Identifying selection strategies based on the practices and preferences of small ruminant farmers to improve the sustainability of their breeding systems

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ABSTRACT

Small ruminant farming is of socio-economic and environmental importance to many rural communities around the world. The SMARTER H2020 project aims to redefine genetic selection criteria to increase the sustainability of the sector. The objective of this study was to analyse the selection and breeding management practices of small ruminant producers and breeders, linked with socio-technical elements that shape them. The study is based on farm surveys using semi-structured interviews conducted in five countries (France, Spain, Italy, Greece, and Uruguay) across 272 producers and breeders of 13 sheep and goat breeds, and 15 breed × system combinations. The information was collected in four sections. The first and second sections dealt with general elements of structure and management of the system and the flock/herd. The third section focused on selection and breeding management practices: criteria for culling and replacement of females, selection criteria for males, use of estimated breeding values and global indexes, and preferences for indexing new traits to increase the sustainability of their system. The fourth section aimed to collect socio-technical information. We used a data abstraction method to standardise the representation of these data. A mixed data factor analysis followed by a hierarchical ascending classification allowed the characterisation of three profiles of selection and breeding management: (1) a profile of producers (n = 93) of small flocks/herds, with little knowledge or use of genetic selection and improvement tools (selection index, artificial insemination, performance recording); these farmers do not feel that new traits are needed to improve the sustainability of their system. (2) a profile of producers (n = 34) of multibreed flocks/herds that rely significantly on grazing; they are familiar with genetic tools, they currently use AI; they would like the indexes to include more health and robustness characteristics, to make their animals more resistant and to increase the sustainability of their system. And (3) a profile of producers or breeders (n = 145) of large flocks/herds, with specific culling criteria; these farmers are satisfied with the current indexes to maintain the sustainability of their system. These results are elements that can be used by private breeding companies and associations to support the evolution of selection objectives to increase the resilience of animals and to improve the sustainability of the small ruminant breeding systems.

Implications

Farmers' expectations concerning new selection traits to improve the sustainability of their farms are very different according to region and breeding system. The main difference observed between producers and breeders, whether involved in dairy, meat

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or wool production, is that breeding advice needs to focus on developing producer and breeder knowledge of the genetic selection and breeding management tools available to them. New breeding programs will also need to consider the diversity of production types and farmers' expectations, to enable them to use genetics as a means of adaption to local and to global changes.

Introduction

Small ruminants are reared in a wide diversity of environments. Sheep and goat farmers are mostly located in less favoured areas with harsh, arid and humid environmental conditions, such as mountains, hills and rangelands. Small ruminants are better adapted to such conditions than cattle (Ernst and Young France, 2008). Moreover, in many of these areas, small ruminants are the only source of livelihood. In addition, these regions are characterised by low-quality forage resources, limited access to good-quality alternative feeds and/or are prone to the impact of climatic change constraints and the occurrence of numerous hazards linked to climate change. Small ruminants are able to use such rangelands and contribute to maintaining biodiversity, providing meat, wool, and milk, sustaining livelihoods, food security and heritage and preventing fire damage in dry areas, among other ecosystem services. In the Mediterranean region, for example, small ruminants make the most of heterogeneous plant resources of variable availability on non-mechanisable or poor-quality land, with difficult relief conditions. (De Rancourt et al., 2006; Gabiña, 2011). They are also adapted to cope with drought and high temperatures (Petit and Boujenane, 2018; Aboul-Naga et al., 2014). Among small ruminant populations, local breeds are considered a genetic resource particularly well adapted to these difficult biophysical environments (Hoffmann, 2013; Hubert, 2011; Lauvie et al., 2015), and their presence helps maintain low-input production systems.

To maintain these benefits in environmentally and economically vulnerable areas, small ruminant farms must preserve their sustainability. As described by Prost et al. (2023) in response to sustainability issues, a variety of alternative agricultural models have emerged, and agroecology (Altieri, 1989) has gained increasing relevance in scientific, political, and social debates in recent years (Wezel et al., 2009). However, agroecological transition is a real challenge that needs to be addressed to increase the adaptive capacity of farms and farmers in environmentally and economically vulnerable areas. The adaptive capacity is based on farmers' dedication to the transition of the system and the mobilisation of local resources (Darnhofer et al., 2010). In livestock production, the agroecological transition can improve system sustainability by altering the diversity of resources used in a given area (Thénard et al., 2021). To develop more agroecological livestock systems (Dumont et al., 2012), many studies have investigated how the development of forage autonomy in livestock farming enhances the sustainability of farms (Lebacq et al., 2015; Magne et al., 2019; Ripoll-Bosch et al., 2013; Thénard et al., 2016). Another resource for farmers is the quest for an animal better adapted to the multiple challenges of sustainability. By focusing on available genetic resources, farmers can improve the adaptive capacity of breeding systems. (Thénard and Sturaro, 2022). In less favoured area, one way to improve adaptative capacity is to use well-adapted local breeds, recognising the role of hardiness in helping livestock cope with harsh environments (Hoffmann, 2013; Hubert, 2011; Lauvie et al., 2015). More generally, farmers have to deal with multiple sustainability challenges. Farmers can use breed substitution or breed combinations to adapt, relying on the genetic characteristics of certain breeds such as dual-purpose, local or hardy breeds, and crossbreeding (Magne et al., 2016; Quénon and Magne, 2021). Another solution is to use "new" selection traits to build more balanced selection objectives, for instance in dairy production, the aims are improving not only the level of milk production but also protein and fat content, longevity, health and reproduction (Miglior et al., 2005). For farms in harsh environments, where there are extensive management systems and/ or labour availability constraints (both reducing the capacity to provide animal care), there is a need for further diversification of selection objectives for small ruminant populations to incorporate functional traits such as behavioural and physiological adaptations, robustness, and health (Dwyer and Lawrence, 2005; Phocas et al., 2014; Marie-Etancelin et al., 2001).

To overcome the multiple challenges linked to sustainable small ruminant production, there is a need to develop new selection traits and breeding objectives, as a means of balancing the environmental, economic and social dimensions of future animal production systems (Olesen et al., 2000; Tixier-Boichard et al., 2015; Phocas et al., 2016). To produce balanced breeding objectives for agroecological transition, recent research seeks to find new selection traits based on the resilience and efficiency of the animal at different levels (animal, breed population and livestock farming system) (e.g., for sheep and goat sectors, Moreno-Romieux et al., 2020). Resilience is defined as an animal's ability to maintain an adequate production performance under challenging conditions (De Barbieri et al., 2023); efficiency is commonly defined as a measure of feed efficiency in animal performance (Le Graverand et al., 2023), but can be broader, when considering system efficiency. Further research has aimed to assess the economic impact of these new selection traits for different farming profiles (Theodoridis et al., 2023). However, integrating new selection traits into the breeding program and assessing the economic impact is not sufficient as a means of enabling change: farmers need to use the new traits and alter their selection/ breeding practices and management plans accordingly. Selection/ breeding practices in the context of new selection traits in small ruminants has not been widely studied, and where there is research it relates to dairy sheep breeding (Labatut et al., 2013; Perucho et al., 2020; Perucho, et al., 2019a; Perucho et al., 2019b). These studies have focused on evaluating farmers' practices with regard to existing collective tools for genetic improvement, and the choice of selection of their future breeding animals based on existing tools. There is a need to understand and analyse how farmers could integrate, or fail to integrate, new resilience and efficiency traits into their breeding practices, for more sustainable livestock system. These new traits would be included to establish new breeding and management strategies. The aim of this study was to identify the selection and breeding practices implemented by small ruminant farmers to enhance the sustainability of their livestock. To achieve this, we identify current practices related to the selection and breeding of animals including the culling criteria used by farmers as an important lever for choosing the animals that will make up the flock/herd. Also, we analyse the views of farmers on the introduction and use of new selection traits. These views are analysed across different systems, breeds and socio-technical environments. Preliminary results had been published in abstract form (Quénon et al., 2022) for the EAAP congress in 2022.

Material and methods

Smarter project as support of this work

The research work that led to this article was part of the European SMARTER (SMAll RuminanTs breeding for Efficiency and Resilience) project. The consortium of the SMARTER project included 27 partners from 13 European countries with 14 Academic or research organisations, and 13 non-academic organisations. The SMARTER project focused on several animal populations, including different breeds and types of production in diverse environments. The analysis of a variety of situations is intended to reinforce this project's results. It is within this general framework that our research work was conducted. Partners from five countries were involved (France, Greece, Italy, Spain and Uruguay) in this research work. Partners in each country defined the relevant breed to study and were responsible for collecting data from the farmers they identified. The general methodological approach is detailed in Supplementary (Figure S1).

Sampling design

To identify a variety of selection and breeding practices, we wanted to cover different production situations in different countries (France, Greece, Italy, Spain and Uruguay). For each of these countries, the most relevant breeds and systems to study were identified on the basis of the agroecological challenges of these territories. Different combinations of farming systems and breeds were identified for each country, and finally 15 combinations (system × breed) were selected (Table 1). In each country and for each breed, we built a breeding sample with experts (agricultural advisers and technicians, geneticists) from private breeding companies and associations, as well as public organisations. For each system × breed, we aimed to cover diverse breeding situations comprising:

(i) The features of the geographical area (e.g. for systems breeding Manech Tête Rousse, we have distinguished between plain / piedmont / mountain areas).
(ii) The farmer's role within the organisation. For the livestock farmers who are eventually, and solely, users of the genetics, we will use the word Producer. For the breeders, who produce animals which can be selected for the breeding programmes, we will use the word Breeder. In general, we will use the word Farmer to group these two categories together.
(iii) Some specific production practices such as lambing/kidding period, prolificity, stocking rate, conventional or organic farming, transhumant or non-transhumant systems.
(iv) Products destination: industry, on-farm processing.

The selection of the farms to be surveyed for each system x breed was based on (i) the farms available in the technical monitoring of the private breeding companies and associations and (ii) the availability and interest of the farmers in participating in this study.

Interview design and process

A semi-structured interview guide was developed that was organised into four main sections (Supplementary Table S1). The first section dealt with general elements of structure and farm management for crops (agricultural area, crop rotation, use of fertilisation and pesticides) and the second section dealt with data for livestock (species, breeds, replacement and culling practices including rate and criteria, reproduction management including use of artificial insemination and/or natural mating, etc.). The third section dealt with the selection and breeding practices used by farmers to manage their flock and herd, and their use of tools and genetic indicators. Farmers were asked to rate their level of agreement, on a 7-point scale (from 1 = "Strongly disagree" to 7 = "Strongly agree", with 4 = "Neither agree nor disagree"), with a series of statements that aimed to assess their knowledge and use of, and views on, estimated breeding values (**EBVs**) and selection indexes (see example Fig. 1). We also asked farmers to rate out of 10 a series of general criteria they used to select breeding animals (e.g. EBVs, health status, pedigree, purchase price, farming system) and a series of specific breeding traits they pay attention to, for which EBVs are available (milk quantity, protein and fat contents, wool traits, litter size, birth and 8-week weight, etc.). If relevant to them, they were then asked to specify any criteria or breeding traits that they use, which had not been mentioned. Farmers were also asked for their preferences regarding breeding traits, for which no EBVs were available, but were nevertheless important to them in order to improve the sustainability of their

Table 1
Description of the combinations of farming systems and sheep or goat breeds that were investigated in the farms-sample studied in the SMARTER project to analyse the producers' and breeders' practices and preferences for breeding and genetics.

Features of the Livestock Farming System (LFS)					
Country	Species and Sector	Description of System × Breed	Intensity level of the LFS management[1]	Breed	Productivity level of the breed[2]
France	Dairy sheep	Milk for PDO Roquefort Cheese	+	Lacaune	++
		Milk for PDO and local cheeses in Pyrénées	+	Manech Tête Rousse	+
	Meat sheep	Lamb production in rangeland area	+/–	Causses du Lot	–
		Livestock& Mixed livestock-crops system	+	Romane	+
Greece	Dairy sheep	Milk for Greek cheese products	+/–	Assaf	++
				Chios	+/–
				Frizarta	+/–
				Lacaune	++
	Milk – meat sheep	Transhumance system with dual-purpose sheep (milk & meat)	–	Boutsko	–
	Dairy goats	Very extensive system with dairy goats	–	Skopelos	+/–
Italy	Dairy goat	Milk production in Alps mountain Semi-intensive system in Alps mountain with dairy goat	+/–	Alpine	+
				Saanen	+
Spain	Dairy sheep	Intensive system of dairy sheep	++	Assaf	+
Uruguay	Wool-meat sheep	Extensive system beef cattle & sheep production (wool/lamb) grazing native pastures	– –	Corriedale	–
				Merino	–

PDO: Protected Designation of Origin
[1] ++ intensive system; + semi-intensive system; +/- semi-intensive or extensive system; – extensive system; – – very extensive system.
[2] ++ high productivity; + medium productivity; +/- medium or low productivity; – low productivity.

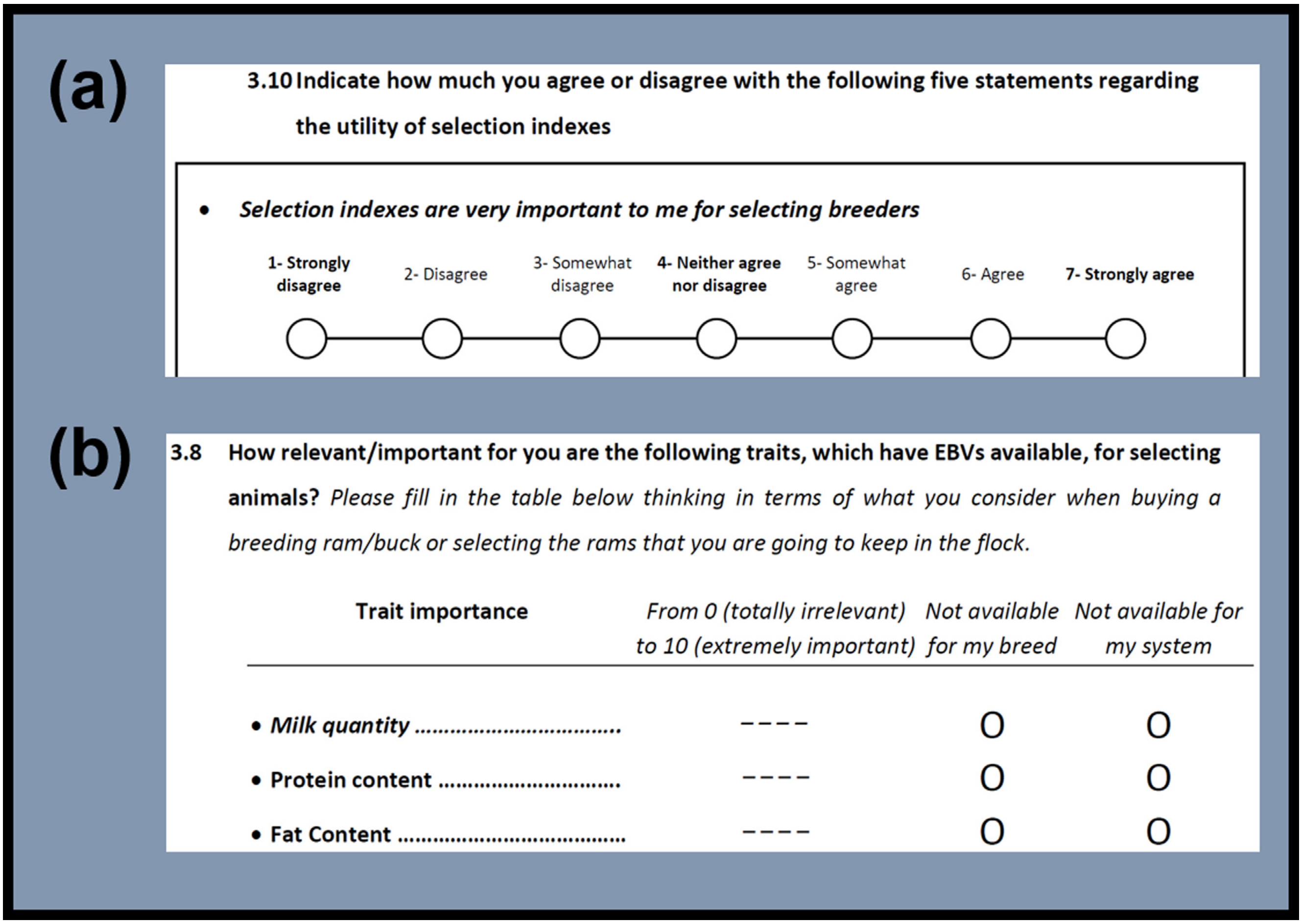

Fig. 1. Examples of question types: (a) level of agreement on a 7-point scale and (b) assignment of a score out of 10. This method was used in the SMARTER project's face-to-face interview guide concerning the practices and preferences of sheep and goat farmers in terms of selection and genetics.

farming system. The fourth section aimed to collect socio-technical characteristics to describe farmers' preferences and choices according to their status and involvement in the genetic improvement system (Producer vs Breeder). We asked farmers whether they were a producer using genetic progress or a breeder making genetic progress, the tools they use and the preferred channels for obtaining information on developments and news on genetics, the most important issues reducing genetic gain or increasing adoption of breeding practices in the industry, in their view. We also asked farmers to rate their level of agreement with a series of statements about the requirements of performance testing, the advantages and disadvantages of genomics and DNA technology, and crossbreeding. Finally, we asked farmers to rate their own level of agreement with sharing information between countries and organisations on pedigrees, phenotypes (i.e. performance) and genotypes (i.e. for genetic evaluations), and to express the extent to which they thought such sharing would be beneficial or not. The final number of interviews that were conducted per country and breed is detailed in Table 2. A total of 272 on-farm interviews in five countries (France, Greece, Italy, Spain and Uruguay), of both producers and breeders of 13 sheep and goat breeds, were conducted.

Data editing

In order to standardise the collection of information from the surveys across five countries and to facilitate their compilation, task members agreed to develop and use a common semi-computerised file template. Raw data in each corresponding section of the interview guide were gathered. While some questions in the interview guide resulted in standardised (e.g. closed-ended questions) and quantitative data, others provided, by design, a wide range of responses, resulting from the expression of the singularity of interviewed farmers. Therefore, a data abstraction method from knowledge engineering (Girard et al., 2008) was used that consisted of building categorical variables broken down into classes to characterise the diversity in farmers' practices regarding selection and breeding management. A total of 12 active variables (Vi.j, i = 1–10, j = 1–5 for categorical variables), both categorical (n = 10) and quantitative (n = 2) that best reflected such diversity among the sampled farmers, were selected (Supplementary Figure S2). Three variables aimed to describe general practices of flock configuration: (i) the replacement rate (V1, in %), (ii) the percentage of animals artificially inseminated in the first attempt on the females of the flock (V2, in %), and (iii) the use of artificial insemination (V3). Two variables described the type of integration of the farmer in the socio-technical environment of the genetic improvement system: (i) the enrolment in a performance-recording organisation (V4) and (ii) the status as producer or breeder (V5). Two variables described culling practices: (i) the number of culling criteria used (V6) and (ii) the type of culling criteria used (V7). Two variables described the current selection practices of farmers: (i) the type of criteria used to select animals (live animals and semen) such as genetic (e.g. EBV values), phenotypic (e.g. actual milk performances) or socio-economic (e.g. purchase price, relationship with the seller) considerations (V8) and (ii) the number of traits

Table 2
Number of conducted interviews per country and sheep or goat breeds in the farms-sample studied in the SMARTER project to analyse the producers' and breeders' practices and preferences for breeding and genetics.

Country	Species/Sector	Breed	No. of interviews	Total
France	Dairy sheep	Lacaune	22	83
		Manech tête rousse	21	
	Meat sheep	Causses du Lot	21	
		Romane	19	
Greece	Dairy sheep	Assaf	6	60
		Chios	11	
		Frizarta	13	
		Lacaune	21	
	Milk-meat sheep	Boutsko	5	
	Dairy goats	Skopelos	4	
Italy	Dairy goat	Alpine	35	50
		Saanen	15	
Spain	Dairy sheep	Assaf	63	63
Uruguay	Meat-wool sheep	Corriedale	9	16
		Merino	7	
Total				272

on which farmers-based selection of breeding animals (V9). Three variables aimed to describe farmers' views on sustainability of their system, characterising the desirable future direction of breeding objectives: (i) the type of traits viewed as relevant to achieve it (V10), (ii) the number of traits to select on to increase sustainability of their system (V11), and (iii) farmers' views on changes to be made to the selection indexes (V12). Furthermore, a set of supplementary variables (SVi.j, i = 1–29 for quantitative variables, j = 1–13 for categorical variables) that described general characteristics of the farm or farmers' practices that were not directly related to the characterisation of selection and breeding management was also considered (Supplementary Table S2). Any supplementary variables were nevertheless relevant to illustrate the groups identified in further analyses: country, total Utilised agricultural area, crop rotation with relative percentages of each crop type, total livestock units, stocking rate, etc.

Data analysis

The objective was to characterise and analyse the diversity of practices implemented by small ruminants' farmers regarding flock/herd selection and breeding practices and improvement in farm sustainability through genetics. As developed by Pagès (2004) to analyse the pattern of relationships of individuals described by both categorical and quantitative variables, we performed Factorial Analysis of Mixed Data (**FAMD**) of a subset of the dataset (272 farms × 12 active variables of which 10 were categorical ones and two quantitative ones). Then, Hierarchical Clustering on Principle Components (**HCPC**) was performed, which used the results of the FAMD to discriminate and characterise groups of farmers with different strategies of selection and breeding management and improvement of farm sustainability through genetics. All statistical analyses were performed using RStudio software (version 4.0.4, RStudio Inc., Boston, MA, USA), with FactoMineR (Lê et al., 2008) and factoextra (Kassambara and Mundt, 2017) packages (Supplementary Material SM1).

Results

The integration of producers and breeders into the socio-technical system and their views on sustainability

The two first axes of the FAMD explained 15.7 and 11.2% of the total inertia, respectively (Fig. 2). We considered these as guidelines for selection and breeding management by small ruminants' farmers and views on genetics and its development. Axis 1 was determined mainly by the integration level of small ruminant farmers in the socio-technical genetic improvement system and performance recording. On the right side of axis 1 (Table 3), were the practices of producers or breeders (V4.1) enrolled in performance recording organisations (V5.1) that consisted of farmers with a significantly higher use of artificial insemination (V2, V3.1, V3.2), relatively stricter flock configuration management, with higher replacement rate (V1), and culling and selection of breeding animals on numerous criteria (V6.3 and V9.3, respectively). Selection practices could include several criteria, but were always genetic-based (V8.2, V8.3) and production-driven (V7.3), such as milking speed and lifetime production and also included traits to increase their farming system sustainability (V10.3). Such practices were associated with an interest in genomics and its development (SV25.2), no-use of crossbreeding (SV23.1), and an unclear opinion on information sharing (SV27.3) with some fears but also expectations of benefits for breeding programmes, breed recognition and import/export of breeding animals (SV28.4). Conversely, on the left side of axis 1 (Table 3), were the farmers with little knowledge of genetic selection (V10.1). These farmers were not enrolled in performance recording organisations (V5.2), unaware of (or unfamiliar with) their genetic progress (V4.2) and based their selection practices on non-genetic criteria (V8.4). Such practices consisted of natural mating with no use of artificial insemination (V3.3) and relatively less strict management of flock configuration (V1, V2, V6.2), but with a focus on functional traits (V7.4). Increasing their system sustainability was viewed as requiring many new traits to select on (V11.3), none of them being related to production but to robustness and health (V10.5). Such views on practices to increase sustainability were associated with a lack of interest in genomics, where development was considered of low priority (SV25.1). Moreover, these farmers were less reluctant to use crossbreeding (SV23.2) and to share information between countries and breeding organisations (SV27.1). Axis 2 was determined mainly by small ruminant farmers' views on farm sustainability and the practices they intended to adopt to make their management more efficient. On the top side of axis 2, there were farmers who did not believe genetics could contribute to increasing their farm sustainability, or who did not view sustainability as a relevant objective. They did not believe there were any traits to select that could increase sustainability (V11.1), nor did they feel the need to (V10.2), as they were satisfied with the current indexes (V12.3) or considered themselves not qualified

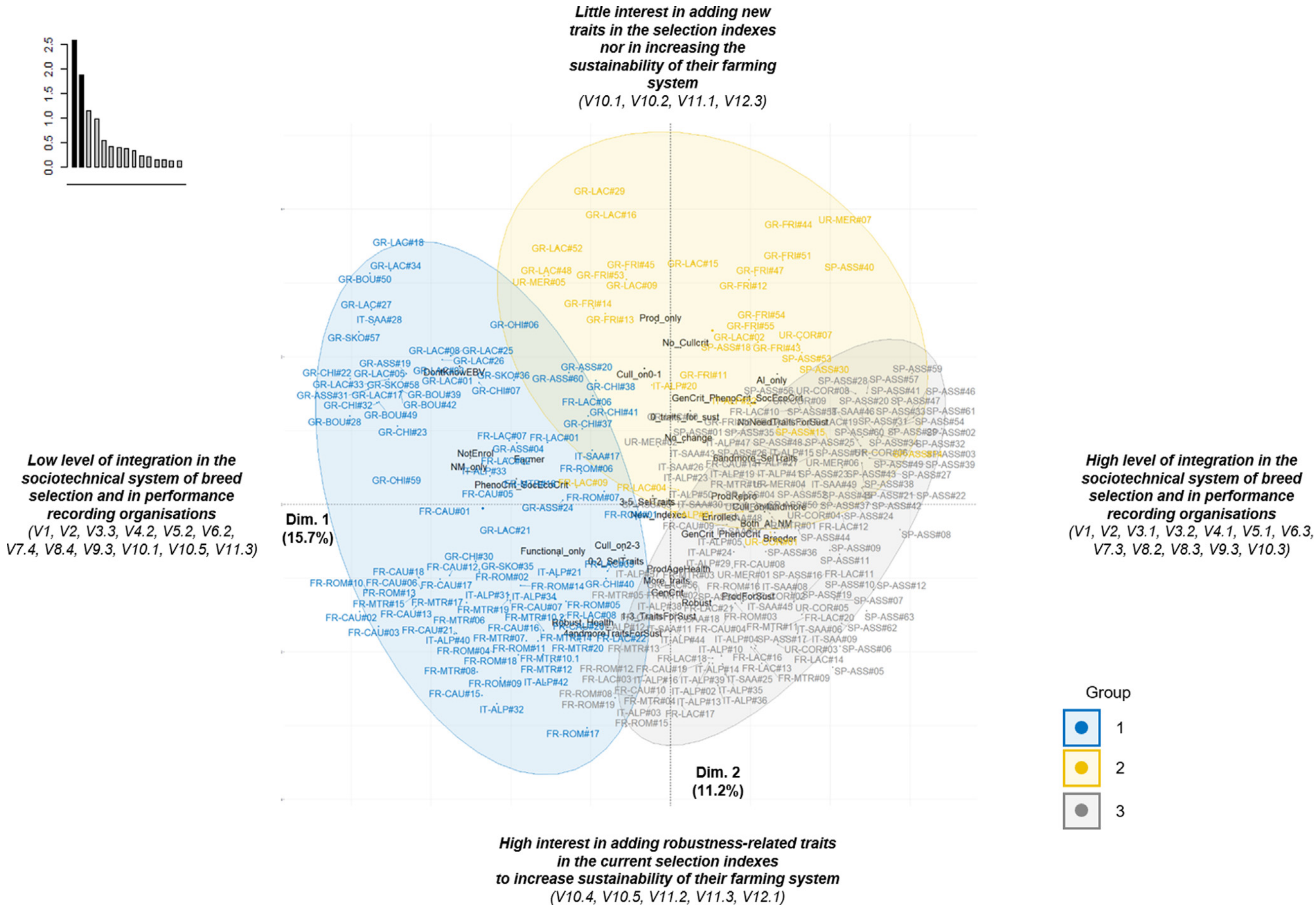

Fig. 2. Three groups of sheep or goat farmers distinguished by their genetic management strategies, their views on sustainability and strategies to increase it on their farms (Dim. 2), according to their level of integration in the socio-technical system of breed selection and performance recording (Dim. 1). The classes of active variables (Vi.j) determining each dimension are defined in Table 3. Group ellipses are plotted against a 90% confidence interval. Data produced for the SMARTER project concerning selection and genetic practices and preferences of producers and breeders.

enough to express their opinion (V10.1). Many farmers managed culling with few criteria (V6.1, V7.5) and mostly production-driven (V7.1). Conversely, on the bottom side of axis 2, there were farmers with expectations of the possibilities offered by genetic selection tools to increase their farming system sustainability. They were mostly not satisfied with the current indexes, in which they wanted to add numerous new traits (V11.2, V11.3, V12.1), especially some related to the functional traits of animals: thus, they viewed their system sustainability through more robustness and animal condition improvement, as well as health (V10.4, V10.5).

Three patterns identified to describe the strategies for selection and genetic choices

The clustering process using the coordinates from the two FAMD axes resulted in three groups of farmers that differed in their level of integration in the socio-technical genetic improvement system and performance recording and to their views on sustainability and the practices to increase sustainability on their farm, through genetics (Fig. 2). Groups can be described in two ways: firstly, identifying the main modalities present in the group (noted M/C); e.g. the group is composed of 93% (M/C) producers; secondly notifying that a modality of the whole sample is essentially present in this group, but not the single one of this group (noted C/M); e.g. the main part of farmers using crossbreeding are mainly in this group (91% C/M).

Group 1 'Non-genetic producers seeking robustness and multifunctionality'. This group of 93 individuals (Table 4) was mainly composed of producers (93% M/C) not enrolled (63% M/C) in performance control organisations. The majority of these farmers did not use artificial insemination (6% using), but they bought rams for natural mating (80% M/C and 93% C/M). They selected their own animals based on non-genetic traits (57% M/C and 73% C/M) and culled them for various traits, including functional ones (63% C/M). The replacement rate was lower in this group (23%), hence, resulting in relatively older-animal flocks. In fact, they had relatively less knowledge of genetics, with the majority (88% C/M) not knowing the meaning of EBVs, and therefore, did not use the tools linked to genetic progress (e.g. indexes, artificial insemination). Their views on sustainability varied, but a significant proportion of producers (42% M/C and 57% C/M) wished to use robustness and health traits to improve the sustainability of their farm.

These producers had relatively small multibreed flocks (47 vs 74 average of Livestock Unit in the group and the whole sample) and used a high percentage of grassland and pasture in the Utilised Agricultural Area (59 vs 43% average in the group and the whole sample). Producers using crossbreeding are predominant in this group (91% C/M), as were two out of three organic farmers (65% C/M) and a large proportion (66% C/M) of meat producers. These were mainly Greek (41% M/C) and French (49% M/C) farmers. Specifically, all producers rearing Chios and Boutsko sheep, and Skopelos goats and a large proportion of Romane (68% C/M) and Causse du Lot (67% C/M) sheep farmers were in this group.

Table 3
Classes of the active (Vi.j) and supplementary variables (SVi.j) significantly represented on the axis from the factorial analysis of mixed data performed to describe genetic management of sheep or goat farmers in the SMARTER project to analyse the producers' and breeders' practices and preferences for breeding and genetics.

Axis/side	Selected classes	Coord.[a]	(cos^2)[b]	v.test[c]
Axis 1 Left Side	V2 – Percentage of AI for first mating*	−0.774*	0.599*	/
	V1 – Replacement*	−0.319*	0.102*	/
	SV16 – Total livestock units*	0.238*	0.056*	/
	SV14 – Percentage of areas using pesticides*	0.197*	0.039*	/
	SV21 – Stocking rate*	0.137*	0.019*	/
	V4.1 – Breeder	−1.357	0.888	−13.086
	V5.1 – Enrolled in performance recording	−0.872	0.871	−12.164
	V3.2 – Use both AI and natural mating	−1.034	0.805	−11.660
	SV1.4 – Spain	2.158	0.796	9.841
	V10.2 – No need new traits for sustainability	1.344	0.508	9.058
	SV26.1 – Don't buy males	1.122	0.925	7.734
	V8.2 – Selection on genetic and phenotypic criteria	0.828	0.407	6.775
	V6.3 – Culling on 4 criteria and more	1.176	0.351	6.528
	V7.3 – Culling on production and reproduction	0.862	0.316	6.265
	SV24.5 – Zootechnical problems only	0.958	0.799	5.640
	V9.3 – Selection on 6 traits and more	1.130	0.266	5.416
	SV27.3 – No clear-cut opinion on information sharing	1.152	0.651	5.145
	SV25.2 – Want to be part of its development	0.287	0.679	4.536
	SV23.1 – Don't use crossbreeding	0.102	0.675	4.110
	SV28.4 – Benefits for breed program	1.029	0.810	3.650
	SV15.1 – Conventional farming	0.122	0.589	3.609
	SV1.5 – Uruguay	1.361	0.610	2.826
	SV2.4 – Wool meat sheep	1.386	0.539	2.782
	V10.3 – Production traits for sustainability	0.908	0.076	2.704
	V8.3 – Selection on genetic, phenotypic, socio-economic criteria	0.773	0.070	2.587
	V3.1 – AI only	1.337	0.070	2.488
	V11.1 – no traits for sustainability	0.247	0.031	2.245
	SV29.8 – Various expectations	0.568	0.471	2.101
	SV2.2 – Dairy sheep	0.196	0.079	1.974
Axis 1 Right side	SV12 – Percentage of meadows/grassland in UAA*	−0.355*	0.126*	/
	SV22 – No. of breeds in the flock*	−0.254*	0.064*	/
	V3.3 – Natural mating only	−2.460	0.885	−13.187
	V4.2 – Producer	−1.836	0.852	−12.852
	V5.2 – Not enrolled in performance recording	−2.511	0.853	−12.155
	V8.4 – Selection on phenotypic and socio-economic criteria	−1.932	0.686	−9.720
	V10.1 – Don't know EBVs meaning	−2.646	0.534	−9.123
	SV26.2 – Don't know EBVs meaning	−2.436	0.568	−8.399
	SV1.2 – Greece	−1.686	0.411	−7.448
	V7.4 – Culling on functional traits only	−1.408	0.369	−6.219
	V6.2 – Culling on 2–3 criteria	−0.599	0.220	−5.008
	V10.5 – Robustness and health for sustainability	−1.035	0.188	−4.963
	SV2.3 – Meat sheep	−1.387	0.352	−4.853
	SV1.1 – France	−0.874	0.270	−4.809
	SV25.1 – Genomics is not a priority	−1.038	0.679	−4.536
	SV24.7 – Various problems	−1.527	0.580	−4.380
	SV27.1 – Agree with information sharing	−0.352	0.531	−4.371
	SV23.2 – Use crossbreeding	−2.411	0.675	−4.110
	SV15.2 – Organic farming	−1.542	0.589	−3.609
	V9.1 – Selection on 0–2 traits	−0.577	0.108	−3.314
	SV26.3 – EBVs are not relevant or not provided	−1.261	0.595	−3.108
	SV3.2 – Meat sheep	−0.644	0.196	−2.724
	V11.3 – 4 traits and more for sustainability	−0.788	0.065	−2.598
	SV29.6 – Increase import–export	−0.696	0.298	−2.329
	SV28.7 – Economic benefits	−0.624	0.327	−2.119
	SV26.5 – Trust judgment for the seller	−1.084	0.191	−2.097
	SV29.1 – Don't know/not interested	−1.758	0.515	−1.998
Axis 2 Top	V11.1 – 0 trait for sustainability	1.263	0.797	13.553
	SV1.2 – Greece	1.894	0.519	9.900
	V6.1 – Culling on 0–1 criteria	1.840	0.403	8.683
	V10.2 – No need new traits for sustainability	1.046	0.308	8.339
	V7.1 – Culling on production only	2.456	0.386	7.844
	V10.1 – Don't know EBVs meaning	1.868	0.266	7.619
	SV26.2 – Don't know EBVs meaning	1.668	0.266	6.804
	V12.3 – No change of indexes	0.836	0.276	6.263
	SV2.2 – Dairy sheep	0.525	0.566	6.257
	V8.3 – Selection on genetic, phenotypic, socio-economic criteria	1.371	0.221	5.427
	V4.2 – Producer	0.541	0.074	4.480
	V7.5 – No culling criteria	2.121	0.160	4.476
	SV13.3 – No fertilisation	0.938	0.647	4.158
	V9.3 – Selection on 6 traits and more	0.705	0.104	4.002
	V3.1 – AI only	1.761	0.122	3.876
	V5.2 – Not enrolled	0.621	0.052	3.559

(continued on next page)

Table 3 (*continued*)

Axis/side	Selected classes	Coord.[a]	(cos^2)[b]	v.test[c]
	SV19.1 – No other species	0.205	0.595	3.486
	SV13.2 – Mineral fertilisation only	1.255	0.278	2.978
	V3.3 – Natural mating only	0.440	0.028	2.789
	SV29.3 – Increase breed population and import–export	0.819	0.258	2.503
	SV29.6 – Increase import–export	0.609	0.228	2.410
	SV25.2 – Want to be part of genomics development	0.126	0.131	2.361
	SV24.1 – No specific problems	0.575	0.163	2.309
	SV28.5 – Benefits for breed recognition and economic benefits	0.689	0.202	2.104
	V8.4 – Selection on phenotypic and socio-economic criteria	0.342	0.021	2.034
Axis 2	SV12 – Percentage of meadows/grassland in UAA*	−0.197*	0.039*	/
Bottom	SV22 – Other land area (moorland, woodland, heathland)*	−0.182*	0.033*	/
	V11.2 – 1–3 traits for sustainability	−1.438	0.542	−9.687
	V10.5 – Robustness and health for sustainability	−1.667	0.488	−9.455
	SV1.1 – France	−1.224	0.531	−7.968
	V11.3 – 4 traits and more for sustainability	−1.670	0.294	−6.510
	V6.2 – Culling on 2–3 criteria	−0.623	0.239	−6.170
	SV3.2 – Meat sheep	−1.390	0.353	−5.755
	V12.1 – Adding new traits in current indexes	−1.098	0.238	−5.369
	V7.2 – Culling on production. health and age	−0.943	0.181	−4.715
	V9.1 – Selection on 0–2 traits	−0.691	0.155	−4.693
	V7.1 – Culling on production only	−1.313	0.159	−4.625
	V4.1 – Breeder	−0.384	0.074	−4.480
	V3.2 – Both AI and natural mating	−0.324	0.081	−4.422
	V10.4 – Robustness for sustainability	−1.346	0.155	−4.206
	V8.1 – Selection on genetic criteria	−1.263	0.142	−4.119
	SV1.3 – Italy	−0.838	0.261	−3.906
	V7.4 – Culling on functional traits only	−0.701	0.092	−3.666
	SV26.5 – Trust judgment of the seller	−1.590	0.411	−3.638
	V5.1 – Enrolled	−0.211	0.052	−3.559
	SV19.2 – Presence of other species	−0.615	0.595	−3.486
	SV20.1 – Both selling to industry and transformation at the farm	−1.285	0.574	−3.461
	SV2.1 – Dairy goat	−0.685	0.215	−3.350
	SV13.1 – Both mineral and organic fertilisation	−0.358	0.428	−3.317
	SV28.6 – Don't know what is to expect from international evaluation	−0.873	0.527	−3.132
	V8.2 – Selection on genetic and phenotypic criteria	−0.321	0.061	−3.103
	SV24.4 – Organisation and zootechnical problems	−0.745	0.496	−3.085
	SV20.3 – Transformation at the farm	−0.710	0.344	−3.021
	SV26.4 – Request EBVs	−0.449	0.424	−2.971
	SV29.1 – Don't know/not interested	−0.717	0.473	−2.708
	SV25.1 – Genomics is not a priority	−0.457	0.131	−2.361

AI: animal insemination; UAA: unit of agricultural area; EBV: estimated breeding values.
[a] Coordinates of the variables on the X and Y axis.
[b] cos^2 for the quality of the variable.
[c] value of the *t*-test.
[*] For quantitative variables (in italics), there are no v.test values.

Group 2: 'Genetic producers seeking production efficiency'. This smaller group of 34 individuals (Table 4) was mainly composed of dairy sheep producers (79% M/C). In this group, flock configuration management practices were based on artificial insemination, with a higher level of use (65%) than in group 1, and productivity was the main criterion for culling animals (65% M/C and 85% C/M). These producers were not interested in specific traits to improve sustainability (71% M/C). Their farms had a relatively low proportion of grassland and pasture in the Utilised Agricultural Area (28 vs 43% average in the group and the whole sample) and the farm areas using pesticides were lower (9 vs 23% average in the group and the whole sample). Half of these producers were Greek (56% M/C); producers rearing Frizarta sheep were mainly part of this group (92% C/M).

Group 3: 'Breeders seeking production efficiency and sustainability'. This large group of 145 individuals (Table 4) consisted mainly of breeders (97% M/C). They had specific flock/herd configuration practices, such as greater use of artificial insemination (59%) combined with natural mating (96% M/C) and a higher replacement rate (27%). These breeders were enrolled in performance recording organisations (99% M/C), had a sound knowledge of the genetics criteria used to select animals (66% M/C), and wanted to be involved in the development of genomic tools (86% M/C). Production traits were the main criteria for selecting animals (72% M/C). For culling purposes, these farmers used the criteria of low level for production and reproductive performances (59% M/C, 72% C/M) or with the animal's age and health (27% M/C, 70% C/M). Some of these breeders were satisfied with the current indices, for the purpose of their system sustainability (51% M/C) or believed that production traits are important in increasing sustainability (77% C/M). Other breeders in this group (20% M/C) wished to include robustness and health traits to increase the sustainability of their farm. Most Spanish breeders were in this group (90% C/M), with the majority rearing Assaf sheep (83% C/M). Many goat farmers (70% C/M) were in this group, rearing mainly two breeds: Saaneen (87% C/M) and Alpin (71% C/M). These larger herds (96 vs 74 Livestock Unit in the group and the whole sample) were reared in relatively intensive farming systems, with a low percentage of meadows and pastures (36 vs 43% average in the group and the whole sample), and with higher farm areas using pesticide (30 vs 23% average in the group and the whole sample).

Table 4
Characteristics of sheep or goat farms in three groups of selection strategies. Classes of the active variables (Vi.j) and supplementary variables (SVi.j) are defined in Supplementary Figure S2 and Supplementary Table S2, respectively. Data from the farms-sample studied in the SMARTER project to analyse the producers' and breeders' practices and preferences for breeding and genetics.

Characteristic	Group 1 (n = 93)	Group 2 (n = 34)	Group 3 (n = 145)
Classes of variables significantly represented in the group	Natural mating only (V3.3) Producer (V4.2) Not enrolled in performance control recording (V5.2) Don't know EBVs meaning (V10.1) Selection on non-genetic criteria (V8.4) Culling on functional traits only (V5.3) Robustness and health for sustainability (V10.5) France (SV1.1), Greece (SV1.2) Meat sheep (SV2.3)	Culling on 0 to 1 criteria (V6.1) Culling on production traits only (V7.2) Greece (SV1.2) No need traits for sustainability (V10.2) 0 trait for sustainability (V11.1) Dairy sheep (SV2.2)	Breeder (V4.1) Both artificial insemination and natural mating (V3.2) Enrolled in performance control recording (V5.1) No need traits (V10.2) or production traits for sustainability (V10.3) Spain (SV1.4)
Group mean value of quantitative variables that are significantly higher than the overall sample mean	Percentage of meadows/grassland in UAA (SV12) No. breeds (SV22)	Percentage of artificial insemination (V2)	Percentage of artificial insemination (V2) Total LSU (SV18) Percentage of areas on which pesticides are used (SV14) Replacement rate (V1)
Classes of variables significantly not represented in the group	Breeder (V4.1) Both artificial insemination and natural mating (V3.2) Enrolled in performance control recording (V5.1) Spain (SV1.4) Selection on genetic and phenotypic criteria (V8.2) Don't need new traits for sustainability (V10.2)	Culling on 2 to 3 criteria (V6.2), on 4 and more (V6.3) Culling on production and reproduction traits (V7.5) or on Production, age and health (V7.4) 1 to 3 traits (V10.2), 4 and more traits for sustainability (V10.3) Robustness and health for sustainability (V11.5) France (SV1.1) Meat sheep (SV2.3)	Producer (V4.2) Natural mating only (V3.3) Not enrolled in performance control (V5.2) Greece (SV1.2) Don't know EBVs meaning (V11.1) Culling on 0 to 1 criteria (V6.1) Robustness and health for sustainability (V11.5)
Group mean value of quantitative variables that are significantly lower than the overall sample mean	Total Livestock Unit SV18) Replacement rate (V1) Percentage of artificial insemination (V1)	Percentage of meadows and grassland in Utilised Agricultural Area (SV12) Percentage of areas on which pesticides are used (SV14)	Percentage of meadows/grassland in UAA (SV12) No. breeds (SV22)
Position of the group on the FAMD factorial plan	Axis 1 Left side Axis 2 both top and bottom side	Axis 1 Right side Axis 2 Top side	Axis 1 Right side Axis 2 Bottom side

EBV: estimated breeding; UAA: unit of agricultural area; LSU: livestock Unit; FAMD: Factorial Analysis of Mixed Data.

Discussion

How could the results have been improved by better sampling of farms?

The first point to note is the lack of homogeneity in the sample surveyed. Upstream of the project, each partner chose to include specific breeds in the research work, based on their own questions and local issues. This has led to not having the same number of farms in each of the different partner countries, and to only a few systems/breeds. As a result, some less-represented systems are not identified in the results, as the analysis gives greater weight to the most common types of systems (in this case, dairy sheep farms). This point is not fundamentally problematic, as the study was not based on the representativeness of small ruminant farming systems (which would have been impossible to achieve). This is why we chose to analyse the data using exploratory statistics (FAMS, HCPC), an approach that consists of identifying operating patterns through a typology. A typology is formed by grouping observations into different types on the basis of their common characteristics, taking into account how each unique individual represents a particular pattern of characteristics (Stapley et al., 2022). This kind of approach has been used for many years in agricultural research to represent diversity as both an instantaneous and dynamic phenomenon (Girard et al., 2001).

The second point concerning the sample is the choice of farmers surveyed. Each of the partners carried out surveys with farmers who were available to participate. The survey process began at the time of the Covid crisis. As a result, some partners had to adapt their sample to the survey to the situation in each country and the availability of farmers. In Spain, for example, only one Assaf producer could be surveyed. This is the main reason why most of the Spanish breeders are in the same group at the end of the analysis. An alternative to expert sampling would have been to use part of the snowball method, a non-probabilistic method for selecting a sample of farms. This method for selecting a survey sample is based on references of first farmers initially sampled and surveyed, who provide the names of others they believe possess the characteristics of interest (Johnson, 2014).

Culling and replacement criteria at the heart of breeding patterns

Our survey has enabled us to identify the key determinants used by farmers to improve their flocks/herds. We can distinguish, choices of criteria for culling practices and for practices enabling genetic progress. As shown by Perucho et al. (2019b), different selection strategies can be distinguished based on culling practices for females and males and the replacement of animals. Our study shows how culling criteria distinguish and structure the three selection and breeding management strategies we have identified. These include production, functional and reproductive traits combined with the use of AI or the purchase of males. The selection of animals is based on different criteria for each group of farmers, but relies heavily on productivity and functional traits. These criteria are the main levers for managing flock performance (Perucho et al., 2020). It should be noted that we based part of the questionnaire on the farmers' evaluation of EBVs as an indicator and selection tool available to them. However, a number of farmers stated during the surveys that they did not know what EBVs were, and consequently did not use them. Farmers' attitude towards the use of genetic tools is a complex phenomenon, but the lack of indicators to measure this attitude (Martin-Collado et al., 2014) means that it is only possible to identify the use or non-use of the tools available in a binary way. However, the use of EBVs could be very promising in helping producers select their animals (Perucho et al., 2020). According to our study, producers that are less inclined to use genetic tools (such as EBV, AI, global indexes) rely instead on purchasing males from other trusted breeders in their vicinity, with similar systems and based on the animals' phenotypic criteria. This is in line with the observations made by Perucho et al. (2019b) in Corsica and Greece.

The involvement of farmers in the collective breeding programs as a prerequisite for disseminating genetic progress

The FAMD results showed that our sample was structured on a first factorial axis around two different poles. On the one hand, farmers from Group 3 with a strong commitment to the local (and/or national) socio-technical system associated with the raised breed. They take part in performance recording and are breeders or producers with a strong knowledge of genetic tools. In view of the advances being made in genetics, they are determined to take part in genomic evaluations, and say they "want to be part of its development". In contrast, producers from Group 1 less familiar with genetic tools focus their selection practices on functional criteria and animal phenotypes. This group includes farmers of local breeds (Chios, Boutsko and Skopelos, Causse du Lot) that make greater use of grassland or pastoral areas. As described by Perucho et al. (2019a), local breeds are recognised as an important element in maintaining biodiversity and variation in farming systems. The systems of this Group 1, which are more focused on the diversity of local resources, are favourable to the agroecological transition (Thénard et al., 2021). Initiating an agroecological transition based on the contribution of genetics implies changing the relationship between producers and breeding organisations. Indeed, the major feeling of producers in any breeds (e.g. Causse du lot) is a lack of consultation and relevant choices of breeding organisations in the selection scheme. As this is explained in many studies (Labatut et al., 2013; Perucho et al., 2020; Perucho, et al., 2019a; Perucho et al., 2019b), the integration of new traits in selection schemes should be linked with the farmers' selection and breeding practices. Moreover, integrating new selection traits into the breeding program and assessing the economic impact is not enough, as our study shows a gap between the expectations of producers who use genetic progress and those of breeders who build it. Also, to succeed in using genetics to contribute to the agroecological transition, targeted policy measures should be considered in order to foster interactions between the different stakeholders of a region by increasing active participation and cooperation on common goals (Perucho et al., 2019a).

The challenge of genomics will be to develop new criteria in accordance with the expectations of breeders and producers

Another point to be drawn from our research work is to identify farmers' expectations for new selection traits useful for strengthening the resilience of livestock farms. The SMARTER project aimed to identify genetic traits that could be used to select more robust and efficient animals. Our sample was structured around two poles around a gradient of interest in adding new traits to selection indexes. Some farmers, unfamiliar with genetic tools, would like to orient their animal selection on the basis of new, phenotypic criteria. Buying rams is a way of staying in touch with selection schemes while emphasising the role of the breed in animal selection practices (Labatut and Hooge, 2016; Perucho et al., 2019a) and even for some farmers rely on conformity to the breed standard as a means of choosing their animals (Labatut, 2009). Although interested in improving the characteristics of their animals, these farmers, especially in Greece, also resort to crossbreeding, which is also a way of improving animal performance. According to Perucho et al. (2019a), crossbreeding could help to increase milk production or to establish compromises between adaptive and productive traits. This is also in line with recent studies ondairy cows (Magne et al., 2016; Quénon and Magne, 2021). Another group of surveyed farmers expressed their satisfaction with the current selection traits used in synthetic selection indexes. They justified this by pointing out that improving animal productivity would mean improving the sustainability of their farms. This confirms the simulation work of Ramón et al. (2021), which shows the role of maintaining productivity in these drought-prone regions. Conversely, other farmers would like to see new traits integrated into selection schemes, in particular traits relating to animal health and robustness. These farmers are interested in selecting animals for resistance to parasitism, or for reduced susceptibility to mastitis. Recent studies are available which suggest that this could be the outlook for future selection schemes. (Aguerre et al., 2018; Oget et al., 2019; Rupp et al., 2019). As for most of the breeders surveyed, they consider the current selection indices to be satisfactory for ensuring the sustainability of their system, and in particular see the arrival of genomics as a way of accelerating genetic progress, and developing more advantageous selection strategies than through conventional quantitative genetic selection (Shumbusho et al., 2015). According to Astruc et al. (2016), this is not only an economic advantage but also a way of giving more flexibility to selection schemes. However, Labatut et al. (2013) warned of the importance of maintaining consistency between selection schemes and farmers. Genomic selection could reconfigure property rights over genetic information.

Finally, for the implementation of new selection programs, the economic interest and the gain from the introduction of new selection traits should be taken into account (Byrne et al., 2010; Theodoridis et al., 2023). Similarly, prioritisation between criteria and the construction of trade-offs is complex, and although it can be modelled using choice-experiment surveys (Byrne et al., 2012), selection choices and the creation of new genetic schemes will have to be made in conjunction with farmers and their expectations. Based on our study, such expectations remain rather vague and above all very disparate depending on many factors such as the farmer, the country and the breed.

Conclusion

Based on interviews with farmers, we have constructed a set of typologies representing the diversity of dynamic and highly complex phenomena, being the strategies of selection and breeding management. The farmers can develop their strategies with two main types of variables (1) culling practices and (2) selection practices. Each farmer's choice of criteria depends on genetic, phenotypic, and socio-economic aspects. The farmers' role in the genetic improvement system (producer vs breeder) is a determining factor in balancing the choices in the criteria mentioned. Farmers' expectations of new traits are still limited and unexpressed. But given the differences between producers and breeders, in terms of criteria and preferences for selection and genetics, more advice and support are needed. The diversity of breeds, countries and production systems also provides elements for analysing the different responses of producers and breeders, mainly in their socio-technical context. These results can be used by private breeding companies and associations as a basis for considering changes in breeding objectives, to improve the resilience of small ruminant farming systems. However, the gap shown by our study between the expectations of producers who use genetic progress and those of breeders who develop it should be bridged by increasing the co-construction of new breeding programs with all stakeholders in the small ruminant sector. This is the key to successfully introducing new sustainability traits into small ruminant genetics and breeding.

Supplementary material

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Ethics approval

Not applicable.

Data and model availability statement

Data are available here and will be made open access when the manuscript is published: https://zenodo.org/record/8279981.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) did not use any AI and AI-assisted technologies.

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Declaration of interest

None.

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