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Assessing resilience of small ruminant farms in Spain: A longitudinal analysis based on FADN

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ABSTRACT

In the last decades, increasingly complex challenges are threatening the viability of European small ruminant farming systems. Thus, studying the resilience of small ruminant farms is key to strengthen their ability to face the current global scenario and guarantee their long-term viability. This study uses FADN (Farm Accountancy Data Network) data from 2014 to 2022 to explore how the three resilience capacities (i.e., robustness, adaptation and transformation) contribute to the resilience of Spanish small ruminant farms and examines which farm characteristics are associated with higher resilience outcomes. Each resilience capacity is quantified by considering changes over time in a set of selected indicators. We defined best and worst performers per year for each resilience capacity and used Elastic Net regression models to understand the probability of farms to belong to the best and worst performers based on a set of farm indicators. Overall, farms were more robust than adaptable or transformable, and that their adaptation and transformation was limited. The probability to belong to the best performing group was variable in the case studies. Still, some indicators increased farms probability of belonging to the best performing group: *Production efficiency* for robustness, and *Hectares per livestock* and *On-farm feed ratio* for adaptation. By contrast, *Family labour ratio* was negatively related to the best performers in terms of adaptation. In these regards, strengthening the resilience of small ruminant farms would require strategies building adaptation and transformation considering the farm indicators that contribute to perform better in these capacities.

1. Introduction

In the last decades, increasingly complex challenges are threatening the viability of European small ruminant farming systems. These include shocks such as Ukrainian War that caused an increase in feed prices, or well-established trends such as the lack of generational renewal and the loss of profitability linked to interrelated socioeconomical factors (Belanche et al., 2021; Benoit and Mottet, 2023; Timpanaro and Foti, 2024). Coping with these challenges requires resilience, which is the ability of farms and farming systems to cope with (un)expected social, economic, environmental and political challenges to maintain the provision of private and public goods (Meuwissen et al., 2019). Thus, studying the resilience of small ruminant farms is key to strengthen their

ability to face the current global scenario and guarantee their long-term viability.

The resilience of farms is enabled by three resilience capacities: robustness, adaptation and transformation. Robustness is the ability to withstand challenges without altering the functioning of the farm; adaptation is the ability to adjust farm operations; and transformation is the ability to restructure farm operations and objectives to overcome challenges (Meuwissen et al., 2019). The study of these three capacities helps to understand what builds the resilience of farms and what are the implications for farms and farming systems (Darnhofer, 2014). This study uses FADN (Farm Accountancy Data Network) data to explore how the three resilience capacities contribute to the resilience of Spanish small ruminant farms and examines which farm characteristics are

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associated with higher resilience outcomes.

Resilience capacities can be quantified and assessed using static or dynamic approaches. Static approaches assess these capacities at a specific point in time, while dynamic approaches rely on time series data to assess how these capacities evolve over time in response to shocks or trends. Previous studies have assessed the resilience capacities of small ruminant farms using static approaches based on farmers' perceptions (Bertolozzi-Caredio et al., 2022; Prat-Benhamou et al., 2024). However, as their definitions imply, resilience capacities are dynamic concepts. Dynamic approaches to resilience require measurements that go beyond individual assets to capture the ability to withstand a variety of impacts over time (Tanner, 2017). Several authors have developed dynamic approaches to measure the resilience of farms. Slijper et al. (2022) designed a methodology to quantify the resilience capacities of European farms based on a dynamic conceptualisation of resilience capacities. The methodology uses the FADN data set from nine European countries to quantify and assess resilience capacities of crop, mixed and livestock farms per country. Martín-García et al. (2025) built on this approach and econometric methodologies to assess economic resilience capacities of crop agricultural farms in Spain. These methodologies made an important contribution to the quantification and assessment of farm resilience. However, assessing the resilience of the European livestock or Spanish crop sectors in broad terms does not allow to capture the specific contextual nuances embedded in farms in different regions. Given the diversity of social, economic and environmental factors that influence the diverse range of farms and farming systems, resilience studies that focus on specific systems can provide more meaningful and contextually relevant insights (Meuwissen et al., 2019).

The aim of this study is to quantify and assess the resilience capacities of small ruminant farms over time and to investigate what farm indicators are related to the probability of farms to perform better in terms of robustness, adaptation and transformation. The study focuses on three small ruminant case studies in Spain, which include sheep and goat farms, and dairy and meat production. For this purpose, we adapted the methodology proposed by Slijper et al. (2022) to the context of small ruminant farms. In doing so, this study provides a sharper analysis of resilience capacities of small ruminant farms compared to previous research. Furthermore, it adds to previous work based on static assessments of resilience by considering longitudinal data series from a representative sample of farms provided by the Spanish FADN dataset.

This paper is structured as follows: first we describe the methodology used to quantify resilience capacities. Next, we present the Elastic Net regression model used to investigate the farm-level indicators related with farms performance across the three resilience capacities. Finally, we discuss the results considering their implications for small ruminant farms.

2. Material and methods

2.1. Indicators to quantify resilience capacities

Robustness, adaptation and transformation are operationalised following Slijper et al. (2022). Each resilience capacity is quantified by considering changes over time in a set of selected indicators, as detailed below and summarised in Table 1.

2.1.1. Robustness

We assessed farms' robustness using three indicators: *resistance*, *shock* and *recovery rate*. These are calculated based on farm profitability, using the rate of return on assets (ROA) as indicator. ROA is defined as net income divided by total assets (Kryszak et al., 2021). We min-max normalised ROA in a scale from 0 to 1 for each year and each case study. Then, 0 represents the less profitable farm and 1 the most profitable farm within a case study in a specific year. This enables to compare farms in the same case study over time. The three robustness indicators were calculated based on time changes of the normalised ROA.

Resistance reflects the change in farms' profitability over time. When ROA decreases from one year to the next, more decrease implies a less resistant farm. *Resistance* can take values from -1 to 0 , where higher values correspond to more robust farms (Slijper et al., 2022). Additionally, farms with no decrease in profitability are assigned the value of 0 .

Shock represents a decrease in profitability of at least 30%. When ROA decreases more than a 30% from one year to the next, the *shock* indicator takes the value of 1 ; in the opposite case, it takes the value of 0 . The occurrence of a *shock* indicates lower robustness.

Recovery rate measures the degree to which profitability recovers following a decline. When ROA decreases from one year to the next, *recovery rate* quantifies how much the ROA is recovered in the subsequent year. This indicator takes the value 0 if no recovery occurs and 1 if there is full or more than recovery. Higher *recovery rate* indicates greater robustness (Slijper et al., 2022).

2.1.2. Adaptation

We assessed adaptation using three indicators: *labour*, *land use* and *feed ratio*. The original definition of the indicators was adapted from Slijper et al. (2022) to better reflect the specific context of the small ruminant systems addressed in this study. We calculated *land use* dividing hectares by livestock units to avoid errors when farms have 0 ha. To calculate the yearly changes, we used the difference instead of the percentage. Then, *labour*, *land use* and *feed ratio* were calculated as the yearly absolute change in livestock units per worker, number of hectares per livestock unit and feed ratio, respectively. These changes, regardless of their direction, represent adaptive processes that reflect

Table 1

Overview of the resilience capacity indicators. Positive "+" (negative "-") directions indicate that higher (lower) values of an indicator imply higher (lower) levels of a resilience capacity. "+/-" indicates that either a positive or negative change implies higher levels of a resilience capacity. Based on Slijper et al. (2022).

Resilience capacity	Resilience capacity indicator (indicator name)	Definition (change in variables)	Direction
Robustness	Resistance (<i>resistance</i>)	Decrease in profitability (%)	+
	Shock (<i>shock</i>)	Occurs if profitability decreases with at least 30% (0–1)	-
	Recovery rate after 1 year (<i>recovery rate</i>)	Degree of recovery after 1 year. Expressed as a percentage of the decrease in profitability (%)	+
Adaptation	Livestock units per working unit (<i>labour</i>)	Change in livestock units (LU) per annual working unit (AWU) (Absolute terms)	+/-
	Hectares per livestock unit (<i>land use</i>)	Change in hectares of utilised agricultural area (UAA) per livestock units (LU) (Absolute terms)	+/-
Transformation	Feed ratio (<i>feed ratio</i>)	Change in the ratio on-farm to total feed costs (Absolute terms)	+/-
	Organic (<i>organic</i>)	Conversion from conventional to organic farming or vice versa (0–1)	+
	Farm type (<i>farm type</i>)	Change in farm type* (0–1)	+
	On-farm transformation of products (<i>product transformation</i>)	Change to on-farm transformation of products or vice versa (0–1)	+

* Based on TF21 classification, which groups farm types according to livestock species and the mixed livestock-crop character of production systems.

farms' flexibility to adjust their management in response to changing conditions.

2.1.3. Transformation

We assessed transformation using three indicators: *organic*, *farm type* and *product transformation*.

Organic refers to the change of a farm from conventional to organic farming or vice versa. *Farm type* reflects a change in the management structure of farms using FADN categorisation of farms. Contrary to Slijper et al. (2022), we used the farm typologies included in TF21 classification of FADN (which groups farm types according to livestock species and the mixed livestock-crop character of production systems) instead of in TF8 (which groups farm types according to the production of crops or livestock). TF21 classification was more meaningful for our study, as we focus on small ruminant farms. For these farms, changes in the livestock species and in the use of land can be considered significant transformations in their structure and management (Martin et al., 2020). *Transform products* refers to a shift in farms production processes towards the transformation of milk or animals (mainly lambs or kids) into dairy products and meat or vice versa. The on-farm transformation of products is widely considered as a diversification strategy that improves farm resilience (Dumont et al., 2020).

2.2. Data

The data set used contains FADN data for the period 2014–2022 covering small ruminant farms located in four regions of Spain: Aragon, Navarra, Basque Country and Andalusia. The FADN is a tool used to evaluate the income of agricultural holdings and the impact of the Common Agricultural Policy. It consists of an annual survey carried out by Member States of the European Union. The Union's responsible services collect accountancy data every year from a sample of farms in the European Union. The FADN is the only source of harmonised micro-economic data, as the data collected and criteria are the same in all countries. Farms are selected to participate in the survey based on sampling plans established at regional level within the Union. FADN information is aggregated into a Standard Results database, which is available for the following dimensions: time (year), geography (country, region), typology (type of farming, TF8/TF14 classification of farm typologies and economic size). Among the different regions in Spain, Aragon, Navarra, Basque Country and Andalusia are selected in this study. We classified farms into three case studies that represent the predominant productive orientations in these regions, considering species (sheep or goat) and production (meat and milk): (1) meat sheep in Aragon and Navarra; (2) dairy sheep in Basque Country and Navarra; and (3) dairy goat in Andalusia. We assumed that farms without milk production are meat producers.

FADN is an unbalanced panel dataset, i.e., not all farms reported data

for every year of the study period. To build the sample: (1) we calculated resilience capacity indicators, and (2) we removed farms with data in less than three years on the three resilience capacity indicators assigned to each capacity. This resulted in a different sample of farms to calculate each resilience capacity. Since we needed one lagged value to calculate most indicators, but two lagged values to calculate *recovery rate*, the sample of farms used for robustness is lower than for adaptation and transformation, as some farms did not have data on three consecutive years. In the end, the farms included to calculate robustness are $N = 78$ in the case of meat sheep, $N = 120$ in the case of dairy sheep and $N = 81$ in the case of dairy goat; and to calculate adaptation and transformation $N = 89$ in the case of meat sheep, $N = 137$ in the case of dairy sheep and $N = 96$ in the case of dairy goat. The descriptive statistics of the variables used to calculate the resilience capacities indicators can be found in Table 2.

Given that composite indicators are sensitive to outliers (OECD, 2008; Slijper et al., 2022), we identified outliers in each case study before normalisation for: ROA, livestock units per working unit (*labour*), and hectares per livestock unit (*land use*). In these variables, values below quartile 1 (Q1) minus 1.5 times the interquartile range (IQR), were set to $Q1 - 1.5 \times IQR$, and values that above quartile 3 (Q3) plus 1.5 times IQR, were set to $Q3 + 1.5 \times IQR$.

2.3. Quantification of resilience capacities

To quantify resilience capacities of farms, we aggregated the resilience capacity indicators into composite indicators following Slijper et al. (2022): for robustness and adaptation, we used principal component analysis (PCA); for transformation, we aggregated the transformation indicators. To construct the composite indicators for robustness and adaptation, PCA was used to obtain the weight of each indicator per case study. PCA is a useful method to assign weights in an objective and endogenous way (Reig-Martínez, 2012). Before performing PCA, indicators had to be min-max normalised in a scale from 0 to 1. The min-max normalisation required to modify some indicators to guarantee they (1) were coded to contribute positively to resilience capacities, and (2) are equal or higher than 0. In the case of robustness indicators: we added 1 to the value of *resistance* and we recoded inversely the value of *shock* (i.e., 1 when there is no shock, and 0 when there is a shock). In the case of adaptation indicators, we calculated the absolute value of all indicators, considering that the magnitude of the change reflected the adaptation of farms no mattering the direction (i.e., the positive or negative sign). After these changes, we min-max normalised all the indicators of robustness and adaptation per year and case study. Then, we run the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy (Kaiser, 1974) to test if PCA was an appropriate method to assign indicator weights per case study. We concluded that PCA was appropriate because the KMO values were equal or above 0.5 in all the

Table 2

Descriptive statistics across years of the variables used to calculate the resilience capacity indicators per case study (2014–2022). As variables are not normally distributed, we present Quartile 1 / Median / Quartile 3 for numerical variables and percentages for categorical variables.

Variables	Meat sheep ^a	Dairy sheep ^b	Dairy goat ^c
ROA ^d	0.06 / 0.10 / 0.16	0.08 / 0.17 / 0.35	0.04 / 0.10 / 0.20
Livestock per worker (LU/AWU)	42.20 / 60.35 / 80.71	17.70 / 27.26 / 40.40	22.44 / 32.79 / 48.27
Hectares per livestock (UAA/LU)	0.86 / 1.45 / 2.33	0.77 / 1.15 / 1.51	0.36 / 1.21 / 3.05
Ratio on-farm feed ^e	0.00 / 0.24 / 0.48	0.00 / 0.00 / 0.00	0.00 / 0.00 / 0.00
Conversion from conventional to organic farming or vice versa (%)	1.2	0.0	0.9
Change in farm type (%)	2.4	2.5	2.5
Change to on-farm transformation of products or vice versa (%)	0.0	1.7	0.0

Abbreviations: ROA = Return On Assets, LU = Livestock Units, AWU = Annual Working Units, UAA = Utilised Agricultural Area.

^a Number of farms equals 78 for ROA and 89 for the rest of the indicators.

^b Number of farms equals 120 for ROA and 137 for the rest of the indicators.

^c Number of farms equals 81 for ROA and 96 for the rest of the indicators.

^d Before min-max normalisation.

^e Values that equal 0 for quartile 1, median and quartile 3 are explained by the low proportion of farms producing their own feed in these systems.

case studies. Thus, we performed PCA to obtain indicators weights per case study and used them to aggregate the indicators into the composite indicators for robustness and adaptation. The KMO values and the weights obtained for each case study can be found in [Appendix A](#).

To construct the composite indicator for transformation, we aggregated all transformation indicators into a variable that takes the value 1 if at least one of the transformations occurred and 0 if no transformation occurred.

2.4. Relation between farm indicators and resilience capacities performance

We analysed what farm characteristics are related to a better performance in resilience capacities, based on the yearly robustness, adaptation and transformation of farms in the period 2016–2022. The sample included farms with data on the three resilience capacities over these years. Therefore, the number of farms per case study equalled the number of farms with data on robustness (see [Section 2.2](#) for details). For each year, some farms showed higher robustness, adaptation or transformation than others in the same case study. Following the operationalisation of resilience applied by [Sauer and Antón \(2023\)](#), these farms can be called *best performers*. By contrast, farms which showed lower robustness, adaptation or transformation compared to their peers, can be called *worst performers*.

2.4.1. Best and worst performers per capacity

Based on the composite indicators of resilience capacities, we defined best and worst performers per year for each resilience capacity. In the case of robustness and adaptation for each case study we (1) calculated the mean value of the composite indicators per year, and (2) assigned in each year the value of 1 to farms with composite values equal to or above that mean (best performers), and 0 to farms with composite values below that mean (worst performers). In the case of transformation, we considered that farms which transformed each year are best performers, and farms which did not transform were worst performers.

2.4.2. Farm indicators

We selected a set of farm indicators that are key to understand the performance of farms in terms of land, capital and labour. [Table 3](#) shows all the indicators selected and their summary statistics; the FADN variables used to calculate them can be found in [Appendix B](#).

First, we included the variables used in the construction of the robustness and adaptability indicators, that allow to understand whether their values are related with a higher or lower performance in resilience capacities. These were ROA (i.e., profitability), *Livestock per worker*, *Hectares per livestock* and *On-farm feed ratio*.

Table 3

Descriptive statistics of the farm indicators for the period 2016–2022. As variables are not normally distributed, we present Quartile 1 / Median / Quartile 3.

Group	Variable	Meat sheep (N = 78)	Dairy sheep (N = 120)	Dairy goat (N = 81)
Management and structure	Herd size (LU)	54.61 / 77.61 / 132.50	34.25 / 46.14 / 61.07	28.36 / 47.97 / 82.15
	Land (ha)	59.24 / 107.22 / 182.38	32.05 / 52.08 / 75.54	23.00 / 69.00 / 185.00
	Owned land ratio	0.04 / 0.20 / 0.52	0.04 / 0.14 / 0.42	0.00 / 0.40 / 1.00
	Total labour (AWU)	1.00 / 1.05 / 2.00	1.00 / 2.00 / 2.00	1.08 / 1.41 / 2.00
	Family labour ratio	0.67 / 1.00 / 1.00	0.96 / 1.00 / 1.00	0.91 / 1.00 / 1.00
Productivity and efficiency	Family labour productivity (€/AWU)	14172.01 / 28899.04 / 57905.57	15194.03 / 26800.85 / 44148.28	11892.75 / 27850.83 / 52718.1
	Labour productivity (€/AWU)	16822.74 / 30780.27 / 50349.64	16742.87 / 27828.26 / 43178.41	12818.84 / 27134.95 / 49565.33
	Production efficiency	0.80 / 1.01 / 1.27	0.98 / 1.23 / 1.47	1.02 / 1.42 / 1.89
Sources of income	Current subsidies / Income	0.29 / 0.36 / 0.46	0.11 / 0.18 / 0.27	0.07 / 0.11 / 0.18
	Decoupled payments / Income	0.16 / 0.21 / 0.28	0.05 / 0.07 / 0.13	0.04 / 0.06 / 0.10
	Livestock payments / Income	0.06 / 0.08 / 0.10	0.02 / 0.04 / 0.06	0.00 / 0.02 / 0.04
	Rural payments / Income	0.02 / 0.04 / 0.08	0.02 / 0.05 / 0.07	0.00 / 0.01 / 0.03
	Other production / Income ^a	0.00 / 0.00 / 0.00	0.00 / 0.00 / 0.00	0.00 / 0.00 / 0.00

The descriptive statistics of the variables ROA (i.e., profitability), *Livestock per worker*, *Hectares per livestock* and *On-farm feed ratio* are included in [Table 2](#) for the period 2014–2022. Values for the period 2016–2022 are very similar.

^a Values that equal 0 for quartile 1, median and quartile 3 are explained by the low proportion of farms with income from other production.

3. Results

3.1. Resilience capacities

Indicators for resilience capacities varied along the studied period (Fig. 1). The results showed that in the three case studies and over the studied period mean robustness was above 0.6, mean adaptation was below 0.4, and transformation was below 10 %. This highlights that, overall, farms were more robust than adaptable or transformable, and that their adaptation and transformation was limited.

Regarding robustness, the average values vary across years pointing out that farms struggled to sustain their profitability and recover. In the meat sheep case, there was a decline in robustness in years 2017 and 2021. In the dairy sheep case, there was a decline in robustness in 2020. In the dairy goat case, there was a decline in 2017, with a declining trend from 2019 onwards. Adaptation was overall constant across years and transformations occurred more often from 2018 onwards.

3.2. Indicators related to resilience capacities performance

Elastic Net Regression showed the main farm indicators that are related to best performers in robustness, adaptation and transformation (Table 4).

The probability to belong to the best performing group was variable in the case studies. Still, there were some indicators increased farms probability of belonging to the best performing group across cases for robustness and adaptation: *Production efficiency* for robustness, and *Hectares per livestock* and *On-farm feed ratio* for adaptation. By contrast, *Family labour ratio* was negatively related to the best performers in terms of adaptation.

Then, other indicators increased or decreased the probability of belonging to the best performing group differently per case study and capacity. Higher ROA contributed to the probability of belonging to the best performing group in the case of meat sheep and dairy goat. This implies that, in these cases, more profitable farms experience fewer drops in profitability compared to their peers. By contrast, in the case of dairy sheep the probability of belonging to the best performing group

decreased with higher ROA. This may be linked to the fact that ROA was very high in these farms, so this indicator may not determine their robustness. *Livestock per worker* and *Herd size* were positively related to best adaptation performers in the case of meat sheep and dairy sheep, suggesting that these farms are more flexible to change labour and livestock. By contrast, in these cases higher *Owned land ratio* was negatively related best adaptation performers, which suggests that farms with more rented land vary more their use more in different years. Higher *Total labour* was negatively related to best adaptation performers in the case dairy sheep and dairy goat. Higher *Labour productivity* was positively related to best adaptation performers in the case of meat sheep and dairy goat. Also, in these cases, higher *Decoupled payments / Income* was positively related to the best adaptation performers. Considering the relationship between land and decoupled payments, this result aligns with the fact that the number of *Hectares per livestock* leads to greater adaptability. In the case of dairy sheep and dairy goat, higher *Other production / Income* was related to a higher probability of belonging the best performing group in robustness. This suggests that having alternative income sources makes more stable the profitability of farms despite unexpected events.

Regarding transformation, we only obtained significant odds ratios in the case of dairy goat. In this case, larger farms in terms of livestock units (i.e., higher *Livestock per worker* and *Herd size*), higher *Family labour productivity* and higher *Rural payments/Income* were more likely to transform.

4. Discussion and conclusion

This paper provides a quantitative assessment of the resilience of small ruminant farms in Spain between 2015 and 2022, using a FADN dataset. We found that robustness was the predominant capacity among these farms, while adaptive and transformative capacities were comparatively limited. We also identified several farm characteristics that are associated with better or worse performance in resilience capacities. The main findings and their implications are discussed in the following sections.



Fig. 1. Resilience capacities indicators over years in each case study.

Table 4

Probability of farms in each case study to belong to the best performing group in Robustness (Rob), Adaptation (Adapt), Transformation (Trans). The values shown correspond to Odds ratios (i.e., above 1 the probability increases, below 1 the probability decreases). Empty spaces correspond to non-significant Odds ratios.

Group	Variable	Meat sheep			Dairy sheep			Dairy goat		
		Rob	Adapt	Trans	Rob	Adapt	Trans	Rob	Adapt	Trans
	(Intercept)	0.56	0.19		0.55	0.5	1	0.09	1.21	0.33
Base variables	ROA	1.71			0.55	1.14		4.03		
	Livestock per worker (LU/AWU)		2.35		0.75	2.78		6.4		2.59
	Hectares per livestock (ha/LU)		15.46			19.04			49.08	0.76
Management and structure	On-farm feed ratio	1	1.92			1.56	1	0.74	2.29	
	Herd size (LU)		7.01		0.95	1.7		0.33		8.96
	Land (ha)	1.07	0.29			2.25		0.67	5.9	
	Owned land ratio		0.51			0.8		1.06	1.41	
	Total labour (AWU)					0.58		3.07	0.28	
Productivity and efficiency	Family labour ratio		0.71			0.53		2.17	0.37	
	Family labour productivity (€/AWU)				1.03	2.24		5.79	1.67	1.13
	Labour productivity (€/AWU)		1.98		1.14	0.59		0.86	1.58	
Sources of income	Production efficiency	2.73	1.35		2.24	0.6		1.95	0.51	
	Current subsidies / Income					2.45		2.09		
	Decoupled payments / Income		3.95		2.23				2.5	
	Livestock payments / Income							0.88	0.29	
	Rural payments / Income		0.6		2.05	0.42			1.25	3.47
	Other production / Income		0.8		1.1	1.57	1	3.88		

4.1. Resilience capacities

Robustness was the main resilience capacity in the small ruminant farms studied. These results are consistent with those reported by Slijper et al. (2022) for livestock farms in Spain, however they contrast previous studies based on farmers' perceptions, in which robustness was rated lower than adaptation (Bertolozzi-Caredio et al., 2022; Prat-Benhamou et al., 2024). This discrepancy between farmers' perception and FADN indicators deserves further investigation. Farmers' perceptions may be influenced by factors that are not captured by FADN data, such as market volatility, dependence on subsidies, or others, which directly affect their sense of stability and control (Soriano et al., 2024). Also, robustness showed several drastic reductions and then recovered in different years. These changes in robustness may be linked to timely reductions in farm benefits associated with increased production costs in these years (MAPA, 2023a, 2023b, 2023c).

Regarding adaptation, we found that small ruminant farms showed higher adaptation capacity compared to the findings of Slijper et al., (2022) for the Spanish livestock sector as a whole. (Slijper et al., 2022). This might be explained by the extensive nature of small ruminant systems, in which land use and on-farm feeds allow for higher flexibility in management, when compared with the intensive farms that predominate in Spain. However, the overall level of adaptation remained limited and relatively stable over time, suggesting that, despite farms have the potential to adapt, changes in management tend to be modest. This may be linked to constraints such as restricted access to land and labour, which have been identified as key barriers to resilience in the small ruminant farms in Spain (Paas et al., 2021; Prat-Benhamou et al., 2025).

The transformation of farms to adopt new businesses was exceptional. However, this could be expected given that transformation require structural changes. Many farmers are either unable or unwilling to implement changes due to factors such as limited knowledge, financial constraints or risk aversion (Dumont et al., 2022). Moreover, some farmers do not perceive the need for transformation because robustness and adaptation capacities already provide sufficient resilience (Martín-García et al., 2025).

4.2. Best performers

The indicators related to the best performer farms in resilience capacities varied across case studies and type of capacity. However, several indicators were consistently related to robustness and adaptation

in all three case studies, as discussed below.

We found that the efficiency of farms (i.e., *Production efficiency*) was related to higher robustness. These results match previous studies that highlighted the key role of efficiency in farms robustness (Sauer and Antón, 2023; Zawalińska et al., 2022). Thus, farms that produce more with lower costs would be in a better position to sustain their profitability when facing challenges.

Farms with more hectares per animal and a higher share of on-farm feed production were more adaptable. These results suggest that adapting is easier when more land is available, as farmers have greater room to manoeuvre and adjust the balance between land and livestock (Perrin et al., 2020). More land per animal allows more extensive management, which has been related to the adaptation capacity of small ruminant farms (Bertolozzi-Caredio et al., 2021). In addition, greater on-farm feed production is also a typical feature of extensive systems (Ripoll-Bosch et al., 2014). Overall, our results highlight that more extensive farms adjusted their management practices more over time, showing greater flexibility to face challenges.

The level of family labour of farms was negatively associated with the adaptive capacity. This implies that farms with more hired labour would tend to be more adaptable. Because hired workers are not part of the household, it may be easier to adjust the workforce to the fluctuations of workload. Considering that adaptation is also related to the land per animal and the on-farm feed production, these results suggest that farms relying more on family labour may have difficulties to adopt certain management practices. This is in line with the results obtained by Martín-García et al. (2025) for crop production, who found that farms with a higher proportion of family labour and owned land had a lower adaptive capacity. These production factors guarantee economic sufficiency and reduce resource dependency but can discourage farmers from adopting changes. It may also relate to the tendency of long-established family farms to focus on maintaining activities rather than modifying management practices to improve short-term performance (Perrin et al., 2024).

4.3. Implications

The resilience of small ruminant farms in Spain is built on their robustness capacity. Although robustness is key in the short term, adaptation and transformation are crucial for ensuring long term resilience (Sauer and Antón, 2023), particularly in the current context of global uncertainty and increasing market, political and climatic instability. The CAP aims "to support viable farm income and resilience of the

agricultural sector across the Union” (European Parliament and the Council, 2024). Yet, CAP payments mainly focus on increasing or stabilising farm income, i.e. robustness, which is key to sustain the profitability of European small ruminant farming systems in the short term (De Rancourt et al., 2006), but have a limited effect on the capacity of farms for adaptation and transformation (Morales-Reyes et al., 2025; Slijper et al., 2022). Strengthening farms resilience would require strategies building adaptation and transformation (Paas et al., 2021). For example, improving access to land and providing advice on land management could contribute to the adaptation capacity of farms; promoting mixed crop-livestock or multi-species farms (Dumont et al., 2020) or investing in mobile slaughterhouses to facilitate direct marketing (Soriano et al., 2024) could facilitate transformation.

4.4. Limitations and further research

This study uses the FADN dataset to quantify resilience in small ruminant farms in Spain. While this approach helps to ensure a representative sample of farms, the purely technical and economic data collected does not reflect certain aspects that could help quantify farm resilience (Morales-Reyes et al., 2025; Slijper et al., 2022). These mainly include social and environmental factors, such as generational renewal or the number of hectares grazed within the UAA. Moreover, the data set does not provide information about why farmers stop sharing data, which may be due to abandonment of farming. Identifying and characterising such farms could determine whether they correspond to the least resilient systems, improving the understanding of resilience loss (Slijper et al., 2022).

Our study highlights characteristics of small ruminant farms in Spain that increase their resilience capacities. However, they were less conclusive for transformation. Due to the limited sample size compared to other studies (Gómez-Limón et al., 2023; Slijper et al., 2022), we could not apply more refined econometric approaches. Further research with larger datasets could explore alternative analytical approaches to better identify the farm characteristics that contribute more to the

resilience capacities of small ruminant farms in Spain.

CRediT authorship contribution statement

Alicia Prat-Benhamou: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Alberto Bernués:** Writing – review & editing, Supervision, Methodology, Investigation, Conceptualization. **Daniel Martín-Collado:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Olaizola Ana:** Writing – review & editing, Methodology, Investigation, Conceptualization. **Soriano Barbara:** Writing – review & editing, Methodology, Investigation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. KMO values and the weights obtained for each case study and for each capacity were PCA was used to aggregate indicators

Capacity	Variable	Meat sheep	Dairy sheep	Dairy goat
Robustness	KMO	0.53	0.5	0.542
	<i>resistance</i>	0.43	0.48	0.43
	<i>shock</i>	0.39	0.46	0.38
	<i>recovery rate</i>	0.17	0.07	0.19
Adaptation	KMO	0.518	0.529	0.527
	<i>labour</i>	0.46	0.43	0.33
	<i>land use</i>	0.37	0.44	0.44
	<i>feed ratio</i>	0.17	0.13	0.23

Appendix B. Description of the variables following FADN coding and calculation of the independent variables used in the Elastic Net regression model

Table B1

FADN codes of variables as included in the data set and definitions provided

FADN code	Definition
SE010	Total labour (AWU)
SE015	Non hired labour (AWU)
SE025	Utilised Agricultural Area (ha)
SE030	Rented Utilised Agricultural Area (ha)
SE080	Total Livestock Units (LU)
SE131	Total Production (Euros)
SE132	Total Production divided by Total Costs

(continued on next page)

Table B1 (continued)

FADN code	Definition
SE256	Other Production (Euros)
SE310	Feed costs for herbivorous livestock (Euros)
SE315	Feed costs for herbivorous livestock produced on the farm (Euros)
SE405	Subsidies net to investment (Euros)
SE420	Farm net income
SE425	Net added value per annual working unit (Euros/AWU)
SE430	Farm net income per family annual working unit (Euros/AWU)
SE436	Total assets (Euros)
SE605	Current subsidies (Euros). Includes variables SE615, SE624 and SE630.
SE615	Livestock payments (Euros)
SE624	Rural development payments (Euros)
SE630	Decoupled payments (Euros)

Table B2

Variables used in the Elastic Net regression model and calculation based on the FADN variable code

Variable	Calculation
ROA	SE420/SE436
Livestock per worker (LU/AWU)	SE080/SE010
Hectares per livestock (ha/LU)	SE025/SE080
On-farm feed ratio	SE315/SE310
Herd size (LU)	SE080
Land (ha)	SE025
Owned land ratio	(SE025-SE030)/SE025
Total labour (AWU)	SE010
Family labour ratio	SE015/SE010
Family labour productivity (€/AWU)	SE430
Labour productivity (€/AWU)	SE425
Production-cost ratio	SE132
Current subsidies / Income	SE605/(SE131 + SE605 + SE405)
Decoupled payments / Income	SE630/(SE131 + SE605 + SE405)
Livestock payments / Income	SE615/(SE131 + SE605 + SE405)
Rural payments / Income	SE624/(SE131 + SE605 + SE405)
Other production / Income	SE256/(SE131 + SE605 + SE405)

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