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Understanding resilience capacities in rural AGRO-Industries: Evidence from Spanish wineries

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A R T I C L E I N F O

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A B S T R A C T

Spanish wineries, deeply rooted in rural territories, are increasingly exposed to overlapping economic, environmental, and social challenges—ranging from declining consumption and rising production costs to labor shortages and climate-induced disruptions. As key actors in rural economies, their resilience is critical not only for their own sustainability but also for the vitality of the regions they support. This study analyzes the resilience capacities of 411 Spanish wineries, using the three-dimensional framework of robustness, adaptability, and transformability. Through survey data and Ordinary Least Squares (OLS) modeling, we examine how internal attributes—such as size, structure, innovation, and rural commitment—interact with perceived external challenges to shape strategic responses. Results show that robustness is reinforced by reliance on local resources but constrained by diversification and rural engagement. Conversely, adaptability and transformability are enhanced by diversity, environmental awareness, and rural involvement, although traditional assumptions about innovation and networks show limited impact. These findings offer new insights into the strategic behavior of rural agro-industries under pressure and highlight the need for nuanced policy approaches that support both structural stability and adaptive change in the face of increasing uncertainty.

1. Introduction

Rural agro-industries across Europe are increasingly exposed to overlapping economic, environmental, and social challenges (Meuwissen et al., 2019; Perrin et al., 2020; Wilson, 2010). Climate change, shifting consumer preferences, labor shortages, and demographic decline threaten the viability of traditional production systems and the sustainability of the rural economies they underpin (FAO, 2018; Finger and El Benni, 2021).

Among these, the wine sector provides a particularly illustrative case. Rooted in local territories and cultural heritage (Ferrer et al., 2022), wineries must now navigate a complex landscape that requires both adaptive strategies and resilient viticultural practices in the face of escalating environmental uncertainties (OIV, 2024). In wine regions, wine production plays a key role not only in agricultural output but also in rural employment, land stewardship, and regional identity. However, in several coastal and lowland areas—such as those in Spain, Italy, Greece and southern California—wine production could face severe contraction or even disappearance by the end of the 21st century if they do not adapt to climatic changes (van Leeuwen et al., 2024). Yet, the capacity of wineries to withstand and respond to disruptions remains uneven and poorly understood.

The concept of resilience has gained significant traction in rural studies over the last two decades. Resilience thinking emphasizes the ability of systems to absorb shocks, adapt to change, and, when necessary, fundamentally transform in response to new conditions to retain their essential functions, structures, identities, and feedbacks (Folke, 2006; Walker et al., 2004). In rural contexts, resilience is often focused on primary production at farmer level (Jones-Bitton et al., 2020; Aguilar et al., 2022), farm level (Darnhofer, 2014; Darnhofer, 2020;

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Bertolozzi-Caredio et al., 2021) and farming system level (Reidsma et al., 2020), leaving apart the resilience assessment of other actors in the agri-food value chain, such as cooperatives, wineries, and processing enterprises embedded in rural territories. These actors —play a strategic role in rural areas by connecting primary production to broader economic and social systems (Golicic et al., 2017; Duarte Alonso et al., 2020; Sauer and Antón, 2023; Soriano et al., 2023).).

In this study, we adopt the meso level as an analytical lens to examine the intermediate dynamics operating between the micro scale—comprising individuals, households, and farms—and the macro scale, which includes policies, markets, and broader drivers such as climate change. The meso level provides a framework for investigating regions or networks that interact within specific geographical or functional contexts (Davidson and Ward, 2024). This perspective is particularly useful for capturing territorial diversity, socio-spatial complexity, and the governance arrangements that shape rural development processes (Erenstein and Thorpe, 2011; McAreavey, 2022). From a socio-ecological systems perspective, the meso level connects ecological and social dimensions, facilitates the analysis of feedback mechanisms and cross-scale effects, and supports both environmental governance and the management of common resources (Li et al., 2020; Ostrom, 2009; Sharifi, 2023).

In agricultural economics, the study of resilience has begun to incorporate more nuanced frameworks. Meuwissen et al. (2019) propose a three-dimensional structure of resilience: robustness (capacity to maintain function without significant change), adaptability (incremental adjustments within existing systems), and transformability (fundamental shifts in structure or strategy). These categories provide a useful lens through which to understand how rural enterprises respond to external stressors—not only by resisting change, but also by embracing it in different forms.

The distinctive characteristics of wineries, compared with farms and regional systems, influence their resilience dynamics (Evren and Akdoğan-Odabaş, 2024). Wineries hold a more transversal position within the value chain, as their activities extend beyond agricultural production—typical of farms—to include processing, distribution, marketing, and even consumption (Niklas et al., 2022; Villanueva et al., 2025). While their operations are embedded within a defined geographical area and therefore part of the regional system, their transversal nature often leads them to engage in activities that transcend local boundaries in terms of distribution, commercialization, and market reach (Serrano et al., 2023).

Conversely, regional systems encompass the full set of interactions occurring within a specific geographical area among diverse actors, influencing the landscape, economy, innovation processes, and governance arrangements (Sutton et al., 2023). These interrelations shape the challenges faced by, and consequently the resilience responses and adaptive capacities of, farms, wineries, and regional systems alike (Spiegel et al., 2021).

For wineries, resilience is primarily anchored in value chain performance and product differentiation, which enable risk mitigation. Their main vulnerabilities stem from factors affecting crop yields, fluctuations in international markets, changing consumption patterns, and demand crises (Villanueva et al., 2025; Del Rey and Loose, 2023). Common resilience strategies include product diversification, the development of new business models (e.g., other wines and spirits), provision of complementary services such as wine tourism, brand protection through Protected Designation of Origin (PDO) affiliation, and targeting high–value market segments (Ferrer et al., 2022).

For farms, resilience largely depends on risk management within primary production systems. They are highly vulnerable to climate change impacts—such as droughts, late frosts, heatwaves, and floods—as well as to price volatility and increasing buyer concentration. Other environmental issues include soil degradation, pest outbreaks, and water scarcity. Adaptive strategies typically involve shifting to more resistant or temporally diverse varieties, adopting precision agriculture practices, improving soil management, joining cooperatives to strengthen bargaining power, and diversifying activities through agritourism (Meuwissen et al., 2020; Spiegel et al., 2021).

At the regional scale, resilience hinges on the collective adaptive capacity of various stakeholders—industries, farmers, and institutions—to respond to changing environmental and socio-economic conditions. Regional vulnerabilities may arise from climatic shocks (e.g., floods, droughts, wildfires), as well as economic or social crises and demographic shifts such as migration. The key mechanisms sustaining resilience include cooperation, governance quality, institutional support, social capital, and collaborative networks among firms, institutions, and knowledge systems (Sutton et al., 2023).

As an empirical setting, this study focuses on the Spanish wine sector—the world's largest vineyard area and third-largest wine producer. Despite its global relevance, the sector faces intertwined economic, environmental, and social challenges that make it a compelling case for resilience analysis. Spanish wineries operate across highly diverse territories and organizational models, ranging from small cooperatives to large export-oriented firms. This heterogeneity, combined with exposure to climate variability, market fluctuations, and demographic pressures, provides a rich context for examining how rural agro-industries develop and mobilize resilience capacities.

This article addresses this gap by analyzing the resilience of Spanish wineries, given the limited attention paid to agro-industrial actors beyond primary production despite their importance in rural economies. Through a nationwide survey of 411 firms, we investigate how wineries interpret and respond to economic, environmental, and social challenges. Specifically, we examine which strategies are adopted, how they align with different resilience capacities, and what factors influence these choices. The attributes considered include firm size, organizational structure (cooperative or private), production practices, diversification, and values such as rural commitment and innovation. Additionally, we explore the perceived relevance of various external challenges, from market fluctuations and climate-related stress to social and regulatory pressures.

Using an inductive classification of strategies and an Ordinary Least Squares (OLS) regression model, we analyze the relationship between winery attributes, contextual challenges, and the activation of each resilience capacity. This methodological approach allows us to quantify patterns in strategic behavior and link them to broader conceptual understandings of resilience in rural development.

Our findings show that robustness is supported by local resource use but weakened by diversification and strong rural social commitment—highlighting potential trade-offs between economic stability and broader territorial engagement. Adaptability and transformability, in contrast, are strengthened by diversity, engagement with rural life, and responsiveness to economic and environmental pressures. Interestingly, attributes often assumed to be central—such as innovation or external networking—appear to exert limited influence on resilience outcomes.

By offering an empirical exploration of resilience in the wine sector, this study contributes to multiple strands of literature: agricultural economics, rural development, and organizational strategy. It also provides policy-relevant insights on how to strengthen resilience not only at the farm level but also among rural enterprises that underpin value chains, employment, and social fabric. The Spanish wine sector serves as a compelling case, but the lessons derived are applicable to other rural agro-industries facing similar challenges in an era of climate uncertainty and global competition.

Methodologically, we operationalize perceived resilience through numeric perception scales, primarily Likert-type items complemented with binary (0–1) variables, allowing managers' qualitative perceptions to be quantified and systematically compared. This approach captures how wineries assess the salience of specific threats and their readiness to respond, offering a structured framework to identify patterns of robustness, adaptability, and transformability (Bertolozzi-Caredio et al., 2021; Meuwissen et al., 2019). By focusing on anticipated rather than experienced disruptions, the study advances a proactive and diagnostic understanding of resilience in the Spanish wine sector, complementing the dominant, event-based analyses in the existing literature.

2. Conceptual framework literature review

2.1. Resilience framework

Resilience has been defined in multiple ways across disciplines. From an organizational perspective, Bhamra et al. (2011) call attention to McDonald's (2006) proposal that "resilience conveys the properties of being able to adapt to the requirements of the environment and to manage the environment's variability." In this sense, resilience refers to a system's capacity to confront challenges and disruptions—such as climate change, diseases, or market fluctuations (Herrero et al., 2010)—while maintaining the provision of both public and private goods (Meuwissen et al., 2019).

The literature commonly distinguishes two main approaches to resilience assessment: (i) indicator-based assessments, derived from socioeconomic and ecological variables defined by researchers, and (ii) perceived resilience assessments, which reflect the perspectives and experiences of system actors. Indicator-based approaches often rely on local data and statistical aggregation, but they tend to be highly context-specific (Jones and d'Errico, 2019; Spiegel et al., 2021). While they provide a structured way to quantify resilience, cross-comparison among agricultural systems exposed to diverse challenges remains difficult. Moreover, such approaches often fail to capture the full complexity of economic, biophysical, sociocultural, and political interactions shaping resilience (Meuwissen et al., 2020), and their conceptualization and measurement can be resource-intensive (Spiegel et al., 2021).

Following Folke et al. (2010), resilience can be interpreted as either general—the capacity to cope with a wide range of known and unknown disturbances—or specific, which refers to the ability to respond to a particular type of challenge. In this sense, perceived resilience approaches (Jones and Tanner, 2017; Spiegel et al., 2021) are particularly useful for assessing specific resilience, as they capture how actors evaluate their own preparedness for concrete stressors affecting their system. Grounding resilience assessment on managers' perceptions has proven to be an effective way to capture the cognitive and behavioral dimensions of resilience, especially in contexts where systemic data are scarce or fragmented (Jones-Bitton et al., 2020; Spiegel et al., 2021). Integrating perceived and indicator-based approaches offers a more comprehensive understanding of resilience and provides a stronger basis for policy and intervention design.

In contrast, perceived resilience assessments—which have gained increasing attention in recent years (Jones and Tanner, 2017; Lockwood et al., 2015; Spiegel et al., 2021)—explore how farmers and rural actors perceive their capacity to anticipate, adapt, and transform their systems in response to shocks or long-term stressors. Integrating perceived and indicator-based approaches offers a more comprehensive understanding of resilience and provides a stronger basis for policy and intervention design. Nevertheless, empirical applications of perceived resilience remain limited in both scope and scale, particularly among agro-industrial and meso-level actors.

To delimit the scope of this analysis, it is essential to consider the three guiding questions posed by Meuwissen et al. (2019): "Resilience of what?" "Resilience to what?" and "Resilience for which purpose?" The first—resilience of what—refers to the system represented by the Spanish wine industry. The second—resilience to what—identifies the main challenges affecting the sector, classified into economic, social, and environmental categories. The third—resilience for which purpose—addresses the goal of maintaining the economic, social, and environmental viability of the wine production system and its value chain. To operationalize this final dimension, the analysis draws on the function indicators proposed by Paas et al. (2021), which evaluate key system functions such as production performance, resource conservation, and social stability.

Various theoretical approaches have been employed to analyze change and vulnerability in rural sectors, including sustainability frameworks, risk management theory, and adaptive capacity models (Darnhofer, 2014; Folke, 2006; Holling, 1973). However, these approaches often emphasize equilibrium or efficiency rather than transformation, making them less suited to capture the systemic and cross-scalar nature of the wine sector's challenges (Cradock-Henry and Fountain, 2019; Petrosillo et al., 2015). The resilience framework, by contrast, allows for the simultaneous examination of stability, incremental adaptation, and structural transformation—dimensions that are essential to understanding how wineries embedded in specific territorial and institutional contexts respond to long-term uncertainty (Bertolozzi-Caredio et al., 2021; Meuwissen et al., 2019; Paas et al., 2021). This makes the robustness–adaptability–transformability typology especially appropriate for exploring the socio-ecological dynamics of the Spanish wine industry, where climatic pressures, market instability, and demographic decline interact with institutional and cultural specificities (Serrano et al., 2023; Sutton et al., 2023).

The tripartite conceptualization of resilience—robustness, adaptability, and transformability (Meuwissen et al., 2019)—offers a particularly relevant lens for analyzing the Spanish wine sector. This framework captures the range of strategic responses required by wineries operating under conditions of climatic variability, market volatility, and demographic decline (Del Rey and Loose, 2023; Pinilla and Sáez, 2021). For instance, robustness reflects the capacity to maintain operations despite yield losses caused by drought or frost (Bisson et al., 2002; Herrero et al., 2010); adaptability entails adjustments in production practices or marketing strategies to cope with shifting consumer demand and evolving regulatory frameworks (Darnhofer et al., 2014; Montoro-Sanchez et al., 2018); and transformability refers to deeper structural changes such as diversification beyond wine production or transitions toward sustainability-oriented models (Giuliani and Bell, 2005; Villanueva et al., 2025). These dimensions therefore align with the key economic, environmental, and social challenges currently affecting the survival and development of Spanish wineries, providing an integrated perspective for understanding how resilience is enacted across multiple scales of rural production (Folke et al., 2010; Spiegel et al., 2021).

In summary, applying the concept of resilience to the wine industry enables the evaluation of the sector's capacity to face and adapt to diverse challenges, with the overarching goal of ensuring long-term economic, environmental, and social sustainability. The strategies adopted by wineries—conditioned by their internal attributes and the nature of external stressors—reflect different resilience capacities, typically classified as.

- Robustness – the ability to withstand shocks and stresses without undergoing significant structural change.
- Adaptability – the capacity to adjust investments, production, marketing, and risk management practices in response to disturbances while maintaining existing system feedbacks.
- Transformability – the capacity to undertake profound changes in internal structure and feedback mechanisms in response to persistent or severe disturbances that render the existing model unsustainable (Meuwissen et al., 2019).

In line with Meuwissen et al. (2019), the study also identifies the attributes that shape how wineries respond to challenges. These attributes—understood as factors, properties, or conditions inherent to wineries, their actors, and their surrounding environments—either facilitate or constrain strategic responses and, consequently, resilience (Cabell and Oelofse, 2012; Soriano et al., 2023). The identification of attributes is context-dependent and must reflect the structural and institutional characteristics of the system under study (Niklas et al., 2022; Paas et al., 2021). Following the approach of Bertolozzi-Caredio et al. (2021), the attributes selected for this research build upon Cabell and Oelofse's (2012) framework, later refined by Paas et al. (2021), adapting it to the particularities of the wine sector. A list with their definition is presented in Table 1.

2.2. Wineries resilience assessment

In this article, resilience is examined within the wine sector, conceptualized as a socio-ecological system (Cradock-Henry and Fountain, 2019). This perspective encompasses the full value chain—from vineyard management to wine production and distribution—integrating social, economic, ecological, cultural, political, and technological dimensions. It follows the humans-in-nature approach (Petrosillo et al., 2015), which recognizes the interdependence between human activity and natural ecosystems.

From an ecological perspective, vineyard cultivation determines the use of agricultural land, water, and other natural resources. Vineyard management practices—such as soil conservation, irrigation, and the application of fertilizers and pesticides—have direct impacts on biodiversity, soil quality, and water availability (De Grandis, 2021). From a social, economic, cultural, political, and technological standpoint, the wine sector involves a wide range of actors, including local communities, permanent and seasonal workers, technical advisors, distributors, and consumers (Giuliani and Bell, 2005; Montoro-Sanchez et al., 2018). Moreover, the sector is organized through knowledge and governance networks such as designations of origin and protected geographical indications, which contribute to the formation of territorial clusters and innovation systems (Montoro-Sanchez et al., 2018; Porter, 1998; Serrano et al., 2023). This multi-scalar configuration helps contextualize the specific challenges and objectives of the wine industry.

The study of resilience in the agri-food sector—a complex, multidimensional domain—has gained increasing academic and policy attention in recent years (Darnhofer, 2014; Zurek et al., 2022). Within this field, the wine sector represents a particularly vulnerable and illustrative case, given its strong dependence on climatic variability and global market dynamics. Climate-related disturbances such as droughts, floods, frosts, and heatwaves directly affect vine growth and the organoleptic characteristics of wine (Bisson et al., 2002; García-García et al., 2023), while socioeconomic shocks—ranging from geopolitical conflicts to trade disruptions—further challenge its adaptive capacity (Del Rey and Loose, 2023).

Table 1
Resilience attributes, definition.

Resilience attribute	Definition
Production coupled with local and natural resources	The system functions as much as possible within the means of the bio-regionally available natural resource base and ecosystem services.
Socially self-organized	The social components of the agroecosystem are able to form their own configuration based on their needs and desires
Supports rural life	The activities in the farming system attract and maintain a healthy and adequate workforce, including young, intermediate and older people
Infrastructure for innovation	Existing infrastructure facilitates diffusion of knowledge and adoption of cutting-edge technologies (e.g. digital)
Functional diversity	Functional diversity is the variety of (ecosystem) services that components provide to the system
Appropriately connected with actors outside the farming system	The social components of the agroecosystem are able to form ties with actors outside their farming system
Diverse policies	Various policy instruments stimulate different mechanisms that improve different resilience capacities
Reasonably profitable	Persons and organizations in the farming system are able to make a livelihood and save money without relying on subsidies or secondary employment

Source: Own elaboration based in Niklas et al. (2022) and Paas et al. (2021).

From a social–ecological perspective, wineries' resilience depends not only on their technical and financial resources but also on their capacity to engage in collective action, adopt sustainable practices, and integrate innovation into production and marketing processes (Cradock-Henry and Fountain, 2019; Gilinsky Jr et al., 2020). However, the literature remains fragmented and event-driven, with most empirical research focusing on resilience as a reactive response to specific crises or natural disasters. For example, studies have examined recovery after earthquakes in New Zealand (Cradock-Henry and Fountain, 2019; Forbes and Wilson, 2018) or the United States (Gilinsky Jr et al., 2020), and in response to trade-related shocks such as Brexit in Spain (Alonso et al., 2020). These studies have advanced understanding of post-event resilience, yet they tend to conceptualize resilience as a capacity revealed only after disruption occurs.

By contrast, proactive or perceived resilience approaches remain underexplored in the wine literature. While indicator-based assessments can map structural vulnerabilities (Jones and d'Errico, 2019; Meuwissen et al., 2020), perceived resilience frameworks emphasize how actors themselves interpret and anticipate threats (Lockwood et al., 2015; Spiegel et al., 2021). This subjective dimension is particularly relevant in the wine sector, where uncertainty about climate, regulation, and consumer behavior shapes strategic decisions long before crises materialize.

Our study contributes to this emerging line of inquiry by adopting a perception-based and forward-looking perspective. Whereas previous research has relied on "real event" data—examining how wineries recovered from tangible shocks such as floods, earthquakes, or market crises—we analyze how wineries perceive their capacity to confront potential, non-tangible risks. This distinction is critical, as it reveals the anticipatory logic of resilience: the ways in which actors prepare for, rather than simply react to, uncertainty.

3. Methodology and data

3.1. Case study: The Spanish wine sector

Spain, which has the largest vineyard area in the world (962,531 ha) and ranks third-largest wine producer after France and Italy, provides a particularly relevant empirical context for analyzing resilience in rural agro-industries. In 2024, Spanish wine production is expected to reach 33.6 million hectoliters—an increase from 30.7 million in 2023 but still 4 % below the five-year average (OIV, 2024). Despite its global importance, the Spanish wine industry faces multiple intertwined challenges that test its resilience at both the firm and territorial levels.

Economically, the sector is affected by declining domestic consumption, intensifying international competition, and rising energy and logistics costs, further aggravated by geopolitical tensions such as the war in Ukraine and resulting supply chain disruptions (OIV, 2023). Trade policy uncertainty, including potential tariff impositions in key export markets such as the United States, adds another layer of risk. Environmentally, wineries are increasingly exposed to climate-related events such as droughts, frosts, and floods (Bisson et al., 2002). Socially, structural issues such as rural depopulation, an aging workforce, and persistent shortages of skilled and seasonal labor further undermine sectoral sustainability (Brugarolas et al., 2010; Pinilla and Sáez, 2021). Moreover, shifting consumer preferences—toward white wines, low-alcohol or natural alternatives, and more health conscious consumption patterns—are reshaping market dynamics and regulatory pressure, including potential increase in alcohol taxation (Del Rey and Loose, 2023).

Within this context, the Spanish wine sector displays a wide diversity of organizational models, from small cooperatives and family run wineries to large export oriented firms. These entities are embedded in heterogeneous territories with varying exposure to economic and environmental stressors.

Such diversity makes the sector an ideal setting to explore how rural agro-industries perceive and respond to risk. Examining the strategic behaviors and adaptive capacities of wineries enables a deeper understanding of which dimensions of resilience—robustness, adaptability, or transformability—are activated under different contextual conditions, and how organizational structure, market orientation, and territorial embeddedness influence those responses.

3.2. Sample

The companies engaged in the wine industry in Spain (code 1102 of the European Statistical classification of economic activities)) form the database used in this study. This database was constructed by combining two sub-databases: the one from the Iberian Balance Analysis System (SABI) and the data from the different Protected Designations of Origen (PDO). All wineries in this database that had a phone number or email were contacted, and a survey was sent to them. After this contact, a second database was created that included only those wineries with email, phone, and those that declared themselves as independent companies with management capacity (Spanos and Lioukas, 2001). The total number of companies was 2799. The final sample consisted of 411 valid responses, resulting in a response rate of 14 %, a figure similar to that reported by Baruch and Holtom (2008). This response rate does not present any issues of significance for the results, as the error represents only 0.1 %, according to the variable of net total turnover for the year 2020. In that year, the sales of the 411 companies amounted to 764 million euros, compared to the 7.3 billion euros generated by the rest of the sector, according to SABI.

The companies in the sample and those in the population show similar results in their balance sheets and income statements, with matches in the sections of operating income, number of employees, assets, and annual results (Table 2).

3.3. Variables

The variables in this study are based on the works of Niklas et al. (2022) and Paas et al. (2021) and aim to identify the resilience capacities of the wine industry in Spain, reflected in the behavior of wineries in response to the challenges they face, based on their attributes.

3.4. Independent variables

The independent variables are the challenges the company faces, and the resilience attributes it possesses.

Challenges: Based on the studies by Niklas et al. (2022), the following challenges are analyzed in the wine industry: cost reduction, international markets, increased quality, direct sales, financing, competition with other beverages, climate change, environmental issues, diseases, and labor issues. The wineries responded to the survey by classifying each of these aspects with a 1 if they considered it a challenge, and a 0 if they did not consider it as such. Depending on their

Table 2
Significance of the sample size.

Variables of the BALANCE SHEET and PROFIT AND LOSS ACCOUNT	Sample average	Population average
Operating income (thousands of EUR)	2454.68	2504.58
Number of employees	11.86	10.32
Total Assets (thousands of EUR)	5499.38	5084.87
Yearly result (thousands of EUR.)	74.13	86.16

Source. Own elaboration based on SABI data.

nature, these challenges will be grouped into economic, environmental, and social categories. Table 3 reports the descriptive statistics of the survey items associated with the identified challenges, grouped into economic, environmental, and social categories, which are subsequently used in the statistical analysis.

Resilience Attributes: These attributes are defined in Table 1. In Table 4 presents the construction of the variables, based on the works of Niklas et al. (2022) and Paas et al. (2021), and references the questions used in the survey. The questions combine objective and subjective elements. Among the subjective elements, Likert scales from 1 to 5 were used, where managers assess their company's position relative to competitors in terms of the availability of various resources, such as networks, human resources, technological, innovation, financial resources, and economic performance.

The use of Likert scales to define variables has been common in previous studies and has proven to be an effective tool for assessing firms' resources, capabilities, and performance (e.g., Homburg et al., 1999; Spanos and Lioukas, 2001; Ferrer et al., 2022; Serrano et al., 2023). This approach follows the perceptual methodology applied in the analysis of winery resilience proposed by Spiegel et al. (2021).

3.5. Dependent variable

The dependent variable in this study is resilience capacity. It is constructed based on the strategies adopted by wineries in response to the challenges they face, classifying these strategies according to their depth within each resilience capacity: Robustness, Adaptability, and Transformability.

The strategies of winemaking companies are based on previous studies by Niklas et al. (2022) and include actions in various areas such as vineyards, business structure, winery infrastructure, grape varieties, wine type, marketing, packaging, communication, and climate impact reduction. These strategies serve as the model's attributes and cannot be pre-classified or predefined under a specific resilience capacity in a generic manner, as they depend on circumstances, the environment, and the sector (Bertolozzi-Caredio et al., 2021; Meuwissen et al., 2019).

In line with previous studies (Bertolozzi-Caredio et al., 2021; Darnhofer, 2014; Daugstad, 2019; Meuwissen et al., 2019; Olsson et al., 2004), the classification of strategies into different resilience capacities reflects the degree of organizational change they imply. Strategies associated with robustness tend to preserve existing structures and functions, aiming to maintain stability in the face of disturbance. Adaptive strategies, by contrast, involve incremental adjustments that strengthen current practices while sustaining the original goals of the organization. Transformative strategies entail more profound reconfigurations, reshaping organizational structures and functions to create

Table 3
Descriptive analysis of variables of challenges.

<Count:5>Question in the survey. Are this issue (….) one of the main challenges facing your winery? 1(yes); 0 (not)	Min	Max	Mean	SD
Cost reduction.	0	1	0.48	0.500
Access to foreign markets	0	1	0.68	0.467
Increasing quality.	0	1	0.38	0.485
The need to develop and increase direct sales	0	1	0.59	0.493
Diversifying	0	1	0.30	0.461
Financial needs.	0	1	0.24	0.430
Increasing competition from other beverages	0	1	0.10	0.304
Economic Challenges	**0**	**1**	**.40**	**.209**
Climate change	0	1	0.36	0.480
Environmental issues	0	1	0.24	0.425
Wine diseases.	0	1	0.06	0.242
Environmental Challenges	**0**	**1**	**.22**	**.293**
Labor problems (lack of workers, lack of skills, etc.)	0	1	0.15	0.359
Social Challenges	**0**	**1**	**.15**	**.359**

Source. Own elaboration

Table 4
Resilience attribute variable and indicators.

Resilience attribute/ Variable	Constructor and questions used in the survey	Indicator values
Production coupled with local and natural resources. Atri.1	1) **Belonging to a PDO/PGI,** value 1 if PDO or PGI, value 0 if not. 2) **Own vineyard**, value 1 if it does, 0 if it does not.	0 neither PDO/PGI, nor own vineyard 0.5, PDO/PGI, or Own vineyard 1, PDO/PGI and own vineyard
Socially self-organized. Atri.2	3) **Cooperative/Social vs. Investor owner firmse**. Value 1 if Cooperative, 0 if not. 4) **Network Resources,** on Likert scale, 1 if it obtains values 4 or 5 on the scale. 0 otherwise.	0 neither Coop/ Soc. or Better Network Res. 0.5 Coop/Soc. or Better Network Res. 1 Coop/Soc. and Better Network Res.
Supports rural life. Atri.3	5) **Local employment**, number of employees above the median value 1, 0 otherwise. 6) **Human Resources**, on Likert scale, 1 if it obtains values 4 or 5 on the scale, 0 otherwise.	0, neither number of employees above, nor Best HR 0.5, number of employees above or Best HR. 1, number of employees above and Best HR.
Infrastructure for innovation. Atri.4	**7) Technological Resources**, on a Likert scale, 1 if it obtains values 4 or 5 on the scale. 0 otherwise. **8) Innovation Resources**, on Likert scale, 1 if it obtains values 4 or 5 on the scale. 0 otherwise.	0, no advantage in both questions. 0.5, advantage in one of the questions. 1, advantage in both.
Functional diversity. Atri.5	**9) Diversity in wine type**, 1 value above the median, 0 otherwise. **10) Diversity in sales channels**, 1 value above the median, 0 otherwise.	0, no advantage in both questions. 0.5, advantage in one of the questions. 1, advantage in both.
Appropriately connected with actors outside the farming system. Atri.6	**11) Exports,** 1 value above median 0 otherwise. **12) Number of destination countries**, 1 value above the median, 0 otherwise.	0, no advantage in both questions. 0.5, advantage in one of the questions. 1, advantage in both.
Diverse policies. Atri.7	**13) Relationship with public entities**, on a Likert scale, on each of the four questions that address the issue, 1 if you obtain values 4 or 5 on the scale. 0 otherwise.	0, no advantage in all four questions 0.25, advantage in only one question 0.5, advantage in two questions 0.75, advantage in three questions 1, advantage in all four questions
Reasonably profitable. Atri. 8	**14) Economic performance** above median value 1, 0 otherwise. **15) Age,** years of life above the median value 1, 0 otherwise. **16) Financial resources**, on Likert scale, 1 if values 4 or 5 on the scale. 0 otherwise.	0, no advantage in all three questions. 0.33, advantage in one of the questions. 0.67, advantage in two of the questions. 1, advantage in all three questions.

Source. Own elaboration

new development pathways.

It is important to note that the concepts of robustness, adaptability, and transformability are academic and are not part of the terminology used by winery decision-makers. Therefore, they are not explicitly mentioned in the surveys. For this reason, it is necessary to develop an inductive system for classifying strategies (Bertolozzi-Caredio et al., 2021). The strategy classification process is illustrated in Fig. 1 and has been agreed upon with industry professionals. To operationalize the concept of resilience, each of the forty-four identified strategies was classified according to the type and depth of change it entails for wineries. Following the framework of Meuwissen et al. (2019) and Bertolozzi-Caredio et al. (2021), strategies were grouped into three resilience capacities—robustness, adaptability, and transformability. The classification process was conducted collaboratively with domain experts, who reached a consensus through a focus group discussion to ensure conceptual consistency with the characteristics of the Spanish wine sector. A detailed description of the classification criteria and the full list of strategies is provided in Appendix A.

Table 5 presents the descriptive statistics for each strategy associated with the three resilience capacities. Each strategy takes value 1 when adopted by a winery, and 0 otherwise. Column 6 indicates the corresponding resilience capacity, following the classification scheme outlined in Fig. 1 and further detailed in Appendix A.

3.6. *Control variables*

Following previous studies, various control variables have been analyzed, including the age of the company, its size based on the number of employees, and its legal structure. The latter is a dichotomous variable that takes the value 1 if the winery is a cooperative and 0 otherwise.

3.7. *Econometric model*

A linear regression model has been used, where the dependent variable is resilience capacity, and the independent variables include attributes, challenges, and control variables. The method applied is Ordinary Least Squares (OLS), which estimates the regression coefficients by minimizing the sum of the squared differences between the observed values and the values predicted by the model.

Thus, YCR_j represents resilience capacity, for which three submodels are developed: YR_j (robustness), YA_j (adaptability), and YT_j (transformability). Where β_0 is the constant. β_1, β_2 and β_3 are the coefficients of the control variables (winery age, size, and legal structure—cooperative vs. private company). β_4 to β_{11} are the coefficients of the eight analyzed attributes. β_{12}, β_{13} and β_{14} are the coefficients of the economic, environmental, and social challenges; e_j represents the error term or residual of the proposed model.

4. Results

The dependent variables in the analysis are Robustness, Adaptability, and Transformability capacities.

Regarding the strategies followed by wineries, Table 5, the most relevant ones are those distancing themselves from modernization, such as "not introducing artificial intelligence (AI)", "not investing in traceability", "not investing in digitalization", and "not investing in management software". On the other hand, the least adopted strategies include "adjusting company size", "increasing size", and "making investments in the vineyard".

The dependent variables—Robustness, Adaptability, and Transformability—are constructed using the weighted mean values of the strategies assigned to each category. The descriptive statistics for these variables are presented in Table 6. It can be observed that Robustness is the most prominent resilience capacity (0.67), while Adaptability (0.36) and Transformability (0.28) show significantly lower values.

Independent variable, Attributes: Table 7 shows the descriptive statistics. Regarding the attributes, which are defined as “intrinsic factors or properties of the wineries that affect their resilience”, the attribute with the highest value was “Production with Natural Resources” (0.87), followed by “Socially” (0.51), and the lowest values were found in “Diverse Policies” (0.24) and “Innovation” (0.27).

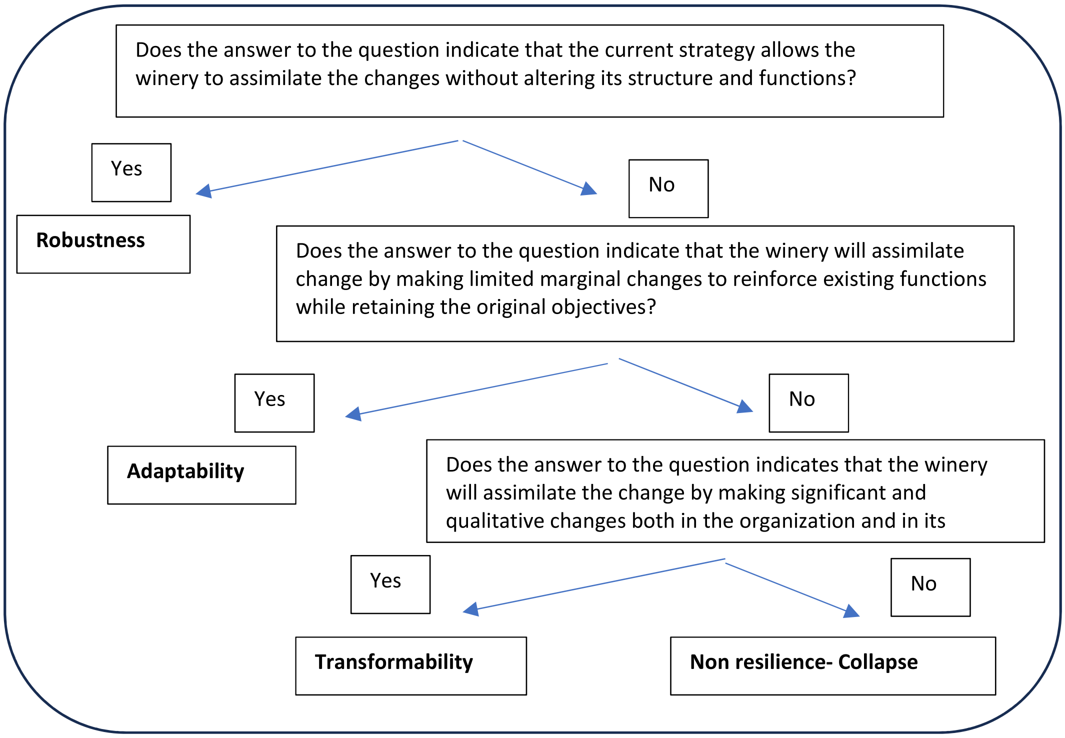

Fig. 1. Deductive scheme to infer resilience capacities, based on Bertolozzi-Caredio et al. (2021).

4.1. Independent variable: challenges

Table 3 presents the descriptive statistics for the challenges variable. In the first column, the specific question from the survey that contributed to the formation of each variable is shown. A grouping of the challenges based on whether they are economic, environmental, or social has resulted in the creation of three new variables: Economic Challenge, Environmental Challenge, and Social Challenge. These will be the variables introduced into the regression model. Regarding the challenges, it is important to highlight that economic challenges predominate for wineries, with an average of 0.40, followed by environmental challenges (0.22) and social challenges (0.15). Among the economic challenges, exports and direct sales stand out. Regarding environmental challenges, climate change is the most significant, while the least significant is vineyard diseases.

Table A in annexes shows the correlation between the defined variables.

4.2. Analysis of the relationship between attributes, challenges, and capacities

The study has assessed the potential multicollinearity between variables using the Variance Inflation Factor (VIF) and the conditioning index. In all cases, the values obtained are below the thresholds recommended by the literature (Hair et al., 2019). Table 8 presents the regression statistics, including the standardized betas and the significance of the independent variables. The regression has been performed for the three capacities and across three models. Model 1: Includes only the control variables. Model 2: Base model + attributes. Model 3: Complete model with challenges.

Regarding the regression model for Robustness Capacity, it is worth noting the low representativeness of the base model. In the base model with attributes, the adjusted R^2 is 0.104. It is highlighted that local and natural resource production positively impacts robustness. On the other hand, robustness is hindered by factors such as the diversity of services offered (in this case, the diversity of wine produced or the use of various distribution channels), support for rural life, and to a lesser extent, socially self-organized activities Regarding the complete model, with an adjusted $R^2 = 0.218$, Robustness is only favored by local and natural resource production. In contrast, it is hindered by economic challenges, environmental challenges, diversity, and support for rural life.

Regarding the regression model for Adaptability Capacity, in the base model with an adjusted $R^2 = 0.006$, it is important to highlight the negative effect of the legal structure, specifically being a Cooperative.

In the base model + attributes, with an adjusted $R^2 = 0.062$, the factors that favor Adaptability include diversity, support for rural life, and to a lesser extent, socially self-organized activities. Conversely, Adaptability is hindered by factors such as size and to a lesser extent, reasonably profitable operations. The complete model improves with an adjusted $R^2 = 0.161$. It can be concluded that economic challenges, diversity, and support for rural life all positively influence Adaptability. In contrast, size hinders Adaptability.

Regarding the regression model for Transformability, in the base model with an adjusted $R^2 = 0.021$, it is worth highlighting the positive effect of size, which disappears in the expanded models. In the base model + attributes, with an adjusted $R^2 = 0.068$, the factors that favor Transformability include diversity and support for rural life. In the complete model, with an adjusted $R^2 = 0.177$, the factors that favor Transformability are environmental challenges, economic challenges, diversity,and social challenges. It is noteworthy that there are no attributes or challenges that significantly hinder Transformability.

Cross-sectional analysis, focusing on the complete model, which presents the best adjusted R^2 (ranging between 0.161 and 0.218), several key points emerge, Control variables: There is no significant impact from age or legal structure, and the negative effect of size on Adaptability is noted. Attributes: Production with natural resources positively impacts Robustness. Support for rural life and Diversity have a negative effect on Robustness but a positive effect on Adaptability and Transformability. In contrast, Socially self-organized, Innovation, Connected Out, Diverse Policies, and Profit have no significant effect on any capacity in the complete model.

Regarding the challenges and focusing on the complete model,

Table 5
Strategy variables and resilience capacities: Robustness, adaptability, and transformability.

Strategies to face the challenges	Min	Max	Mean	SD	Type of capacity
1. Adjusting costs in the vineyard	0	1	0.2847	0.45181	Adaptability
2. Adjusting costs in the winery	0	1	0.4185	0.49391	Adaptability
3. Adjust costs in the management of the company	0	1	0.2433	0.42960	Adaptability
4. Adjust the size of the company	0	1	0.0292	0.16856	Adaptability
5. Increase investment in the management of the company	0	1	0.3650	0.48201	Adaptability
6. Increasing the company's direct sales	0	1	0.3990	0.49030	Adaptability
7. Change vats, barrels, vats or tanks in the winery	0	1	0.4988	0.50061	Adaptability
8. Introduce new management software	0	1	0.1898	0.39261	Adaptability
9. Reinforce the reception of wine tourists	0	1	0.3333	0.47198	Adaptability
10. Maintain the current level of manpower	0	1	0.6618	0.47367	Robustness
11. Maintain communication strategy	0	1	0.5572	0.49733	Robustness
12. Maintain orientation in the reception of wine tourists	0	1	0.6667	0.47198	Robustness
13. No changes in yeasts and S02 treatments used.	0	1	0.7567	0.42960	Robustness
14. No change in current phytosanitary treatments	0	1	0.5426	0.49879	Robustness
15. No increase in the company's direct sales	0	1	0.6010	0.49030	Robustness
16. No change in the level of investment in the vineyard	0	1	0.4331	0.49611	Robustness
17. No change in the level of investment in the winery	0	1	0.3966	0.48979	Robustness
18. No change in the level of investment in the company's management	0	1	0.3650	0.48201	Robustness
19. No change in the size of the company	0	1	0.5255	0.49996	Robustness
20. Do not change the number of vats, barrels or tanks in the winery.	0	1	0.5012	0.50061	Robustness
21. Do not change the current vine varieties	0	1	0.5864	0.49308	Robustness
22. Do not change the types of wine you are making.	0	1	0.6350	0.48201	Robustness
23. Not to build new buildings in the winery	0	1	0.7105	0.45410	Robustness
24. Do not introduce digitalization tools	0	1	0.8151	0.38870	Robustness
25. Do not introduce AI	0	1	0.9562	0.20489	Robustness
26. Failure to introduce new management software	0	1	0.8102	0.39261	Robustness
27. Not investing in measurement and analysis instruments	0	1	0.4939	0.50057	Robustness
28. Not investing in packaging	0	1	0.7567	0.42960	Robustness
29. Not investing in traceability	0	1	0.8321	0.37422	Robustness
30. Increase the size of the company	0	1	0.0657	0.24805	Transformability
31. Increase investment in the vineyard	0	1	0.1411	0.34857	Transformability
32. Increase investment in the winery	0	1	0.1630	0.36983	Transformability
33. Change communication strategy	0	1	0.4428	0.49733	Transformability
34. Change labor to machines	0	1	0.1655	0.37204	Transformability
35. Construct new winery buildings	0	1	0.1898	0.39261	Transformability
36. Produce new types of wine	0	1	0.1800	0.38470	Transformability
37. Changes in phytosanitary treatments, biological control or alternative solutions	0	1	0.4574	0.49879	Transformability
38. Change yeasts and implement alternatives to SO2	0	1	0.2433	0.42960	Transformability
39. Introduce digitalization tools	0	1	0.1849	0.38870	Transformability
40. Introduce AI (artificial intelligence)	0	1	0.0438	0.20489	Transformability
41. Invest in measurement and analysis tools	0	1	0.3844	0.48705	Transformability
42. Invest in packaging	0	1	0.2433	0.42960	Transformability
43. Invest in traceability	0	1	0.1679	0.37422	Transformability
44. Plant new varieties of vines	0	1	0.2360	0.42515	Transformability

Source. Own elaboration

Table 6
Resilience capacities.

Strategy	Min	Max	Mean	SD
Robustness	0.03	1.00	0.6683	0.15674
Adaptability	0.00	0.90	0.3638	0.21177
Transformability	0.00	0.98	0.2835	0.21815

Source. Own elaboration

Table 7
Descriptive statistics of attribute variables.

	N	Min	Max	Mean	SD
Atri1. Production Natur Res.	401	0	1	0.8728	0.24502
Atri2 Socially	388	0	1	0.5077	0.27363
Atri3. Supports RL	388	0	1	0.3673	0.36977
Atri 4. Innovation	393	0	1	0.2684	0.39100
Atri 5. Diversity	407	0	1	0.4238	0.38487
Atri 6. Connected out	333	0	1	0.4775	0.43416
Atri 7 Diverse Policies	387	0	1	0.2442	0.25283
Atri 8. Profit	318	0	1	0.3485	0.28018

Source. Own elaboration

economic challenges are the most relevant, positively influencing all the resilience capacities. In order of importance, these challenges affect: Adaptability, Robustness in negative way, and to a lesser extent, Transformability.

Regarding environmental challenges, these have a positive effect on Transformability, a negative effect on Robustness, and no effect on

Table 8
Regression results.

	Robustness			Adaptability			Transformability		
	Model base	Base + Attributes	Full Model	Model base	Base + Attributes	Full Model	Model base	Base + Attributes	Full Model
	Beta	Beta	Beta	Beta	Beta	Beta	Beta	Beta	Beta
Control variables:									
Age	−0.015	−0.036	−0.019	0.032	0.057	0.030	0.024	0.028	0.030
Size	−0.089+	0.043	0.032	−0.056	−0.162*	−0.161*	0.169*	0.072	0.077
Legal structure	−0.037	0.051	0.030	−0.102+	−0.086	−0.077	−0.025	−0.086	−0.058
Attributes									
Atri1. Production Natur Res.		0.158*	0.176+		0.034	0.027		−0.001	−0.011
Atri2 Socially		−0.117+	−0.079		0.110+	0.077		0.061	0.030
Atri3. Supports RL		−0.180+	−0.150*		0.168*	0.150*		0.141+	0.112
Atri 4. Innovation		−0.094	−0.099		−0.006	0.021		0.032	0.016
Atri 5. Diversity		−0.224***	−0.156*		0.177+	0.126+		0.212*	0.161*
Atri 6. Connected out		.0.056	0.075		−0.030	−0.041		−0.043	−0.064
Atri 7 Diverse Policies		−0.006	−0.011		0.074	0.072		−0.015	−0.003
Atri 8. Profit		0.089	0.039		−0.120+	−0.066		−0.026	0.003
Challenges									
Economic Challenges			−0.274***			0.326***			0.131*
Environmental Challenges			−0.203**			0.044			0.265***
Social Challenges			−0.036			0.019			0.132*
R^2	0.010	0.144	0.263	0.015	0.104	0.209	0.030	0.110	0.224
R^2 Adj	0.001	0.104	0.218	0.006	0.062	0.161	0.021	0.068	0.177
N	338	246	246	338	246	246	338	246	246
Durbin-Watson	1.977	1.987	1.960	1.954	2.111	2.006	2.025	2.104	2.063
F	1.157	3.580	5.893	1.693	2.471	4.351	3.399	2.616	4.766
Change in R^2	0.010	0.144	0.263	0.015	0.104	0.209	0.030	0.110	0.224

Source. Own elaboration. Standardized estimation coefficients are reported; ***p < 0,001; **p < 0.010; *p < 0,050; +p < 0,100

Adaptability. Finally, social challenges only influence Transformability positively.

Fig. 2 presents a chord chart illustrating the most relevant relationships between the independent variables and the three resilience capacities considered as dependent variables. Only statistically significant positive relationships in the full model are displayed. The size of each segment reflects the relative importance of the corresponding variable, with larger areas indicating stronger explanatory weight. As shown, robustness—the capacity with the smallest representation—is influenced solely by production based on natural resources. In contrast, both

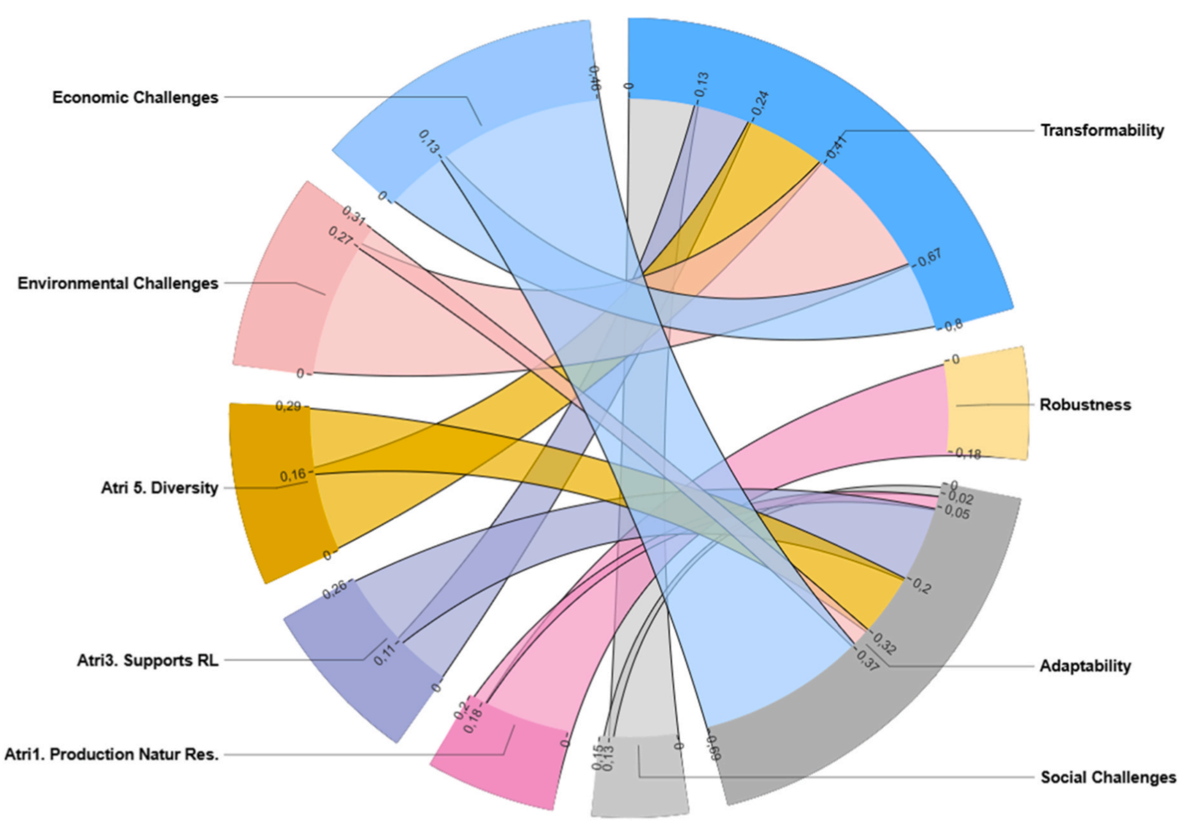

Fig. 2. Chord chart showing statistically significant positive relationships between explanatory variables and resilience capacities.

adaptability and transformability exhibit a greater number of significant associations with the explanatory variables. The width of the connecting chords denotes the strength of each relationship: the broader the chord, the stronger the link between the explanatory variable and the corresponding resilience capacity. Notably, social challenges, the variable with the smallest overall representation, are connected exclusively to transformability, suggesting that social drivers primarily stimulate qualitative or structural change within the sector.

5. Discussion and conclusions

This study offers empirical insights into the resilience capacities of wineries in Spain, framed through the threefold lens of robustness, adaptability, and transformability (Bertolozzi-Caredio et al., 2021; Meuwissen et al., 2019). Based on a national survey of 411 firms, the findings reveal that different winery attributes and perceived challenges distinctly shape each resilience capacity.

Robustness is positively associated with the use of natural local resources—confirming previous findings on the stabilizing effect of territorial anchoring (Bertolozzi-Caredio et al., 2021). However, both diversification (in products and channels) and strong social commitment to rural life negatively impact robustness. These results suggest that economic stability may at times conflict with broader territorial engagement or strategic diversification—tensions also observed in other agro-industrial contexts (Cradock-Henry and Fountain, 2019). Diversification and robustness can indeed be seen as conceptually opposed: if robustness entails maintaining a firm's structure despite external pressures, diversification involves change and thus a departure from pure robustness. In the Spanish wine industry, this is consistent with the role of Protected Designations of Origin (PDOs), whose strict rules of membership and territorial identity may discourage diversification to preserve the symbolic and reputational value of place.

Adaptability and transformability, in contrast, are positively influenced by diversity, support for rural life, and exposure to economic and environmental pressures. These findings align with prior studies showing that wineries adapt better when they align with downstream markets and changing consumer preferences (Duarte Alonso and Bressan, 2015; Kangogo et al., 2020; Soriano et al., 2023). Notably, adaptability decreases with firm size, supporting the idea that smaller, more flexible structures are more agile in adjusting to change (Duarte Alonso et al., 2020; Gilinsky Jr et al., 2020). Wineries thus act as meso-level anchors in rural territories, linking local production systems with regional development (Bosworth et al., 2020). Their ability to adapt and transform under external pressures reflects not only organizational resilience but also the broader adaptive capacity of rural regions.

The impact of challenges also differs by resilience dimension. Economic challenges emerge as the most influential, positively affecting both robustness and adaptability. This supports previous findings that resilience in the wine sector is often economically driven (Duarte Alonso and Bressan, 2015; Spiegel et al., 2020; Soriano et al., 2023). Environmental challenges, meanwhile, are strongly linked to transformability—indicating that climate-related risks push wineries toward deeper structural changes (Tscholl et al., 2022, 2024). Social challenges only impact transformability, perhaps reflecting the organizational shifts needed to address rural depopulation and labor shortages (Brugarolas et al., 2010; Pinilla and Sáez, 2021).

The observed transformative capacity among Spanish wineries thus forms part of a broader debate on rural transitions, where adaptation to climate and market change implies reconfiguring not only firms but also entire territorial systems (Darnhofer, 2021).

Some attributes—such as innovation, external networking, and profit orientation—do not show significant effects on resilience in the full model. This finding contrasts with prior literature that often identifies innovation and collaboration as resilience enablers (Bertolozzi-Caredio et al., 2021; Golicic et al., 2017). One possible explanation lies in the type of innovation considered. In this study, innovation was measured primarily as competitive innovation—based on the availability of resources that enhance differentiation and advantage (Porter, 1985). However, other forms of innovation, such as adaptive innovation, may play a greater role in resilience. Adaptive innovation emphasizes responsiveness to change, risk, and uncertainty, and tends to be collective and context-dependent rather than an individual competitive asset (Andriyani et al., 2024).

As for organizational structure, cooperatives show lower adaptability compared to private firms, echoing Soriano et al. (2023), who suggest cooperatives may prioritize stability (robustness) over change. Legal form and age have limited impact overall, reaffirming that resilience is more related to strategic orientation than to static structural factors (Gilinsky Jr et al., 2020). Strategies such as support for rural life and reliance on local resources not only enhance firm-level adaptation but also contribute to social cohesion, employment continuity, and the reproduction of local knowledge—key elements of rural place resilience (Steiner et al., 2023).

Conceptually, this study extends the understanding of rural resilience by linking firm-level strategies with place-based adaptive capacities. While most research has focused on resilience as a property of communities or regions, our findings show that enterprises—especially meso-level actors like wineries—are central to how rural areas absorb shocks, adapt to structural change, and initiate transformation. The threefold framework of robustness, adaptability, and transformability offers a dynamic lens to observe how economic, social, and environmental dimensions interact in shaping territorial resilience. Robustness represents the maintenance of local functions and heritage; adaptability captures incremental adjustments within existing rural systems; and transformability reflects deeper transitions that redefine rural economies and landscapes. By empirically operationalizing these dimensions, this article bridges the micro–meso gap in resilience research and contributes to a more systemic understanding of how rural places evolve under uncertainty.

From a policy perspective, these findings highlight the need for tailored strategies. Strengthening resilience in the wine sector should not focus exclusively on robustness but also encourage adaptability and transformation through incentives for diversification, sustainable practices, and rural engagement. In this regard, resilience should be approached as a multi-pathway process (Walker et al., 2004; Zurek et al., 2022), where firms combine strategies depending on their context, values, and exposure to change.

In summary, there is no single resilience strategy for wineries. Instead, they navigate resilience through a combination of capacities—some rooted in stability, others in proactive change (Bertolozzi-Caredio et al., 2021; Walker et al., 2004; Zurek et al., 2022). Understanding how these capacities interact offers valuable insights for supporting the long-term viability of rural agro-industrial actors in the face of growing environmental, social, and economic uncertainty.

6. Limitations and future research

Some limitations that could be identified in the study. First, regarding the sample and response rate: although the sample size is considerable (411 wineries), a higher response rate could provide a more accurate view of the characteristics of the entire wine industry. Second, the focus on Spain limits the generalization of the results to other wine regions around the world, as the characteristics of the wine sector can vary significantly between countries due to factors such as climate, regulations, and business structures.

Another limitation concerns the classification of resilience strategies. Assigning strategies to robustness, adaptability, or transformability can be complex, as some wineries may adopt hybrid strategies that do not fit neatly into a single category, potentially leading to classification ambiguities.

Finally, the study relies on perception-based measures to assess resilience. While these scales have been validated in prior research, they represent an inherent limitation, as they could be complemented with indicators based on actual observed events or outcomes. Moreover, the use of Likert-type scales and binary (0–1) variables, while useful for quantifying perceptions, may lack some versatility and fail to capture subtle nuances in managerial assessments.

Addressing these limitations in future research could improve the robustness and accuracy of resilience analyses and provide a more comprehensive understanding of adaptive behavior in the wine sector.

CRediT authorship contribution statement

Juan Ferrer: Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Barbara Soriano:** Writing – review & editing, Validation, Supervision, Methodology, Investigation, Formal analysis, Conceptualization. **Vicente Pinilla:** Writing – review & editing, Validation, Supervision, Investigation, Data curation, Conceptualization. **Raul Serrano:** Validation, Supervision, Investigation, Data curation. **Silvia Abella-Garcés:** Writing – review & editing, Investigation, Data curation.

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

During the preparation of this work the authors used ChatGPT in order to improve language and readability. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Declaration of 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.

Appendix A. Classification criteria and decision logic

To strengthen the classification of strategies within the three resilience capacities—robustness, adaptability, and transformability—the research team conducted an expert consultation process. Initially, experts were briefed on the conceptual distinctions among the three capacities, emphasizing the depth of change each implies for wineries. A subsequent focus group was organized, in which participants discussed the applicability of this methodological framework to the wine sector and reached a consensus on the most appropriate decision model.

- Robustness. Strategies were classified as robustness when they did not imply any structural or functional modification within the winery but rather the maintenance or continuity of existing practices (strategies 10–29). For example, the continuation of communication strategies was interpreted as a manifestation of robustness, as it reflects persistence rather than change.
- Adaptability. When a strategy involved change but not a qualitative transformation—such as reinforcing, adjusting, or scaling up an already established practice—it was categorized as adaptability. This group includes strategies related to adjustment and reinforcement (strategies 1–4 and 9).
- Incremental strategies. Strategies involving an increase in activity or investment were further differentiated. Those implying significant transformations—such as expansions in company size or vineyard and winery investments—were classified under transformability (strategies 30–32). Conversely, incremental actions that represented adaptive extensions of existing practices (e.g., managerial improvements or direct sales) were considered adaptability (strategies 5–6).
- Transformative changes. Most strategies implying qualitative shifts in the organization or its operations were categorized as transformability (strategies 33, 34, 37, 38). The only exception was the renewal of barrels and tanks (strategy 7), which was deemed part of regular operational maintenance and therefore classified as adaptability.
- Investments and innovation. All investment-related strategies were categorized as transformability (strategies 41–43), as were the development of new wines and grape varieties (strategies 36 and 44) and the construction of new facilities (strategy 35).
- Technological strategies. The introduction of new technologies was classified depending on their transformative potential. The adoption of digitalization and artificial intelligence tools (strategies 39–40) was deemed transformability, while the incorporation of new software (strategy 8) was interpreted as a routine update and thus assigned to adaptability.

Decision logic

If no change or modification was identified → robustness (strategies 10–29).
If a change was identified.

- Adjustment or reinforcement of existing practices → adaptability (strategies 1–4, 9).
- Maintenance-oriented improvement (e.g., renewal of existing equipment or software updates) → adaptability (strategies 5–8).
- Major structural or strategic change → transformability (strategies 30–44).

Table A1 summarizes the full classification, indicating for each strategy its type of change, assigned capacity, and rationale for inclusion. This operationalization ensures transparency and reproducibility in the assessment of resilience capacities.

Appendix A
Classification of Strategies by Resilience Capacity

Strategy No.	Strategy Description	Type of Change	Assigned Capacity	Rationale
1	Adjusting costs in the vineyard	Reinforcement	Adaptability	Incremental adjustment to improve efficiency without altering structure

(continued on next page)

Appendix A (*continued*)

Strategy No.	Strategy Description	Type of Change	Assigned Capacity	Rationale
2	Adjusting costs in the winery	Reinforcement	Adaptability	Operational optimization maintaining same production system
3	Adjusting costs in company management	Reinforcement	Adaptability	Administrative adjustment to existing management practices
4	Adjusting company size	Reinforcement	Adaptability	Minor organizational adjustment within existing framework
5	Increase investment in management	Increment (adaptive)	Adaptability	Builds on existing managerial structure to improve performance
6	Increasing direct sales	Increment (adaptive)	Adaptability	Expands established marketing channels without structural change
7	Change vats, barrels, or tanks	Increment (routine renewal)	Adaptability	Regular maintenance investment to sustain operations
8	Introduce new management software	Increment (technical update)	Adaptability	Routine upgrade to existing digital tools
9	Reinforce reception of wine tourists	Reinforcement	Adaptability	Strengthens existing enotourism activity
10	Maintain current manpower	No change	Robustness	Continuity of employment structure
11	Maintain communication strategy	No change	Robustness	Preserves established marketing approach
12	Maintain orientation in wine tourism	No change	Robustness	Ensures stability of current visitor engagement practices
13	No changes in yeasts or SO_2 treatments	No change	Robustness	Maintains production stability and product quality
14	No change in phytosanitary treatments	No change	Robustness	Continuity of agricultural practices
15	No increase in direct sales	No change	Robustness	Retains current sales channels
16	No change in vineyard investment	No change	Robustness	Sustains existing vineyard management practices
17	No change in winery investment	No change	Robustness	Maintains operational continuity
18	No change in management investment	No change	Robustness	Stability in administrative resources
19	No change in company size	No change	Robustness	Maintains structural stability
20	No change in winery equipment	No change	Robustness	Retains existing production capacity
21	No change in vine varieties	No change	Robustness	Preserves genetic and product continuity
22	No change in wine types	No change	Robustness	Maintains product portfolio
23	Not building new winery buildings	No change	Robustness	Avoids structural expansion
24	No introduction of digital tools	No change	Robustness	Maintains traditional management systems
25	No introduction of AI	No change	Robustness	Maintains manual or traditional operations
26	No new management software	No change	Robustness	Preserves existing information systems
27	No investment in measurement and analysis	No change	Robustness	No technological upgrade
28	No investment in packaging	No change	Robustness	Maintains current packaging strategy
29	No investment in traceability	No change	Robustness	Retains traditional control mechanisms
30	Increase company size	Structural change	Transformability	Alters organizational scale and production capacity
31	Increase investment in vineyard	Structural change	Transformability	Substantial change in production capacity and resource use
32	Increase investment in winery	Structural change	Transformability	Expands production infrastructure
33	Change communication strategy	Structural change	Transformability	Reorients brand identity and market positioning
34	Replace labor with machines	Structural change	Transformability	Shifts production system and labor structure
35	Construct new winery buildings	Structural change	Transformability	Expands physical and operational infrastructure
36	Produce new types of wine	Structural change	Transformability	Introduces new products and modifies feedback mechanisms
37	Change phytosanitary treatments	Structural change	Transformability	Alters ecological and agronomic system interactions
38	Change yeasts/alternatives to SO_2	Structural change	Transformability	Modifies fermentation process and product profile
39	Introduce digitalization tools	Structural change	Transformability	Transforms management and production processes
40	Introduce AI (Artificial Intelligence)	Structural change	Transformability	Introduces new decision-making paradigm
41	Invest in measurement and analysis tools	Structural change	Transformability	Incorporates new monitoring and innovation systems
42	Invest in packaging	Structural change	Transformability	Redesigns marketing and distribution processes
44	Plant new vine varieties	Structural change	Transformability	Alters agricultural base and long-term system dynamics

Note: The classification of the 44 strategies was validated through an expert focus group. Each strategy was assigned to one of the three resilience capacities (robustness, adaptability, transformability) based on the magnitude and qualitative depth of change involved. This table provides full transparency regarding the operationalization of the dependent variable.

Annexe 1

Table A

Correlations. * is significant at the 0.05 level. ** is significant at the 0.01 level.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
Age (1)	1																
Size (2)	,080	1															
Juridic (3)	,045	,078	1														
Atri1. Product.Natur Res. (4)	-,004	,025	-,386	1													
Atri2 Socially (5)	,020	,165	,028	-,051	1												
Atri3. Supports RL (6)	-,001	,392	,018	,085	,303	1											
Atri 4. Innovation (7)	-,018	,206	-,042	,120	,198	,445	1										
Atri 5. Diversity (8)	,039	,311	,075	,032	,054	,252	,124	1									
Atri 6. Connected out (9)	-,053	,223	-,130	,205	,051	,190	,166	,068	1								
Atri 7 Diverse Policies (10)	,098	,223	,044	,115	,077	,237	,208	,171	,110	1							
Atri 8. Profit (11)	,112	,200	,076	-,056	,242	,300	,161	,059	,113	,148	1						
Economic Challenges (12)	,054	,048	-,041	,052	,027	,036	-,034	,177	,056	,009	-,101	1					

(*continued on next page*)

Table A (*continued*)

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
Environmental Chall. (13)	-,026	,053	-,116	,105	,042	,106	,133	,162	,102	,029	-,009	,112	1				
Social Challenge (14)s	-,010	,066	,025	-,096	,001	,019	,024	-,023	,032	-,055	,007	,049	,139	1			
Robustness (15)	-,029	-,122	-,041	,086	-,170	-,232	-,170	-,242	-,017	-,068	-,027	-,298	-,239	-,063	1		
Adaptability (16)	,022	-,049	-,112	,118	,099	,098	,095	,230	,019	,070	-,020	,408	,154	-,016	-,588	1	
Transformability (17)	,039	,189	-,017	,052	,157	,212	,160	,287	,073	,108	,093	,223	,320	,109	-,765	,478	1

Data availability

Data will be made available on request.

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