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From farm to shelf: managing agrobiodiversity and product diversity in agri-food supply chains

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Abstract

Purpose – This paper explores biodiversity management within agri-food supply chains, a critical yet underexplored area in supply chain management research. It investigates biodiversity management strategies across different supply chain nodes, analysing its role in the agri-food industry, factors influencing decision-making and barriers and drivers of biodiversity strategies' adoption.

Design/methodology/approach – The study employs a qualitative approach, conducting 14 semi-structured interviews with key actors (six farmers, four processors and four retailers) across two Italian agri-food supply chains. It examines how agricultural and managerial practices at each stage contribute to biodiversity management.

Findings – Results reveal that biodiversity management is shaped by diverse practices and decisions across supply chain nodes, from agricultural production to processing and retail. The findings underscore opportunities to incorporate biodiversity into policies and supply chain strategies to promote a sustainable biodiverse agri-food system.

Originality/value – Addressing a critical research gap, this study provides new insights into biodiversity management within agri-food supply chains. It offers valuable perspectives for researchers, policymakers, and practitioners seeking to advance sustainability in agri-food systems.

Keywords Biodiversity, Supply chain management, Qualitative analysis, Multi-case study

Paper type Research paper

1. Introduction

Over the past century, approximately three-quarters of the biodiversity in agricultural crops has been lost, with just 12 plant species meeting 75% of global food needs (FAO, 2019). This decline is driven by multiple factors, including intensive farming practices, dietary shifts, and the homogenization of agricultural landscapes (Kehoe *et al.*, 2017). Monocultures, extensive pesticide use, and genetically uniform crops have increased vulnerability to pests and diseases while reducing resilience to climate change (Altieri *et al.*, 2015). Beyond farm-level impacts, this high-input agricultural model has shaped global diets, fostering dependence on a few dominant crops.

In high-income countries, food systems prioritize standardized, highly processed products that emphasize convenience and shelf stability over nutritional quality. These markets rely on a small number of commodity crops—primarily wheat, maize, and rice— leading to diets that are calorie-rich but often micronutrient-poor (Mattas *et al.*, 2023). Meanwhile, many Global

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South regions, despite facing challenges related to food insecurity and economic constraints, retain greater agricultural and dietary diversity, largely due to the continued cultivation of local plant species (Kennedy *et al.*, 2022). However, economic pressures and trade policies increasingly push these regions toward export-oriented monocultures, reducing local access to biodiverse food sources and exacerbating nutritional deficiencies. This trend underscores the interconnectedness of food supply chains and policy choices, shaping both environmental sustainability and dietary health.

In response, policy frameworks, particularly in the European Union (EU), promote biodiversity-based agriculture, emphasizing crop diversification and legume cultivation as key strategies for sustainability (European Commission, 2022). These measures are particularly relevant in Mediterranean regions, where traditional diets are built on diverse plant species and seasonal, locally sourced foods. By supporting agricultural diversity, such policies not only enhance ecosystem services and mitigate environmental degradation but also reinforce the Mediterranean diet's role in preserving biodiversity. Beyond its nutritional and ecological benefits, this diet is deeply embedded in local traditions, where food is not only a means of sustenance but also a key element of cultural heritage and geographical identity (Mattas *et al.*, 2023).

Despite recent policy recognition of biodiversity loss, many business managers, particularly sub-tier suppliers in resource-intensive sectors, have yet to integrate biodiversity into their operations. Insights into supply chain actors' decision-making on biodiversity could uncover conservation opportunities and move towards sustainable food systems.

However, in the literature, biodiversity management has received little attention so far (Salmi *et al.*, 2023). While some studies investigated biodiversity impacts in environmental assessments at the production stage (Knudsen *et al.*, 2019), and the influence of market pressures on agricultural diversity (Garcia-Yi, 2014), others argue for a greater emphasis on examining how supply chain dynamics specifically contribute to biodiversity conservation goals (Lockie and Carpenter, 2010). Although firms often influence their own sustainability practice and those of their direct suppliers, addressing biodiversity loss at the sub-tier supplier level remains more challenging (Villena and Gioia, 2018). Recent studies indicate that responsibility for various environmental impacts within global food systems extends beyond farmers including processors, distributors, retailers, and consumers (Notarnicola *et al.*, 2017). This underscores the need to consider diverse actors within agri-food systems, ranging from smallholders engaged in local food systems to firms embedded in national or globalized supply chains. This study addresses these gaps by investigating biodiversity management strategies across different supply chain nodes, exploring the interplay between firms and biodiversity. It focuses on agrobiodiversity at the production stage and product diversity at downstream stages to understand biodiversity conservation along the chain. Employing a multi-case study approach, the research investigates the lentil and buckwheat supply chains in Italy, drawing on empirical data from semi-structured interviews with farmers, processors, and retailers.

This paper is organized as follows. Section 2 gives an overview of biodiversity in supply chain management, identifying key literature gaps that shape the research questions. Section 3 details data collection and methodology. Section 4 presents the findings and their discussion in relation to existing research. Finally, Section 5 summarizes conclusions, outlines study limitations, and offers recommendations for stakeholders and future research directions.

2. Background and research questions

2.1 Biodiversity: definitions and insights

Biodiversity refers to the variability among living organisms across all ecosystems —terrestrial, marine, and aquatic ecosystems —encompassing diversity within species, between species, and of broader ecosystems (UNEP/CBD, 1992). This definition, adopted by the Convention on Biological Diversity (CBD), promotes biodiversity conservation beyond the food sector to areas deeply dependent on natural resources (Salmi *et al.*, 2023).

Biodiversity is crucial for sustainable food systems and healthy diets, connecting agriculture and nutrition across three distinct levels. At the macro level, it supports ecosystem services vital for agricultural production. At the farm level, it ensures productivity, stability, resilience, and the overall sustainability of agroecosystems. At the dietary level, agricultural diversity is essential for dietary variety and human health (Berti and Jones, 2013).

Agricultural biodiversity, or agrobiodiversity, refers to the diversity of living organisms within an agroecosystem that contribute to food and agriculture (FAO, 2019). It manifests across several interconnected dimensions, including habitat or landscape diversity, ranging from intensively managed farmland to semi-natural habitats under extensive management; species diversity, encompassing both domesticated and wild species that interact with or depend on agroecosystems; and genetic diversity, reflecting genetic variation within and between species (Heywood, 2013). This study specifically investigates biodiversity in terms of crop species diversity and considers both inter-species (diversity between species) and intra-species (genetic variation within species) biodiversity, emphasising their ecological and production dynamics.

Recent global policies have extended the focus beyond crop genetic resources to include organisms that enhance agricultural productivity and sustainability, such as pollinators, which support soil fertility, water purification, and climate resilience (FAO, 2007).

Understanding these biodiversity aspects is critical for supply chain actors aiming to integrate biodiversity into management practices. Business managers must assess biodiversity not just by species counts but by its role in ecosystem dynamics and the impact of resource management on these processes (Salmi *et al.*, 2023). Building on these insights and acknowledging the multifaceted nature of biodiversity, this study poses the following first research question:

RQ1. What facets of biodiversity ca be identified at different stages of the supply chains under investigation?

A comprehensive understanding of biodiversity is necessary for developing complete management strategies that align food system resilience with biodiversity conservation goals.

2.2 Biodiversity in supply chain management

Biodiversity considerations within supply chains extend beyond sustainable practices, requiring stakeholder engagement across processing, retail, and consumer levels to address environmental issues through biodiversity-focused management. Scaramuzzi *et al.* (2021) emphasize the importance of conserving underutilized landraces and marketing biodiversity-enhancing products. Strategies include reintroducing underutilized crops, promoting local varieties, and overcoming barriers like the high cost for lower-yielding varieties. However, research on biodiversity-focused supply chain management remains limited, with little evidence on how firms address and safeguard biodiversity (Blanco-Zaitegi *et al.*, 2022).

This study explores biodiversity conservation in supply chain management, expanding the focus from individual firms to the entire chain. Drawing from Carter *et al.* (2017)'s supply chain practice view (SCPV), we examine inter-organizational dynamics and the role of biodiversity-oriented agri-food systems in farming practices and product offerings. Managing agri-food supply chains entails intricate and interconnected decisions on crop planning, harvesting, processing, marketing, logistics, integration, cooperation, risk management, and environmental sustainability (Salmi *et al.*, 2023).

To delve into actors' decision-making, the following question will be explored:

RQ2. What key factors define and influence the decision-making of actors within these supply chains?

Gaining insight into the multitude of factors influencing decision-making processes within supply chains is essential for developing strategies that foster the long-term efficiency and sustainability of agri-food systems.

2.3 Factors affecting biodiversity management strategies

Understanding biodiversity management in agri-food supply chains requires identifying both the factors that facilitate the adoption of biodiversity strategies and those that hinder their implementation. At the farm level, adoption is influenced by various factors, including agronomic considerations such as risk management, resilience strategies (Lin, 2011), and environmental variability (Fraser *et al.*, 2012). Barriers include insufficient research on local crop varieties, limited technical knowledge about minor crops, land constraints, climate uncertainties, and price fluctuations (Meynard *et al.*, 2018). Profitability remains the primary determinant in crop selection, driven largely by expected harvest quantities and market prices (Lami *et al.*, 2023). Consequently, strategies emphasizing economies of scale and specialization in high-performing crops have been implemented throughout the agri-food chain. Downstream challenges include coordination difficulties with minor crops, lack of long-term contractual agreements and logistical constraints in collection (Meynard *et al.*, 2018) and storage of small minor crops volumes (Morel *et al.*, 2020).

Based on these insights, a deeper understanding of these factors at the supply chain level could offer novel perspectives for a sustainable agri-food industry. To this end, the last research question is addressed:

RQ3. What barriers and drivers influence the adoption of biodiversity management strategies by the actors involved in these supply chains?

This theoretical framing underscores the study's exploratory approach, grounded in extant literature and empirical observations, aiming to interpret how biodiversity is managed across diverse supply chain contexts.

3. Methods

This study follows a qualitative multi-case study research approach (Yin, 2014), suited for exploratory research with many variables exceeding available data (Sacchi *et al.*, 2019). Restricted data availability leads to smaller sample sizes, with case-based research typically involving 14 to 41 interviewees (De Sá *et al.*, 2019).

To overcome the constraints of limited data availability in single case studies, scholars increasingly employ multi-case studies as a comparative strategy that enhances the robustness of findings while preserving in-depth analysis within each case. Examining multiple cases allows for cross-case comparisons, broadening the analytical scope beyond a single context and strengthening the study's external validity. In this study, this approach involves repeated interactions with two agri-food supply chains to gather detailed insights and generate comprehensive evidence (Yin, 2014). To ensure diverse perspectives, purposeful sampling was used, selecting actors across different roles, production systems, and geographic locations. While sampling may introduce biases, such as the overrepresentation of proactive actors, this was mitigated by diversifying the sample to capture a broader range of experiences and decision-making practices.

3.1 Selected cases: lentil and buckwheat supply chains

Italy is among Europe's most biodiverse countries, with a high density of animal and plant species across varied climates and ecosystems (Finocchiaro and Piccini, 2008). This richness extends to its agri-food sector, where traditional crop varieties are closely tied to specific regions and cultural identities. Italy also leads in products with denomination of origin and geographical indication in Europe, covering a wide range of agricultural goods (European Commission, 2024a, b). Beyond individual products, strong farmer-to-consumer food networks—including direct sales, farmers' markets, short supply chains, and cooperatives—help valorise local biodiversity and promote sustainable agricultural practices, benefiting both rural livelihoods and consumer diets.

Case study 1 examines the Italian lentil supply chain, highlighting genetic diversity across local, regional, and territorial cultivars (Sonnante and Pignone, 2007). It includes commercial green lentils and region-specific Protected Geographic Indication (PGI) varieties, such as "Castelluccio di Norcia" PGI in Umbria, with a well-established market, and "Altamura PGI" in Apulia, which has experienced growing commercial popularity. Farmers within and beyond PGI areas typically sell lentils to cooperatives and processors of dried, semi-processed or pasta-based lentil products, which are distributed through both large-scale and alternative/organic retailers.

Case study 2 focuses on the buckwheat supply chain. Buckwheat contributes to biodiversity through crop rotations that enhance soil health, conserve water, and reduce weed, pest, and disease pressure, while also serving as a pollinator crop (FAO, 2007). Despite these benefits, Italy imports most of its buckwheat, with domestic production limited mainly to Alpine regions (Brunori *et al.*, 2005). Rising demand for gluten-free, nutrient-rich foods has spurred interest in local production. Farmers sell buckwheat to processors, including millers and producers of bakery items, *pizzoccheri* [1] or buckwheat-based pasta, which are then distributed through supermarkets and alternative/organic retailers.

3.2 Data collection

Interviewees were conducted face-to face or online between November 2022 and January 2023 targeting three different actors' categories in both lentil and buckwheat supply chains: 6 farmers, 4 processors, and 4 retailers, across different Italian regions (Table 1). A total of 14 in-depth semi-structured interviews were conducted.

The interview guide was informed by previous studies (Kaufmann and Den, 2011; Sacchi *et al.*, 2019), aiming to capture biodiversity management within agri-food networks. The interview protocol was designed to align with the research questions, ensuring a comprehensive exploration of key study themes.

To ensure comparability and coherence in data collection and analysis, the same protocol was applied across both case studies. Each interview began with an overview of the study's objectives, followed by informed consent and permission to audio-record (Section 1). Interviews were structured around open-ended inquiries, to explore five key areas of interest: crop varieties and production/sales volumes (Section 2); supplier and seller relationships, including contractual agreements, cost structures and pricing strategies (Section 3); consumer preferences and market trends (Section 4); and finally, challenges and expectations for crop diversification (Section 5).

3.3 Data analysis

The unit of observation consists of individual actors (farmers, processors, retailers) operating in the lentil and buckwheat supply chains, while the unit of analysis extends to their biodiversity management practices, relationships, and decision-making processes.

The data analysis process is based on a six-phase inductive thematic analysis (Braun and Clarke, 2006). Transcriptions from interviews have been imported into the NVivo 12 software for data coding. The process involved: data familiarization through active reading and note-taking (Phase 1); generation of initial codes to group the data into meaningful key categories (Phase 2); organizing codes into potential themes (Phase 3); refining themes by merging or discarding based on data support (Phase 4); defining and labelling final themes for the analysis report (Phase 5); and summarizing findings with selected extracts aligned with research questions and literature (Phase 6) (Braun and Clarke, 2006).

To ensure robust data collection and analysis, the study adhered to validity criteria (Kaufmann and Den, 2011). The first criterion, *credibility*, measures the trustworthiness of the findings. It was maintained by employing the same interview protocol in both case studies with interviews conducted by multiple researchers to enhance internal validity. For triangulation purposes, data collection and cross-checking were conducted from different sources, including company websites and newspaper articles featuring the company and interviewed participants.

Table 1. Case studies' sample

No	Supply chain	SC node	Type of production system	Product	Job function	Interviews length	Mode
1	Lentils	Farmer	Conventional	Dried PGI lentils	Owner	1 h 5 min	Online
2		Farmer	Organic	Dried lentils	Owner	33 min	Online
3		Farmer	Conventional	Dried PGI lentils	Owner	35 min	Online
4		Processor	Conventional and Organic	Dried lentils	Marketing manager	1 h 39 min	In-person
5		Processor	Conventional and Organic	Dried lentils	Owner/Head of operations	1 h 7 min	Online
6		Processor	Organic	Dried and pasta	Quality manager	1 h 25 min	In-person
7		Retailer	Conventional and Organic	Dried lentils	Quality manager	1 h 8 min	In-person
8		Retailer	Conventional and Organic	Dried lentils	Head of IV and V range products division	1 h 5 min	In-person
9	Buckwheat	Farmer	Conventional and Organic	Buckwheat flour and crackers	Owner	56 min	Online
10		Farmer	Organic	Dried buckwheat	Owner	1 h 6 min	Online
11	Buckwheat and lentils	Farmer	Organic	Dried, flour and pasta	Owner	1 h	In-person
12		Processor	Conventional and Organic	Pasta	Owner/Head operations	52 min	Online
13		Retailer	Organic	Dried, pasta, flour	Purchase manager arable crops division	1 h 42 min	In-person
14		Retailer	Conventional and Organic	Pasta	Head of fresh and frozen foods' division	59 min	Online

Source(s): Authors' own work

This was complemented by cross-checking information, asking similar questions to different interviewees to validate responses. The second criterion, *transferability*, examines whether the findings can be applied in other contexts or settings. While quantitative research seeks generalizability, qualitative research focuses on providing rich, context-specific insights but with relevance beyond the immediate study context. Theoretical sampling was utilized to enable generalization of findings across different contexts. The respondents were key informants who held pivotal roles in the firms' operations and were actively engaged in the supply chain connection. A sample of farmers capable of offering insights relevant to the research objective was shortlisted in collaboration with one of the largest Italian farm associations, Confagricoltura [2]. As interviews advanced, selected farmers recommended further contacts based on their network within the supply chain. The third criterion, *dependability*, relates to the consistency and stability of the findings over time and under different conditions. It was addressed by employing member checks, where participants were asked to verify the accuracy of the data. This approach involved gathering insights from multiple informants within each category and throughout the supply chain. Finally,

confirmability addresses the objectivity and neutrality of the research findings. To ensure objectivity, all interviews and documents were analysed by three different co-researchers.

4. Results and discussion

Building upon the process of thematic analysis, encompassing data familiarization, initial coding, and theme identification, six broad themes emerged: (1) Biodiversity, (2) Economics, (3) Climate change, (4) Market, (5) Policy and (6) Socio-cultural aspects. Given the research focus on biodiversity, two additional targeted themes were identified: (1) Barriers and (2) Drivers towards biodiversity management. Table 2 summarizes the mean coverage for each theme, calculated from multiple observations recorded throughout the study, offering a comprehensive overview of the trends across actor categories.

In line with the research questions, the findings are presented in the following sections.

4.1 Theme 1: biodiversity dimensions

The first key theme centres on biodiversity, encompassing two primary nodes: agrobiodiversity and product diversity. Agrobiodiversity is further delineated into sub-nodes representing specific biodiversity facets: inter-species diversity (variation between species) and intra-species diversity (genetic variation within species), while product diversity represents the range of products derived from these species.

Delving into agrobiodiversity within the lentil and buckwheat supply chains, respondents shed light on evolving perspectives. Stakeholders underscored the growing significance of legumes, notably lentils, advocating for a re-evaluation and expansion of legume varieties integrated into agricultural practices. A retailer expressed this sentiment, stating:

> Legumes didn't have the relevance they have now. We worked on a large project to re-evaluate legumes, for the inclusion of at least two varieties of the same legume [in the product range]. For example, we included black chickpeas to complete the range of classic chickpeas (Retailer-lentils)

This highlights a focus on intra-species diversity, as efforts are directed toward expanding varietal options within a single crop species. However, other stakeholders emphasized the importance of inter-species diversity, prioritizing the diversification of legume species rather than varietal differentiation. As articulated by a retailer:

> We believe a lot in the use of legumes, in my opinion it is not so much a theme of variety of lentils, but it is lentil instead of beans, instead of chickpeas. It is not intra-variety (Retailer-lentils)

Table 2. Dictionary of themes and mean coverage

No	Themes	Definition	Average frequency of mentions
1	Biodiversity	Two types of diversity: agrobiodiversity and product diversity	9.21
2	Economics	Price and costs, and perceptions on recent price inflation	3.92
3	Climate change	Climate change related events affecting cultivation	1
4	Market	Contracts regulating actors' interactions and price mechanism setting in the market	6.57
5	Policy	CAP policy measures	0.5
6	Socio-cultural aspects	Actors' perceptions on consumers' preferences, and collaboration among stakeholders	2.21
	Targeted themes		
7	Barriers	Main barriers towards biodiversity conservation across actors	2.64
8	Drivers	Main drivers towards biodiversity conservation across actors	2

Source(s): Authors' own work

For buckwheat, biodiversity is integrated into sustainable farming through crop rotation with legumes or cereals. Despite this, both lentils and buckwheat exhibit notable intra-species diversity. Respondents discuss the availability of different varieties, emphasizing the suitability to specific geographical region:

> Our seed supplier, in addition to the Lileja variety, has the Arpe which is another type of buckwheat, a little smaller, very productive, but more typical of mountainous areas, unlike here which is a flat area. Then there is Bamby, which is always a suitable variety for cultivation even here, but it has a difficult availability, the most available is the Lileja variety (Farmer-buckwheat)

> Some people use Du Puy, a French variety. Some use Laird, the big Canadian one. Then, some local varieties of Altamura lentil have been selected by the PGI consortium and these seem to be the most popular lentils (Farmer-lentils)

These findings show a growing recognition of agrobiodiversity's value in these supply chains, where farmers increasingly prioritize varietal diversification to enhance resilience in agricultural production. This aligns with the literature emphasizing how biodiverse agricultural systems can mitigate agronomic and environmental risks associated with monocultures (Scaramuzzi *et al.*, 2021). Inter-species diversity broadens genetic resources within these supply chains, indicating opportunities for further exploration and utilization. Research confirms that farmers acknowledge their role in contributing to diversified landscapes, through agronomic rotations or by indirectly supporting wildlife habitats (Martinelli *et al.*, 2022). Additionally, greater intra-species diversity reduces reliance on chemical inputs by improving weed suppression and winter survival (Reiss and Drinkwater, 2022).

Both supply chains revealed a wide range of lentil and buckwheat-based products, encompassing dry, pre-cooked or ready-to-eat items, and derivatives such as flour and pasta. Retailers emphasized the versatility of buckwheat in various culinary applications, spanning pasta, pastry, bakery products, and gluten-free alternatives:

> [buckwheat]It is quite exclusively a pasta-type product, where buckwheat is not used alone but mixed with other ingredients. We may also find it in some pastry or bakery products. Buckwheat is also used alone in products intended for specific diets such as gluten-free, but also in mixtures with other products intended for the more conventional market (Retailer-lentil and buckwheat)

Lentils, deeply embedded in Italian cuisine, enjoy widespread consumer acceptance. Their cultural significance has facilitated the integration of lentils into diverse recipes, supporting market acceptance of new varieties. In contrast, buckwheat remains regionally significant, particularly in Alpine areas where dishes like *pizzoccheri* highlight its long-standing culinary role. However, the rising demand for gluten-free diets has broadened interest in buckwheat, positioning it as a versatile alternative in health-conscious markets.

The availability of diverse lentil and buckwheat-based products underscores expanding consumer choices. Research suggests that product diversity not only enhances market opportunities but also supports agrobiodiversity conservation by promoting the utilization of a wider range of crop varieties (Acciani *et al.*, 2020).

Overall, the study underscores the interconnectedness between agrobiodiversity and product diversity within supply chains, emphasizing the importance of holistic approaches to promote biodiversity management while meeting consumer demands.

4.2 Themes 2–5: key factors in decision-making

The analysis identified five other key themes shaping decision-making: economics, market, climate change, policy, and socio-cultural aspects.

Economic factors significantly influence lentil production and diversification strategies, with price inflation emerging as a prominent concern. Rising costs for fuel, machinery, inputs, packaging, and food prices were frequently cited by supply chain actors:

> The cost of diesel has increased, as all farm management costs and irrigation cost. Last year we certainly suffered from inflation. However, we saw it in all agricultural products made in Italy, not just lentils (Processor-lentils)

> Unfortunately, we also had to adjust the sales prices, due to the increase in energy costs. We weren't able to recover these expenses, so in these years we really had to deal with it (Farmer-lentils and buckwheat)

These findings align with recent evidence on rising food prices in latest years, driven by increased costs in energy, transportation, packaging, machinery, and labour, alongside rising costs of animal feed and fertilizers (European Commission, 2024b).

The second theme concerns market-related aspects. Results show that stakeholders predominantly operate through yearly contracts, normally renewed on the basis of long-term relations. These contracts not only stipulate the quality and quantity of purchased products but also guarantee a minimum price for suppliers:

> We make an annual supply contract before sowing. We guarantee a price that is always the same and does not fluctuate according to the market, unless the market rises more than what expected in the contract. We set a price, if the market goes up beyond what offered as it happened this year, we follow the market, so the farmer doesn't lose out. But if the market goes down, we stay on the minimum guaranteed price (Retailer-lentils and buckwheat)

This aligns with research showing that long-term contracts ensure stability for farmers while allowing flexibility to respond to the market, ultimately supporting biodiversity-friendly practices (Salmi *et al.*, 2023).

The third theme relates to the issue of climate change, involving different extreme weather events in cultivation of these crops. However, concerns about climate change seem to be mainly held by farmers in both supply chains, particularly regarding rising temperatures disrupting crop growth throughout the year:

> In recent years there have been anomalous situations related to temperatures. This year there have been low temperatures until the end of April not allowing the crop to grow and then the explosion of temperatures up to 40°C, which accelerated ripening (Farmer-lentils)

> There have been cooler years. During the flowering period, which is precisely the most decisive period for the yield of buckwheat, we were doing well because there were no temperatures that were too high. But unfortunately, the ever-increasing peak temperatures, even daily ones above 28°, greatly depreciates the yield (Farmer-buckwheat)

Recent literature shows that rising global temperatures have intensified extreme weather events, significantly reducing crop yields (Anderson *et al.*, 2020). In the upcoming years, agricultural sector and food security are expected to face substantial challenges, with impacts varying by region and crop.

The fourth theme focused on policy. The Common Agricultural Policy (CAP) plays a major role in biodiversity decision-making. Farmers express concerns about restrictive regulations, such as pesticide bans, which they see as disincentives for growing legumes:

> The new CAP will not favour lentils, just as other legumes. To get the eco-scheme 4, you need to follow crop rotation between cereals and legumes, and in legumes, as in forage crops, the use of pesticides is prohibited. Managing legumes without pesticides is very impractical and, in my opinion, this can only lead to the disappearance of this crop. (Farmer-lentils)

Similarly, buckwheat farmers noted the lack of CAP recognition for buckwheat as a pollinator-friendly crop, ultimately limiting its support:

> In the drafts of the new CAP, buckwheat was not considered as a honey plant. Instead, it could very well fit into eco-scheme 5 and get an integrated contribution, for example, as a minor culture. So, if you don't directly transform buckwheat in your farm, but you have to buy it somewhere else, I don't see how farmers would be able to cultivate it without any aid (Farmer-buckwheat)

These findings seem to accentuate specific criticisms within the ongoing discussion regarding recent revisions to the CAP. Specifically, Cuadros-Casanova *et al.* (2023) argued that incentives favouring the cultivation of crops eligible for economic support have led to increased production of a limited range of varieties, consequently leading to the homogenization of cropland and a negative impact on biodiversity. Moreover, they also documented the absence of interventions aimed at preserving or bolstering the diversity of wild pollinators at local and landscape levels.

Lastly, a broad theme concerning socio-cultural factors emerged among stakeholders. Trust and collaboration play a key role, particularly in the lentil supply chain, where PGI systems such as consortiums or cooperatives, foster strong relationships among farmers, processors, and retailers. This aligns with Aggarwal and Srivastava (2016) who found that supplier selection, joint planning, and information sharing drive collaboration, leading to profits, waste reduction, and supply chain efficiency.

Consumer preferences also shape decision-making, with retailers focusing on attributes like organic certification and Italian origin rather than specific lentil varieties:

> Up to now consumers have always seen lentils as a fairly basic product, with no specific demand for particular varieties. [. . .] Through our private label, we had the chance to introduce an organic product, focusing on cultivation methods rather than the type of lentil. Moreover, our goal is to work with products that are 100% Italian, [. . .] sourced from various regions across Italy. (Retailer-lentils and buckwheat)

Recent studies demonstrate that attributes like cultivation methods and origin exert a greater influence on market prices and consumer preferences than intrinsic characteristics like colour and variety (Acciani *et al.*, 2020).

Consumer trends are also shifting for buckwheat, with growing demand among non-celiac consumers. This trend reflects changing tastes in the market, as evidenced by a processor:

> What we have witnessed is that there has been an evolution on the part of the consumer. Not only the celiac consumer intolerant buys this type of pasta, but it has now become a pasta by choice and therefore not just by necessity. This has also characterized an evolution on the shelf, so much so that in some distribution chains we are no longer included in the gluten-free pasta category, but we are in the shelf of special pasta, close to whole wheat pasta, spelled pasta, kamut etc. This suggests that the consumer today also chooses this product not for a medical problem, but by choice (Processor-lentils and buckwheat)

These findings are consistent with recent research suggesting gluten-free products are increasingly perceived as healthier alternatives by the general population (Xhakollari *et al.*, 2021).

4.3 Themes 6 and 7: barriers and drivers towards biodiversity management

The study identified key barriers and drivers influencing biodiversity management across farmers, processors, and retailers. Figure 1 presents radar charts comparing these factors across actor categories. The variation in scales across charts reflects the differing frequency with which each topic was mentioned.

Farmers face major challenges, including yield variability among different crop varieties (including PGI lentil types), and high production costs. Implementation of crop diversification is also challenged by limited land availability and inadequate technical expertise. This is consistent with Meynard *et al.* (2018) who observed that a lack of technical knowledge regarding certain diversification crops often leads to crop failure and abandonment. In contrast, training and educational initiatives promoting agroecological strategies have shown to positively influence farmers' crop diversification decisions (Kpienbaareh *et al.*, 2024).

Furthermore, unpredictable weather conditions and unsuitable soil, particularly in the case of buckwheat, have further contributed to declining productivity and frequent low or no yields in recent years. These challenges align with the findings of Morel *et al.* (2020) who identified

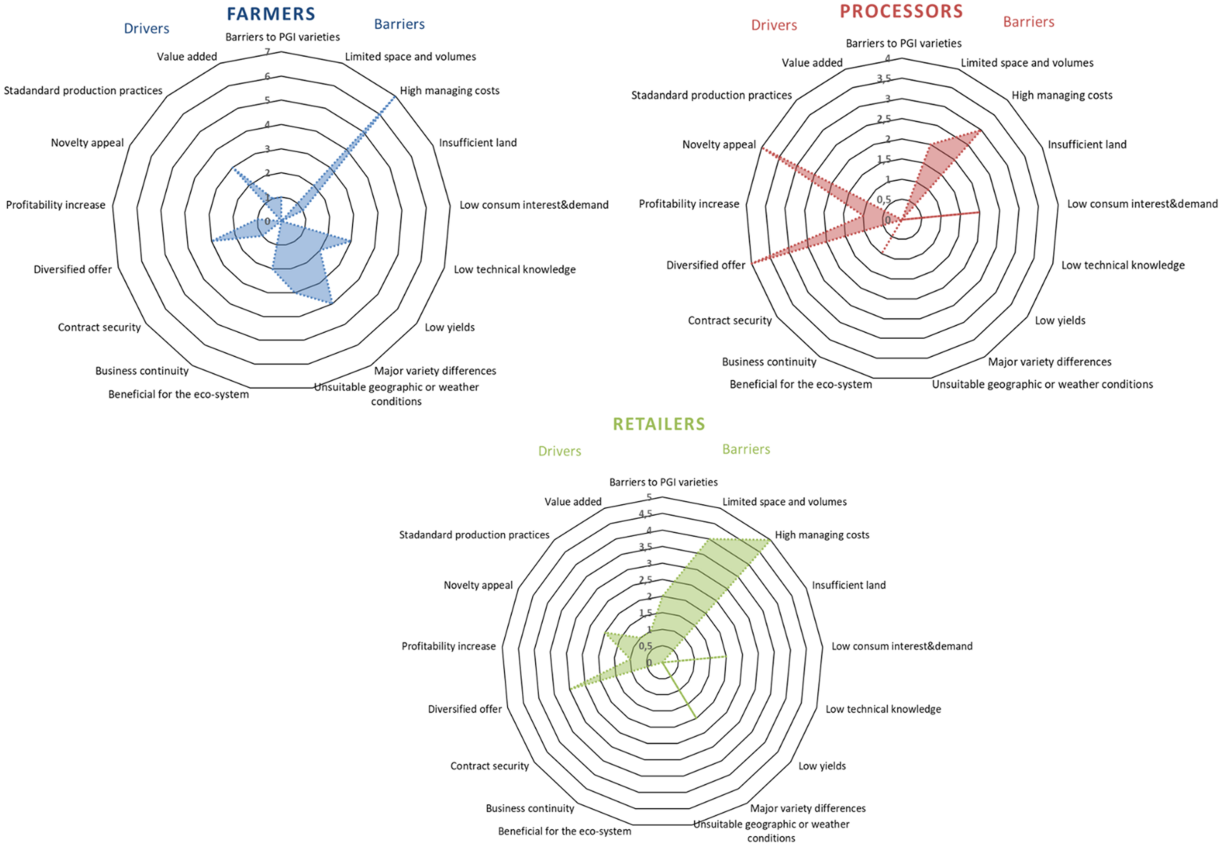

Figure 1. Barriers and drivers. Source: Authors' own work

insufficient technical knowledge about minor crops, lack of appropriate equipment, and the absence of crop varieties suited to local conditions as major barriers to crop diversification at the farm level. For instance, buckwheat is found to grow best on specific soil types, particularly sandy and acidic soils in high-latitude or northern regions (Small, 2017). However, the current study indicates that cultivating different types of lentils or buckwheat does not necessarily require special farming practices; the processes remain relatively standard. While legumes and protein crops can be harvested using the same equipment as cereals, other crops like oilseeds require specific harvesting machinery (Meynard *et al.*, 2018). Despite these challenges, buckwheat farmers recognize its benefits for product diversification, attracting central purchasers, and securing year-round contracts with buyers. Beyond business benefits, buckwheat cultivation also supports ecosystem services through flowering and pollination.

Similarly, processors identify both drivers and barriers. At this stage, they cite high management costs and lack of consumer interest and low demand for differentiated varieties as barriers to biodiversity management, specifically in the case of lentils. These findings align with earlier research showing that variety and colour have minimal impact on consumer purchasing decisions (Acciani *et al.*, 2020). However, processors of lentils and buckwheat generally focus on the benefits associated with biodiversity management. They see product diversity as a way to attract novelty-seeking consumers and support business continuity, especially when certain varieties are unavailable.

Lastly, retailers face various obstacles, including high management costs, limited consumer interest in differentiated crops, storage limitations, and small product volumes, making it difficult to scale biodiversity-driven products. This is confirmed by Morel *et al.* (2020) who found that supply chain constraints—particularly logistics in processing and retail—limit the market potential for minor crops. According to Meynard *et al.* (2018) and Morel *et al.* (2020), limited volumes available across different regions drive up transaction costs and disadvantage minor crops at both the processing and retail stages. Despite these barriers, in this study, retailers recognize that product differentiation can boost novelty appeal, profitability for all value chain actors, and consumer interest. These findings are in line with Lami *et al.* (2023), showing profitability as a key driver for adopting certain supply chain management practices. Additionally, retailers note that these differentiated products, when reaching the retail stage, not only follow standard production practices but also create added value. As illustrated by Sacchi *et al.* (2019), supply chain value can be enhanced through quality-based differentiation (e.g. ancient varieties, organic methods) and stronger linkages between producers, processors, and consumers.

5. Conclusions

This study offers critical insights into biodiversity management within agri-food supply chains, distinguishing between agrobiodiversity (genetic diversity within and between species) and product diversity (product variety at processing and retail levels). It examines decision-making factors and identifies key barriers and drivers influencing biodiversity practices.

Findings highlight differences between the two crop cases. Lentils, embedded in Italian food culture and supported by PGI labels, benefit from strong consumer recognition, whereas buckwheat, though gaining popularity due to gluten-free demand, remains a niche crop with lower market familiarity. Policy interventions, such as the CAP and eco-schemes, yield mixed outcomes: while PGI protections enhance product value, restrictive eco-scheme measures (e.g. pesticide bans and the lack of recognition of buckwheat as a pollinator-friendly crop) challenge crop diversification.

Addressing economic and policy barriers—high costs, limited land and storage, and technical constraints—is essential to advancing biodiversity-friendly practices. Aligning policies more closely with supply chain realities can foster agrobiodiversity. Although stakeholders recognize the importance of biodiversity in enhancing ecosystem services, market competitiveness, and supply chain sustainability, long-term policy support and consumer education are critical to expanding biodiversity adoption.

5.1 Implications for policy, practice, and society

Policies should better support agrobiodiversity and product diversity in agri-food supply chains. Enhancing CAP frameworks to encourage diverse crop cultivation—particularly legumes and underutilized crops—could mitigate restrictive measures, such as pesticide limitations in legume production. Targeted support for crops like buckwheat, which contribute to pollination and sustainable farming, could further promote biodiversity. Strengthening CAP eco-schemes is crucial to preventing biodiversity loss and ensuring ecological sustainability across Europe.

Additionally, stabilizing market conditions for agricultural inputs, such as fuel and machinery, is essential to mitigate inflationary pressures affecting farm profitability and sustainability. Simplifying regulatory processes, particularly for smallholder farmers, could further stabilize farming operations while maintaining environmental standards.

From a managerial perspective, biodiversity strategies offer opportunities across the supply chain. Farmers can improve technical expertise in crop diversification to enhance resilience and economic viability. Partnering with seed suppliers to access regionally adapted crop varieties could help mitigate climate-related risks. Processors can innovate by differentiating products through biodiversity management, leveraging the growing demand for gluten-free and health-conscious options. Retailers should increase the visibility of biodiversity-driven products, emphasizing their environmental and health benefits. Enhanced collaboration across the supply chain would optimize logistics, storage, and distribution for minor crops, increasing the availability and appeal of biodiversity-enhanced products.

At the societal level, raising consumer awareness about biodiversity-friendly products is crucial. Educational campaigns highlighting the health and ecological benefits of biodiversity-enhanced products can influence consumer preferences and create demand for diversified crops. Research institutions can support this transition by conducting impact assessments and developing guidelines to help supply chain actors adopt sustainable practices.

5.2 Limitations and future research

While this research offers valuable insights, some limitations should be acknowledged. Firstly, while allowing for in-depth analysis, the study's relatively small number of participants could limit generalizability. Additionally, the focus on two Italian case studies means findings may not fully apply to other regions with different institutional settings. Additional research should explore biodiversity across diverse settings where it may take other meaning and across various case studies to identify shared challenges and best practices.

Further studies should examine how policy frameworks interact with market incentives and consumer behaviour to affect biodiversity outcomes. Studies on diversification strategies and niche markets can provide valuable insights for future policy adjustments. Further investigation into digital innovations for transparency and traceability in biodiversity-friendly supply chains and stakeholder involvement—including government bodies and industry associations— can shed light on biodiversity's societal impact. Finally, this study lays the groundwork for future quantitative research to model the complex relationships within the agri-food supply chain and their effects on biodiversity, leading to more data-driven recommendations for sustainable agricultural practices.

Notes

1. *Pizzoccheri*, originating from Valtellina, Sondrio (IT), are a variety of buckwheat-based pasta.
2. Confagricoltura website: https://www.confagricoltura.it/eng

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