairy goats; S: dairy sheep

Breeds	Alpine (G)	Saanen (G)	Lacaune (S)	Corse (S)	Basco-Béarnaise (S)	Black-Faced Manech (S)	Blond-Faced Manech (S)
Population (thousands)	450	350	1,130	85	90	80	270
% in breeding program	27%	20%	20%	21%	30%	12%	28%
# new males in AI per year	50	40	445	25	44	26	146
%AI in breeding program	34%	34%	85%	36%	50%	45%	50%
Annual genetic gain (genetic std)	0.17	0.17	0.23	0.10	0.16	0.11	0.17

2. Implementation of genomic selection

Genomic selection (GS) has been gradually put in place over the last 5 years (Astruc *et al*., 2016, Carillier *et al*., 2013), starting in 2015 in Lacaune breed, then Manech and Basco-Béarnaise sheep breeds in 2017, the Alpine and Saanen goat breeds in 2018 and the Corse sheep breed in 2020. With GS, progeny test has been totally (in sheep breed) and partially (in goats) suppressed and young males with genomic proofs are used as sires since sexual maturity, allowing a decrease in generation interval. The genetic selection pressure is done using GEBVs at birth, with reliabilities (using the method to approximate reliabilities in single-step genomic evaluation proposed by Misztal *et al*., 2013) ranging from 0.40 to 0.70 according to the reference population size. Currently, the practical impact of GS has only been assessed in the Lacaune breed as the other breeds have just started. This impact has been estimated at a 30% higher genetic progress of the total merit index than traditional selection.

3. Current breeding goals

The breeding goals take into account production (fat & protein yields and contents) and functional (somatic cells, udder morphology) traits for all breeds but Corse where the selection criterion is still milk yield. In addition, resistance to scrapie has been integrated since the early 2000's in sheep.

The weight of the functional traits varies between 40 and 50%, except in Black-Faced Manech (15%) and of course in Corse breed (milk yield only). The similar weights for the different traits indicate that the desired and economic objectives are similar and therefore robust across species and breeds.

This shows that resilience traits (somatic cell count for resistance to mastitis, PrP genotypings for resistance to scrapie and udder morphology for both a healthier udder and a better ability for machine milking) are already being taken into account and almost all breeds are already heading toward balanced breeding goals.

II – A strong effort of R&D to meet the needs of more balanced breeding goals

The main demand from the stakeholders, and mostly the breeders, is to improve the resilience and the ability of adaptation of their animals. The resilience is intended as the ability of the animals, to undergo minimal perturbation from their performance trajectory and to get a fast recovery when submitted to an environmental challenge (climatic, disease, nutritional, etc). The adaptation is intended as the ability of the animals to live, breed and perform in their pedo-climatic environment and traditional system of production.

The need to improve efficiency also exists, even though it is maybe less pressing, in dairy sheep and goats than resilience. Efficiency consists in managing an optimal input/output balance. In turn, this means having good dairy, growing, reproduction and health performances, without excessive feed intake (feed efficiency) and without producing excessive greenhouse gases. This paper only focuses on resilience and adaptation.

Farmers, breeding organisations and related stakeholders are increasingly aware of the climatic change with its consequences on temperature and pastures and forages production and availability and of the more frequent health challenges (blue tongue, ticks, gastrointestinal parasites). They search animals able to tackle the challenges and manage the trade-off between efficiency of production and resilience, including reproduction and health and body reserves dynamics. In addition, the demand from the society of more agro-ecological agricultural system requires more resilient animals and production systems.

Besides the interest for improving adaptation and resilience, implementing more balanced breeding goals should result, in the long term, in a better management of genetic diversity. Indeed, selecting animals with a large spectrum of resilience-related abilities (in addition to efficiency-related abilities) will allow to maintain a large variation of alleles and haplotypes for a better capacity of adaptation to any possible environmental or external challenge.

Consequently, a huge effort has already been done and is currently being done to meet these needs with various R&D projects, among them SMARTER (Moreno *et al*., 2020, SMARTER web site, 2018), iSAGE (ISAGE website, 2016), RUSTIC (Astruc *et al*., 2021), ARDI (ARDI website, 2017;Granado-Tajado *et al*., 2019), PARALUT.

III – Actual and expected benefits from recent and on-going project on adaptation and resilience

The following sections give some examples of the issues that have been investigated with emphasis on some main results.

1. Adaptation to climatic change

The adaptation to climatic change has been studied in the iSAGE project in dairy sheep and goats from different countries (Carabaño *et al.*, 2020). The main French results illustrates that there is a genetic variation regarding the animal response on milk yield production across a range of temperature. Moreover, the genetic merit of an animal is not the same depending on the temperature and each animal has his own pattern of behavior. For milk yield, the ranking of the animals at low temperatures is not the same as the one for higher temperature. Therefore, it is possible and profitable to select animals better adapted to higher temperature.

2. Genotype x Environment interactions

A recurrent question from the breeders and their organizations is whether their selected animals and breeding goals are well adapted to all the systems in which the animals are raised. Some interesting answers were obtained in the iSAGE project (Buisson *et al.*, 2020, Larroque *et al.,* 2018). For example, in the Lacaune breed, if we split the population in clusters representing a relevant variety of systems which might possibly display genotype by environment interactions, we observe that (i) the heritability of the traits is similar across the systems, suggesting that there is no (or very small) scale effect (Figure 1); (ii) the high correlations between systems (with some exception for somatic cells) indicates that there are few re-ranking of animals across systems (Figure 2).

Therefore, we can conclude that selection is well adapted to the range of environments where the breeds are raised. This means that the best males whose breeding value has been estimated using information across a large and representative panel of flocks/herds (reference population or sufficient numbers of daughters in sufficient numbers of flock/herds) will also be the best across all the flocks/herds of the population.

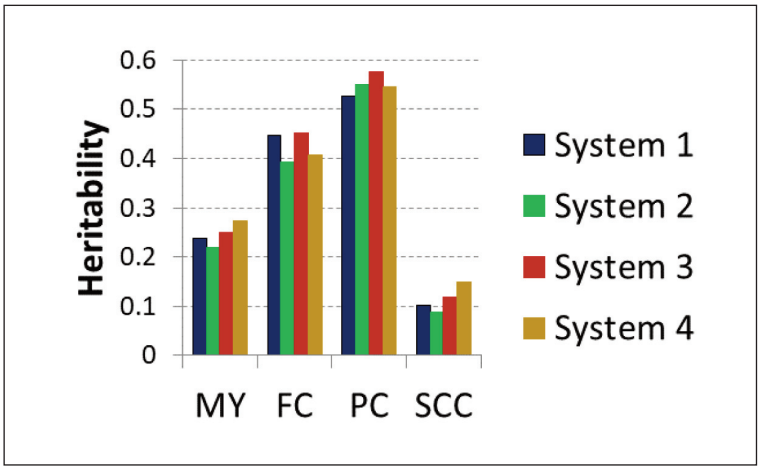

Fig. 1. Heritability of milk yield (MY), fat content (FC), protein content (PC) and somatic cells (SCC) across clusters of flocks representing the different production systems in Lacaune breed.

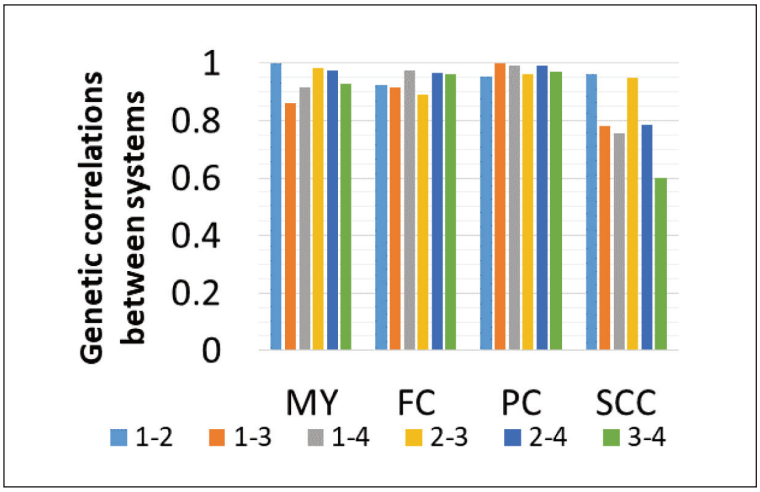

Fig. 2. Genetic correlations between clusters for milk yield (MY), fat content (FC), protein content (PC) and somatic cells (SCC) in Lacaune breed.

3. Functional longevity

Functional longevity is a good synthetic candidate trait to express resilience, because it incorporates different functional abilities for avoiding involuntary culling. Work based on the methods and tools developed in French dairy cattle shows that in both sheep and goats, functional longevity is positively correlated with udder health and morphology, fertility and persistency. Longevity based on life productive length, thus requiring data already collected through performance recording) should cope with various culling causes that cannot be easily and comprehensively recorded per se (Palhière *et al*., 2018, Buisson *et al*., 2020).

4. The SMARTER project and resilience-related traits

The Horizon 2020 SMARTER project (2018-2022) specifically deals with breeding for efficiency and resilience traits in small ruminants (Moreno-Romieux *et al*., 2020). The overall aim is to improve efficiency (higher feed efficiency, mitigation of greenhouse gases, optimization of dynamics of body reserve) while improving resilience, that means while managing the trade-off between both abilities.

In France, besides precise phenotyping in experimental farms, various measures are being carried out in a network of 30 commercial dairy farms. The phenotypes collected in the commercial farms are reproduction, longevity, culling causes, resistance to gastro-intestinal parasites, health scoring, medium infra-red (MIR) spectra as proxy for biological traits, metabolites to relate with health and body reserves. We must emphasize the great promise of MIR spectra, in dairy species for which samples of milk are regularly taken through the milk recording designs, to assess easily hard-to-measure traits.

This mix of academic (cutting-edge novel traits) and non-academic resources (easy-to-measure proxy for the latter novel traits) should result in practical recommendations for on-farm selection on resilience (and efficiency) traits in the future. The resilience traits studied in SMARTER are disease traits, behavioural traits, foetus and lamb/kid survival traits, longevity traits.

5. Resistance to gastrointestinal parasites

Resistance to gastrointestinal parasites is of increasing interest, especially in the Atlantic mild and humid area, at least for 2 reasons: because of growing evidence of anthelmintics resistance, and the negative impacts of anthelmintics molecules on the entomofauna of the soil in the pastures.

A design of controlled infections was conceived for rams gathered in station and has been used in the Pyrenean breeds for a decade (Jacqui *et al*., 2015). Faecal egg counts of nematodes are a proxy for resistance, with a large variability across rams (Figure 3). This trait is moderately heritable (Aguerre *et al*., 2018, Astruc *et al.,* 2017). Breeding values are yearly predicted and used in the breeding program. Breeding values of males are worth and useful, as proved by an experiment that showed that offspring from the 50% top sires (the more resistant) excrete on average half as many parasites eggs as those from 50% bottom sires (the more susceptible) (Aguerre *et al*., 2018).

Selection is therefore an efficient way to increase resistance to nematodes challenge in sheep, with a strategy based, (i) in the short term, on using resistant rams in flocks where there is presence of parasites resistant to treatment; (ii) in the medium term, on including resistance in the Total Merit Index. A similar approach is being tested in goats.

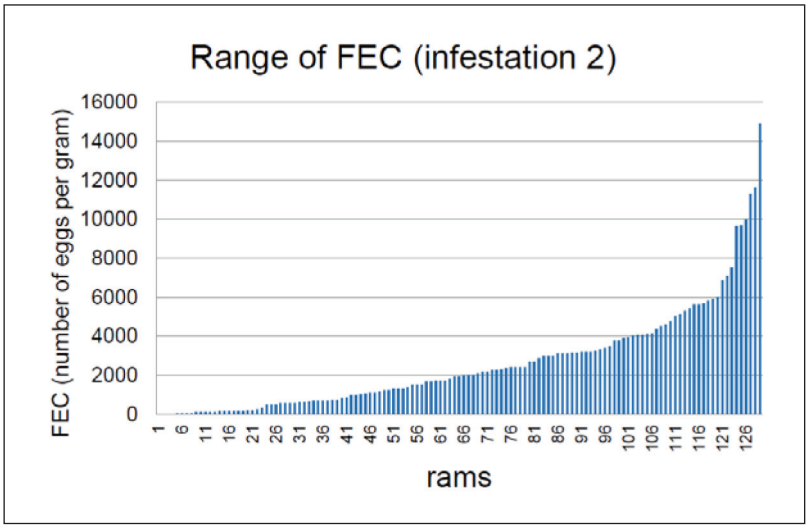

Fig. 3. Faecal Egg Count (FEC) distribution for young Blond-Faced Manech rams in a control challenge of infestation by Haemonchus contortus in 2014 (source Astruc *et al*., 2017).

6. Benefits from international cooperation

All the results presented in this paper, and the efficiency of the approaches leading to such results and to their concrete application in the breeding industry, lay on across-country cooperation. Regarding the research step, the different novel traits and novel approaches benefit from international projects with different teams working jointly on similar topics, exchanging their views, and permitting to build more robust “meta-results”. Then, regarding the application, small ruminant populations have a limited size and within country reference population are often small; consequently, as resilience and adaptation traits are hard-to-measure traits, pooling together data might be a prerequisite for success stories.

Consequently, it is beneficial to increase international cooperation, especially by proposing harmonized recommendations for recording resilience related traits, but also by assessing and promoting pooling of data to implement across country evaluations. Such an initiative of international cooperation is at the heart of some major projects such as SMARTER or ARDI. In the case of the SMARTER project, one of the purpose is to create an initiative of across-country evaluation in small ruminants. In the case of the ARDI project (Granado-Tajado *et al*., 2019), the goal is to go further and to implement a joint across-border selection program and a nutshell of an across-country breeding society.

IV – Conclusion

In French dairy small ruminants, breeders are increasingly addressing the issue of selecting more adapted and more resilient sheep and goats. Global warming, new health challenges, demand of the society for more agro-ecological and sustainable systems are strong drivers and incentives for this impetus. Novel adaptation and resilience-related traits have been / are under study, thanks to various projects. Some of them might rapidly be / are already included in selection criteria. Building more balanced breeding goals should benefit from more efficient genomic selection and also from international cooperation. This puts emphasis on the importance of joining research and development, and academics' and stakeholders' input.

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