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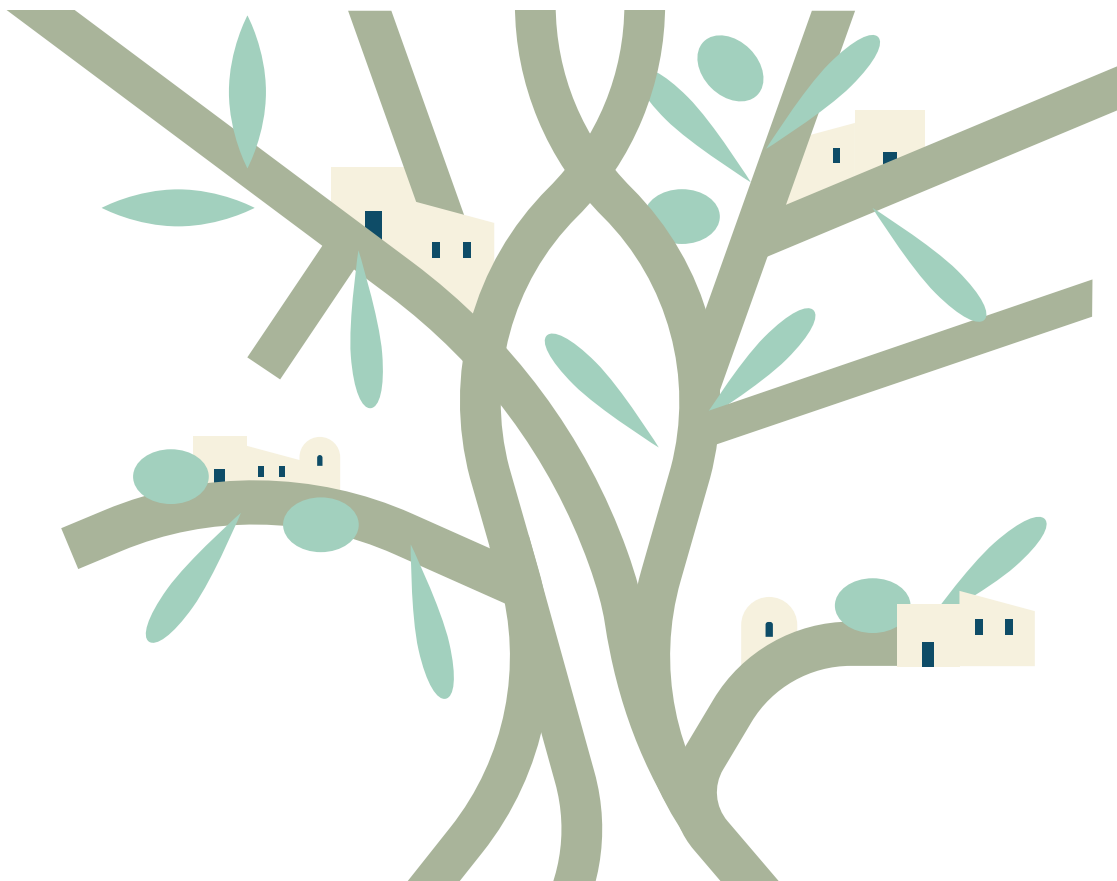
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Enhancing sustainability by
multi-criteria analysis of novel
durum wheat cultivation
practices in Italy

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FOREWORD

Rozakis et al. evaluate the sustainability of alternative durum wheat cultivation practices in Southern Italy using a multi-criteria decision analysis framework. Results reveal a structural divergence between socially optimal and privately optimal systems. Intercropping with lentil and arbuscular mycorrhizal fung (AMF) inoculation ranks first under policy-oriented weights due to superior soil health and biodiversity performance, whereas conventional cultivation remains preferable under farmer-oriented weights because of higher gross margins. The dual-ranking approach highlights the sustainability gap between public objectives and private incentives, providing evidence for targeted policy instruments to support agroecological transition in Mediterranean cereal systems.

Demurtas examines how the rapid diffusion of pharmaceutical interventions, particularly glucagon-like peptide-1 (GLP-1) therapies is reshaping food systems by altering consumption patterns, agri-food markets, agricultural production incentives, and cultural food practices. While recognizing their potential public-health benefits, the analysis highlights risks of decoupling nutrition from food systems, with implications for sustainability, rural livelihoods, and food heritage. The paper argues for an integrated food-systems perspective that situates pharmaceutical innovation within broader strategies for sustainable, culturally grounded, and resilient diets.

Giordano et al. analyse a co-design methodology developed and implemented by CI-HEAM Bari across 17 countries within agrifood innovation ecosystems. Drawing on both implementation experience and selected literature on open innovation and innovation ecosystems, the paper shows how participatory co-design enhances the relevance, ownership, and effectiveness of interventions. The paper contributes to the operationalisation of participatory approaches in youth entrepreneurship support, moving beyond theoretical frameworks towards practice-oriented evidence.

The socio-economic changes experienced by women engaged in three Women's producer organisations (WPOs) in Siliana Governorate, Tunisia are explored by *Mazhoud et al.* Paper assessed the economic benefits and collected women's narratives about changes in social relations at community and family level, in social skills, and in self-perception. The financial gains were generally modest, especially compared to alternative sources of income. Women nevertheless valued their participation in WPOs. Tunisian WPOs offer more than financial benefits: they foster social support, personal development, and a way towards empowerment.

This study analyzes the regional competitive structure of ten major producer countries in the 2005-2023 period using Revealed Comparative Advantage (RCA) and Constant Market Share (CMS) methods. *Ural and Direk* reveal a strategic divergence between the Mediterranean and New World blocs. The analysis demonstrates that high specialization does not automatically translate into market share gains. Success increasingly depends on technological modernization, particularly super-high-density (SHD) production systems, strategic market diversification, and climate adaptation capacity rather than historical dominance.

Makedon et al. analyse green management and its role in shaping innovative strategies aimed at fostering sustainable enterprise development. The results indicate that integrating green initiatives with innovation-oriented strategies can strengthen economic performance, enhance corporate reputation, and improve long-term competitiveness. The implementation of eco-innovations contributes to the optimization of production processes, reduction of carbon emissions, and improvement in energy efficiency. These findings demonstrate broader societal benefits related to resource efficiency, emission reduction, and sustainable economic development.

Riadh Cherif provides the first integrated analysis of how Tunisia's organic olive transition interacts with macroeconomic volatility to determine export performance. Results reveal a robust long-run relationship: a 10% expansion in certified organic area increases export value by 6.5–7.0%. Conversely, a 10%-dinar depreciation reduces exports by approximately 7%, contradicting standard price-competitiveness theory. The author identifies a novel indirect channel: exchange rate volatility affects exports primarily by disrupting organic land allocation decisions. Threshold analysis shows organic benefits intensify beyond 45,000 hectares.

This study carried out by *Belaidi and Benmehaia* investigates the technical efficiency of olive farms in Béjaia, Algeria, using primary data from a stratified survey of growers conducted in 2025. Results reveal pronounced heterogeneity, with a strongly bimodal efficiency distribution and an average efficiency level of 0.39. The findings imply that productivity gains in perennial systems depend less on marginal input adjustments and more on the coherence and regularity of orchard management. The study contributes fresh evidence on efficiency determinants in perennial agriculture and informs ongoing efforts to modernize Algerian olive sector.

The local olive oil sector in Algeria is facing a crisis due to a traditional system that is not very competitive, characterised by old orchards, poor maintenance, manual harvesting, fragmented land and the predominance of family farms. The authors *Saidi and Akli* aim to identify priority levers for action for a sustainable development strategy. The analysis enabled the strategic factors to be ranked. The study concludes that collective organisation is the fundamental lever for overcoming structural weaknesses and committing to the sustainable development of the olive oil sector in M'Chedallah region.

Enhancing sustainability by multi-criteria analysis of novel durum wheat cultivation practices in Italy

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Abstract

This study evaluates the sustainability of alternative durum wheat cultivation practices in Southern Italy using a multi-criteria decision analysis framework. Based on experimental field data from Basilicata, six cropping scenarios—with or without fertilization, intercropping with lentil, and/or application of arbuscular mycorrhizal fungi (AMF)—are assessed across environmental, economic, and social criteria. The PROMETHEE outranking method is combined with the Analytical Hierarchy Process (AHP) to integrate quantitative indicators and expert-based qualitative judgments, while group decision techniques address stakeholder heterogeneity. Two weighting perspectives are simulated: a policy-maker viewpoint emphasizing environmental performance, and a farmer viewpoint prioritizing profitability and risk reduction. Results reveal a structural divergence between socially optimal and privately optimal systems. Intercropping with lentil and AMF inoculation ranks first under policy-oriented weights due to superior soil health and biodiversity performance, whereas conventional cultivation remains preferable under farmer-oriented weights because of higher gross margins. Lentil intercropping without AMF emerges as a compromise solution, balancing income stability and environmental improvement. The dual-ranking approach highlights the sustainability gap between public objectives and private incentives, providing evidence for targeted policy instruments to support agroecological transition in Mediterranean cereal systems.

Keywords: Durum wheat, Italy, Agricultural sustainability, Ecosystem services, Multi-criteria analysis.

1. Introduction

Climate change is expected to be followed by strong, yet unpredictable, impacts on rural development and the agricultural sector. A recent meta-analysis by Farah *et al.* (2025) examines

the multifaceted impacts of climate change on agricultural productivity by means of systematic literature review targeting peer-reviewed articles published between 2015 and 2024. The review finds that climate change significantly impacts global agricultural productivity, with

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projections indicating up to a 14% decline in food production by 2050 if adaptation measures are not implemented. The risk of damage to essential ecosystem services highlights the need to re-evaluate the conventional, input-dependent farming systems, and to identify and implement transition pathways toward establishing more resilient and sustainable systems adapted to altered conditions. Strengthening the resilience of farms improving soil health are well aligned with sustainability and the efficient use of natural resources (Gardner *et al.*, 2019).

Relevant research has been undertaken in this direction, altering cultivation practices to achieve: i) soil health restoration, ii) carbon sequestration and hence, nutrient recycling, iii) higher water infiltration and retention, with implications extending the scale of the single farm (water resources management, floods attenuation). Such practices comprise intercropping with leguminous crops decreasing external N supply Glaze-Corcoran *et al.*, 2020), using water use efficient genotypes, restoring / “engineering” soil and root microbiota for improving nutrient (N, P) and water uptake (e.g., arbuscular mycorrhizal fungi) thus reducing the input of chemicals and energy (Gesesse *et al.*, 2023). Soil and water management strategies have proven effective in improving resilience but require policy and financial support for large-scale adoption. Thus in order to promote farm resilience and sustainability with alternative cultivation practices should consider economic, environmental, and social dimensions and subsequent trade-offs. This requires knowledge from different disciplines plus decision-support methods that acknowledge the subjective importance of relevant objectives and goals.

Multicriteria methods provide the framework to solve such decision problems and the capacity to select the most efficient practices. Among an increasing number of multicriteria algorithms and tools, Sadok *et al.* (2008) undertook a critical review regarding the selection of those suitable for the sustainability assessment of cropping systems. The recommended methods not only have to address conflicting criteria but also identify specificities of the application domain such as incommensurability, non-compensation, and incomparability. These basic features are ade-

quately integrated by outranking methods that do not require a common scale or a utility function to aggregate the criteria but compare alternatives in pairs and assign a degree of preference or dominance based on the criteria.

Outranking methods have demonstrated flexibility to tackle real decision problems in agriculture e.g. to sort cropping systems (Arondel & Girardin, 2000) to adapt water supply strategies at the basin level (Kumar *et al.*, 2016); to evaluate the provision of ecosystem services Chatzinikolaou *et al.* (2015); and to evaluate climate change adaptation alternatives (Nigussie *et al.*, 2018) among a large number of relevant applications. The Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) is a discrete multi-criteria decision technique often implemented to support the selection and ranking of alternative cultivation practices. For instance, Cano *et al.* (2023) assessed various cropping systems for sustainable intensification. Talukder and Hipel (2018) used the method to compare the sustainability of five cropping systems in coastal Bangladesh, PROMETHEE is enriched with prospect theory to evaluate and rank climate change adaptation practices in maize cropping systems related to tillage. (Król *et al.*, 2018).

In this paper, Multi-criteria Decision Analysis (MCDA) is applied to durum wheat cultivation in Southern Italy to rank alternative practices aiming at sustainability through improving soil health. Peculiarities of the case study obliged to enhance PROMETHEE algorithm with group aggregation of preferences and application of Analytical Hierarchy Process (AHP). PROMETHEE allows combining objective measures with subjective information based on how particular actors perceive their importance. In cases when evidence on alternatives’ performance over one or more criteria is weak, expert knowledge from scientists and practitioners can be used in workshops to provide qualitative judgments on alternatives. Pairwise comparisons of these judgments yield quantified information in percentage priorities using the AHP. These priorities populate evaluation matrices along with tangible indicators for MCDA algorithms. In case of numerous participants, this information must be aggregated using

group decision algorithms. Group Decision methods properly integrating preferences in the presence of many participants in the decision-making process, found in the existing literature have been critically overviewed considering the degree of consensus among decision makers (DMs) to suggest appropriate algorithms.

The manuscript is organized as follows. The materials and method section presents basic information of the case study, then it comprises a brief presentation of the PROMETHEE algorithm and implementation process. Then the evaluation of aggregation techniques of individual to group judgments through the AHP method is detailed along with assumptions to select the most efficient and sound algorithm. In Section 3, the case study and the experimental design information are input for calculations, presenting the implementation outcomes of the methods in the Italian case and detailed results. Discussion of the findings and conclusive thoughts follow complemented by highlights on areas of further research to conclude the paper.

2. Materials and methods

2.1. The case study material

Scientific research teams in soil, agronomy, and social sciences collaborate to enhance soil health and microbiota in selected cropping systems under climate change conditions in the Mediterranean. The principal hypothesis is that improvements in the resilience of small family farms in the Mediterranean Region at scales able to cause impact require the adoption of integrated and easily adaptable approaches. The average total utilized agricultural area per farm in Italy is 24.1 hectares, with approximately 19.1 hectares dedicated to durum wheat. Durum wheat plays a crucial role in Italy's agricultural landscape by its socio-economic and environmental impact. In southern Italy, durum wheat is grown on 1.2 to 1.3 million hectares, with Basilicata contributing around 85,000 hectares to this figure. In Italy, the Basilicata region is the third largest producer of durum wheat behind Apulia and Sicily, recording 115,160 ha in 2022 (8% of the country area according to www.statista.com).

In this frame, field studies have been performed in Basilicata, Italy aiming at soil restoration in durum wheat production to be achieved by strategies that include no-tillage, intercropping, and the promotion of soil microbiota, all of which aim to improve soil productivity and resilience in the face of adverse climatic conditions. There is evidence for additional sustainable agricultural techniques, such as intercropping with leguminous species and the application of arbuscular mycorrhizal fungi (AMF), which have the potential to enhance crop resilience and soil health (Volpe *et al.*, 2018; Balestrini *et al.*, 2019). In this context, a field study was performed to assess the effect of intercropping of two genotypes (Marco Aurelio and Maestà) of durum wheat (*Triticum turgidum* subsp. *durum*), one of the most important crops in Southern Italy, with a legume species (*Lens culinaris*, cv Eston), as well as the effect of application of a fungal inoculum as bio-stimulant (arbuscular mycorrhizal fungi (AMF)-based inoculum) in durum wheat cultivation. The field study was conducted during two consecutive cropping seasons (2021-2022, and 2022-2023) and it was conducted in a single experimental site (*i.e.*, Metaponto, Matera, Italy) using a randomised block design with 4 m² parcels. In each parcel, 11 plant rows, 20 cm apart from each other, were used. In the first season, a total of 40 parcels were established across the 6 Scenarios (see section below "Defining the alternatives"). In detail, four repetitions per scenario were used, except for the fertilized and unfertilized treatments (Scenario 1 and Scenario 2, respectively) that were replicated twice. In the second season, Scenario 6 was discarded, and 30 parcels were established in an adjacent field within the same experimental site (three replicated parcels per scenario; Zampieri *et al.*, 2025). Besides soil health monitoring, quantitative responses of tested varieties/crops, including pre- and post-harvest agronomic parameters (*i.e.*, phenology, plant biomass, and yield), were evaluated. The shift in soil and root microbiota under different conditions was also investigated. Particularly, for the microbiota profiling (DNA-based community analysis), soil was collected at the parcel level (40 soil samples in the first season and 30 in the second, for

70 soil samples overall; Zampieri *et al.*, 2025). This design provides replicated, controlled evidence for Scenario comparison under the local pedoclimatic conditions. However, because the experiment was conducted at one site, and some agronomic and environmental results may be site- and year- dependent, validity should be considered as limited to the specific context.

To identify compatible solutions for the adaptation of smallholder farms (defined after Davidova *et al.*, 2014 (<5 ha)), the dominant form of farming systems in the Mediterranean, to climate change, our work employed a bottom-up multi-actor approach to stimulate a strong interaction between researchers and key actors (policy-makers, farmers) of the agricultural sector from proposal onset.

2.2. Research method for decision-making at the farm level

a) A brief reference to the PROMETHEE methods

The Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) method has great advantages in outranking alternatives through qualitative and quantitative evaluations (Brans *et al.*, 1986). The PROMETHEE family of outranking methods was first introduced in the form of partial ranking alternatives (PROMETHEE I). Subsequently, the method extended to a full-ranking approach (PROMETHEE II). The PROMETHEE methods belong to the family of the outranking multi-criteria decision-making methods, introduced by B. Roy (1991). Afterward, the method was extended to PROMETHEE III, IV, V, VI, and PROMETHEE GDSS (Behzadian *et al.*, 2013; Mareschal, 2018; Mateo, 2012). In this text, we elaborate on PROMETHEE I AND II.

b) The PROMETHEE process flowchart

1. Based on the differences between the performance values of each pair of alternatives, a "Preference function" showing the preference of the DM for alternative "a" over another alternative "b" is chosen, separately for each criterion, and a matrix containing all the preference indices per criterion is created.

2. The partial preference indices are multiplied by the weights corresponding to different criteria and summed up, and the matrix of the global preference indices is created.

3. Based on the latter matrix, a leaving flow (row sum) and an entering flow (column sum) are calculated giving the outranking and the outranked character of the corresponding alternative respectively. In PROMETHEE I the partial preorder of the alternatives takes place based on both entering and leaving flows.

4. For the PROMETHEE II complete preorder, a net flow per alternative is calculated by subtracting its entering from its leaving flow, and the greater an alternative's net flow, the higher its position in the final ranking.

In a multi-criteria decision problem, PROMETHEE requires that a specific preference function is associated with each criterion. The purpose of a preference function (which we note as $P(d)$ in this text) is to convert the difference $d = (\text{performance value of action a}) - (\text{performance value of action b})$ on a given criterion, from the criterion scale to a normalized 0-1 degree of preference. 0 means that there is indifference between a and b, values close to 0+ mean weak preference for a over b, values close to 1- mean strong preference for a over b, and 1 means that there is a strict preference for a over b. Regarding the preference functions, we must note that larger absolute differences cannot lead to lower preference degrees.

The Promethee method suggests 6 types (shapes) of preference functions, some of which accept preference and/or indifference thresholds, as well as intermediate preference states. As a simple example, Figure 1 shows the shape of typical preference functions defined below in detail. The horizontal axis corresponds to the value of the difference between two actions on one single criterion and the vertical axis corresponds to a degree of preference $H(d)$ between two actions (from 0 to 1) depending on the difference d . "q" is the indifference threshold (the largest absolute difference that is considered negligible and gives a preference degree = 0) and "P" is the preference threshold (the smallest absolute difference that corresponds to a strict preference, in other words, gives a preference degree = 1).

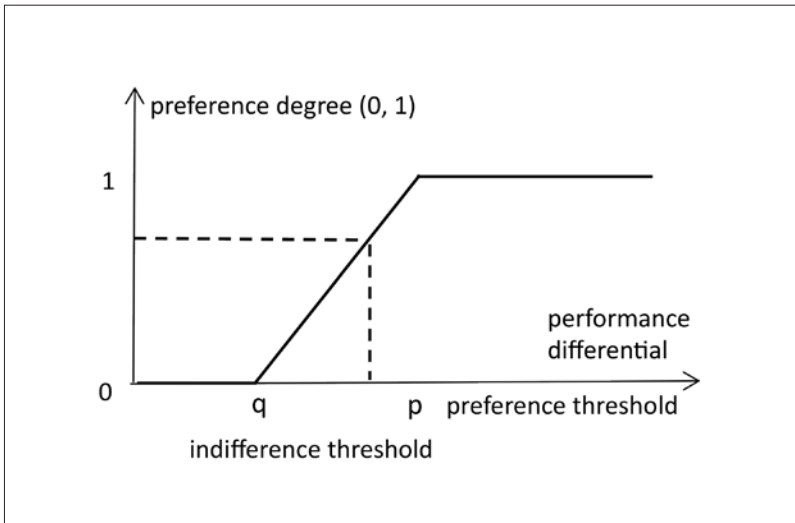


Figure 1 - The shape of a typical preference function (Linear).

Source: Mareschal (2018)

The six usual Preference Functions in PROMETHEE are: Usual Criterion: Any positive difference translates to full preference (1) as there is no threshold ($p=q=0$). U-shape Criterion uses an indifference threshold (q) (If $d \leq q \rightarrow$ no preference, If $d > q \rightarrow$ full preference). V-shape Criterion uses a preference threshold (p) (Preference increases linearly from 0 to 1 until p , after $p \rightarrow$ full preference). Level Criterion uses two thresholds: q and p (small difference $\rightarrow$ no preference, medium difference $\rightarrow$ partial preference, large difference $\rightarrow$ full preference). V-shape with Indifference uses both q and p ($d \leq q \rightarrow$ no preference, linear increase between q and p , $d \geq p \rightarrow$ full preference). Gaussian Criterion uses parameter s (standard deviation of normal distribution) that translates to smooth, continuous increase in preference. It is suitable when preference grows gradually and non-linearly. Full description of the 6 types (shapes) of “Preference functions” in the seminal paper by Brans *et al.* (1986).

The choice of appropriate Preference Functions

Mareschal (2018) elaborates on the subjects of the choice of threshold determination but “Visual PROMETHEE” MCDA software also makes suggestions for threshold values (www.promethee-gaia.net). This procedure doesn’t include the Type II (U-shape) and Type VI (Gauss-

ian) preference functions. In practice, the Type II preference function is seldom used and the Type VI preference function can be used as an alternative to the Type V preference function. The choice of the good preference function for a criterion can be made according to the following principles:

1. If the criterion has a continuous numerical scale (real numbers):
 - a) If we want to introduce an indifference threshold (and thus neglect small differences), we should consider using a Type V Linear preference function.
 - b) If we want small differences to play a role in the PROMETHEE computation, we should consider using a Type III V-shape preference function.
2. If the criterion has a discrete numerical scale (small integer numbers) or a qualitative scale (few ordered levels):
 - a) If the number of possible values is small (≤ 5) and the values are perceived as quite different from each other, we should consider using a Type I Usual preference function.
 - b) If the number of possible values is larger or we want to have a weaker degree of preference for smaller differences, we should consider using a Type IV Level preference function.

The PROMETHEE method is often implemented to support the selection and ranking of

alternative cultivation practices as it satisfies the prerequisites set by Sadok *et al.* (2008) providing two variants, the first allows for incomparability whereas the second results in a complete preorder of alternatives.

2.3. The decision process implementation

The overall objective

The overall objective of this exercise is to provide evidence regarding alternative practices of cereal cultivation for soil sustainability in South Italy. Sustainability recalls the long-term survival of a system thus environmental goals (i.e., protection of soil and water resources and climate change mitigation) should be pursued in parallel to social and economic objectives by farm businesses and agricultural households (i.e., increase farm income, reduce energy consumption, working time and labour costs). A picture of

conflicting objectives is thus drawn recalling appropriate methods to determine the most efficient compromise alternatives for restoring soil health in a typical farm. These are related to ecosystem services (the goods and services provided by ecosystems for humans); provisioning services that can be extracted from nature (food production in terms of grain yield and/or by-products), regulating services that make life possible for people, moderate natural phenomena and make an ecosystem clean, sustainable, functional, and resilient to change (carbon storage, disease control), supporting services underlying natural processes that allow the earth to sustain basic life forms (nutrient cycling, water cycle, soil formation, production quality) and cultural services (traditional knowledge transfer, spiritual values, leisure time among those directly related to farms). Ecosystem services imply criteria to pursue as well as corresponding indicators facilitating evaluation.

Table 1 - Decision process Steps.

<i>Step</i>	<i>Input</i>	<i>Process</i>	<i>Output</i>
1. Problem structuring	Sustainable durum wheat systems	Define decision objective and perspectives	Structured multi-criteria decision problem
2. Select alternatives	Experimental cultivation systems	Select mutually exclusive alternatives	Set of decision alternatives
3. Define criteria	Sustainability framework	Define criteria and sub-criteria	Hierarchical criteria structure
4. Performance matrix	Experimental field data – economic calculations	Quantify performance of alternative over measurable criteria	Decision frame and performance matrix
5. AHP module	Expert judgments for qualitative criteria	Pairwise comparisons for priorities consistency check	Quantitative performance in 0-100 scale
6. Stakeholder weighting scenarios	Global weights Divergent view points	Elicitation of policy maker's versus farmer preferences	Distinct weight sets
7. PROMETHEE application	Performance matrix stakeholder specific weights	Define preference functions – compute pairwise partial preference indices – calculate flows	Complete ranking (PROMETHEE II) for each stakeholder perspective
8. Comparative ranking analysis	Net Flow values for both scenarii	Compare rankings – detect non-dominated and compromise solutions	Stakeholder sensitive ranking comparison – policy making for sustainable durum wheat systems

Setting criteria for decision-making

Environmental, economic, and social criteria were selected through consultation with farmers and experts and information drilling from the scientific field experiment. Criteria reported in the literature of agricultural sustainability are usually grouped in the three pillars economic, social, environmental, for each one of them a large number of sub-criteria can be gathered from different papers. We limited the number of subcriteria for each pillar not only to keep in manageable burden but also to avoid the weighting bias that appears when higher level criteria are splitted in too many subcriteria (Hämäläinen and Alaja, 2008). Thus we retained those evaluated as most important in the relevant literature for South European agriculture (Abdallah *et al.*, 2018). The first two of these criteria are Socio-economic (Labour & Managerial difficulty) and also express the “Invested effort” of the farmer. The next two refer to the farm’s financial performance (Monetary gross profit & Yield variability) and belong to the category of Provisioning Ecosystem Services. Environmental criteria complete the picture; supporting ecosystem services such as Nutrients in soil (N, P, K) and microbiota biodiversity as well as Soil organic carbon (SOC) & Risk of Diseases regulating the ecosystem.

Environmental criteria

Soil organic carbon (SOC), measured in percentage: according to the 2002 EU soil strategy, the maintenance of soil organic matter is one of the major tenets in preventing soil erosion as it affects water retention capacity. The higher value of the indicator shows the more sustainable farms in terms of maintaining soil fertility.

Nutrients in soil (N, P, K), measured in parts per million (ppm): nitrogen (N), phosphorus (P), and potassium (K) are the primary macronutrients for plant growth and development and are the three most important limiting factors frequently added as fertilizers in modern agriculture (Kulcheski *et al.*, 2015).

Microbial biodiversity, measured as alpha diversity indexes Chao1 and Shannon (Shannon-Wiener). The Chao1 Index is a non-parametric estimator of species richness that accounts for the number of rare species in a community,

particularly focusing on those observed only once or twice, providing an estimate of the total species richness based on the observed data. The Shannon Index is a measure of biodiversity that accounts for both the abundance and evenness of the species present in a community (Chao & Shen, 2003).

Risk of diseases, measured as disease index from 0 to 9 (where 0 indicates healthy and 9 indicates completely damaged leaf). Plant diseases are significantly affected by the diversity of hosts and environmental conditions, as well as by the adopted agricultural management (Laine, 2023).

Economic efficiency

Mean gross profit (GP), in euro: it is used instead of net profit thus we do not consider depreciation of durable goods because we compare different versions of the same crop, and machinery used is readily available in arable farms, pieces of machinery not available are rent.

Standard deviation yield (SD), measured in percentage from the mean: this is the dispersion measure used to calculate the time series of average yields provided by different parcels within experimental fields. The lower the standard deviation the higher the farm’s income stability, thus it is considered in the financial indicators.

Social performance

Labour, in hours, this is an ambivalent criterion as job creation is desirable from the society point of view whereas labour use as factor of production is a cost from the producer’s viewpoint. Small versus large farms have different viewpoints regarding labour, the former rely on family labour whereas the latter use predominantly hired labour.

Managerial difficulty: requirements and restrictions that should be taken into account in plant cultivation in the sense of complexity and intelligence for effective production at the field level. This dimension is included in the social criteria as it is related to the knowledge basis and capacity building in the agricultural sector.

Weighting the criteria

There was evidence that various stakeholders would attach different importance or select dif-

ferent criteria altogether, farmers placing more weight on financial and economic objectives while scientists, policymakers and the public emphasize social and environmental priorities. This is why we firstly distinguished the two divergent viewpoints then to use a hierarchical structure of criteria to facilitate arbitrary weighting (Cinelli *et al.*, 2021). Firstly we assigned the three pillars of sustainability in the higher level. In the lower level of hierarchy socio-economic pillar consists in job creation and managerial difficulty, for the financial pillar yield risk related to food security issues whereas gross profit denotes the value added. Finally for the environmental pillar weights can be assigned to four subcriteria, namely Soil Organic Carbon, microbial diversity, risk of disease, NPK nutrients in soils. Importance is assigned by the decision makers, policy makers tend to allocate higher preference to social and environmental dimensions whereas farmers and businesses assign weights to the financial/economic efficiency secondly to the environment and the society at large.

For the farmers, farm sustainability at the short and medium term is of paramount importance at the same time one observes them taking into account longer term consequences related to the environmental impacts. This is in line with classic economic thought along with the search for compromise among apparently incompatible objectives as James (2006) points out. “Adam Smith certainly promoted profit-seeking, private property, and free market exchange consistent with the strict economic perspective. However, his writings are also consistent with many aspects of sustainable agriculture. For example, Smith argued that people ought to exercise restraint in their pursuit of self-interest, and he believed in balancing economic with environmental and social considerations” (James, 2006). In order to evaluate the alternatives we selected arbitrarily weights to the criteria to represent policy makers and farmers profiles, as it is further explained in the next section

Defining the alternatives

Conventional cereal cultivation, although supplemented by negative externalities, is characterized by high yields and economic performance.

From the environmental perspective, conventional cultivation causes soil depletion, groundwater pollution, and atmospheric contamination, and also requires extensive use of agrochemicals (Bux *et al.*, 2022). Thus, several alternative cultivation practices are selected to study their efficacy in the frame of sustainable agriculture. Their basic features are presented below.

Scenario 1. Conventional durum wheat cultivation (fertilized with inorganic fertilizers)

Activities for growing conventional durum wheat include preparatory tillage and sowing, fertilization, herbiciding or phytosanitary treatment, and harvesting. Emerged weeds are controlled by hand. Material flow analysis adds data regarding seeds, fertilizers, diesel, urea, and electricity. (Source pilot farm). Fertilization is carried out with 70 kg ha⁻¹ of N in ammonium nitrate form, applied during coverage (growth stages 25-29, Zadoks *et al.*, 1974).

Scenario 2. Durum wheat cultivation without inorganic fertilization

In this Scenario, all activities of Scenario 1 are performed, except the application of inorganic fertilizer.

Scenario 3. Durum wheat cultivation with the application of bio-based products (AMF inocula)

In this Scenario, inoculum based on AMF is used as bio-stimulants during the sowing. The inoculum is generally provided as a powder. It can be mixed with different substrates, including soil. The used AMF inoculum was the commercial product “INOQ ADVANTAGE” (INOQ GmbH, Germany) which includes *Rhizoglossus irregulare*, *Funneliformis mosseae* and *Funneliformis geosporum*. All other activities as in Scenario 2 are performed and no inorganic fertilizer is applied.

Scenario 4. Durum wheat cultivation in intercropping with lentil

An intercropping treatment with lentil (Eston cultivar) is performed. Integrating grain legumes into cereal-based cropping systems can promote crop diversification and improve factors such as farm nitrogen self-sufficiency. Though a minor grain legume, lentil provides nutritional benefits

Table 2 - Cost distribution by cropping activity for different alternatives.

<i>Activities</i>	<i>Scenario 1</i>	<i>Scenario 2</i>	<i>Scenario 3</i>	<i>Scenario 4</i>	<i>Scenario 5</i>	<i>Scenario 6</i>	<i>units</i>
Preparatory tillage & sowing	250	250	250	300	300	300	euro/ha
Fertilization	150	0	130	130	130	130	
Phyto protection	80	80	80	80	80	80	
Tillage – herbiciding	90	90	90	90	90	90	
Inoculation AMF			60	0	60	80	
Irrigation rainfed	0	0	0	0	0	0	
Harvesting	100	100	100	100	100	100	
<i>variable costs</i>	<i>670</i>	<i>520</i>	<i>710</i>	<i>700</i>	<i>760</i>	<i>780</i>	
<i>expected yield</i>	<i>2.27</i>	<i>1.41</i>	<i>1.86</i>	<i>1.82</i>	<i>1.84</i>	<i>2.36</i>	t/ha
<i>price</i>	<i>380</i>	<i>380</i>	<i>380</i>	<i>380</i>	<i>380</i>	<i>380</i>	euro/t
<i>inflow</i>	<i>862.6</i>	<i>535.8</i>	<i>706.8</i>	<i>691.6</i>	<i>699.2</i>	<i>896.8</i>	euro/ha
<i>gross margin</i>	<i>192.6</i>	<i>15.8</i>	<i>-3.2</i>	<i>-8.4</i>	<i>-60.8</i>	<i>116.8</i>	euro/ha

and is now used in cereal-legume intercropping systems in Mediterranean areas. (Tosti *et al.*, 2023). In Scenario 4, all other activities as in Scenario 2 are performed and no inorganic fertilizer is applied.

Scenario 5. Durum wheat cultivation in intercropping with lentils and the application of bio-based products (AMF inocula) on durum wheat genotypes

In this Scenario, AMF inoculum is applied on rows sowed exclusively with durum wheat. All other activities as in Scenario 2 are performed and no inorganic fertilizer is applied.

Scenario 6. Durum wheat cultivation in intercropping with lentils and the application of bio-based products (AMF inocula) on wheat genotypes and lentils

In this scenario, AMF inoculum is applied to all rows of durum wheat and lentil. As in Scenario 2, all other activities are performed, and no inorganic fertilizer is used.

Evaluating the alternatives

Performance vectors for three criteria (labour effort, gross margin, and yield variability) were

provided by the researchers having implemented the pilot cultivations based on evidence collected from the experimental fields. Detailed costs by activity were elaborated to estimate gross profit and labour input (Table 2).

Cross-section estimates from different plots across the pilot's harvest were used to approximate the variance of yields and then calculate the yield variability. We observe that conventional cultivation requires the highest labour effort and results in significant gross profit. Scenario 6 offers the second-best gross profit and also the least yield variability (Table 3). However as explained in the Case study material section since we have agronomic data from two seasons of S1-S5, but only from one season of S6 (Zampieri *et al.*, 2025) we will not include this latter in the alternative cultivations set and subsequent analysis.

Other socio-economic criteria performance of alternatives is rather based on subjective perceptions of farmers; environmental impacts are often measurable in the long term only. In such cases, expert knowledge can be mobilized involving scientists and/or practitioners during workshops to explicit qualitative judgments on

Table 3 - Alternative cultivation configurations.

<i>Scen id</i>	<i>Durum wheat cultivation alternatives</i>	<i>Labour h/ha/year</i>	<i>Gross profit euro/ha</i>	<i>Yield variability stdev/mean</i>
Sc1	Conventional durum wheat cultivation (fertilized with inorganic fertilizers)	16	192.6	15.0%
Sc2	Durum wheat cultivation without inorganic fertilization	12	15.8	27.0%
Sc3	Durum wheat cultivation with the application of bio-based products (AMF inocula)	13.33	-3.2	17.7%
Sc4	Durum wheat cultivation in intercropping with lentil	12	-8.4	11.0%
Sc5	Durum wheat cultivation in intercropping with lentils and the application of bio-based products (AMF inocula) on durum wheat genotypes	13.33	-60.8	11.4%
Sc6	Durum wheat cultivation in intercropping with lentil and the application of bio-based products (AMF inocula) on wheat and lentil	13.33	116.8	6.4%

alternatives under examination. Pairwise comparison of farmers' and/or experts' judgments can transform preference relationships to quantified performance. This is expressed in percentage priorities by means of the AHP algorithm as in Senapati and Das (2024) who quantified agricultural conditioning factors performance in terms of land suitability. Percentage priorities are then inserted to the multicriteria performance (pay-off) matrices along with tangible indicators to implement MCDA algorithms. In such cases the presence of numerous participants is suggested in order to collect different judgments, then such information has to be aggregated using group decision algorithms.

2.4. Methodology for group decision-making using AHP

As multiple stakeholders are involved in various stages of the decision-making, preference surveys often strive to reveal the perceptions of respondents with homogenous and heterogeneous characteristics (values, level of expertise, interests, social status, etc.) and to reflect them into a consensus ranking of acting alternatives, meant to represent a collective preference, according to specific decision criteria. This is how the concept of multi-criteria group deci-

sion-making (GDM) problems is generated, with its great challenge being to make as many DMs as possible to be as satisfied as possible with the final decision result. MCDA provides a variety of methods that address this challenge, even in the most complex situations in terms of opinions' plurality or consensus scarcity. However, the efficiency of those methods is often relative as it strongly depends on how well-adjusted their framework is to the special attributes of each specific problem; namely the number, location, and education of DMs, the degree of consensus and interaction among them, the availability of information, the relative importance of DMs' opinions, the number of alternatives allowed in the final ranking, the time and technology available to reach a conclusion, the negotiation opportunities, etc.

The AHP is one of the most popular MCDA methodologies (Bernasconi *et al.*, 2014). It is recognized for its simplicity and efficiency in weighing attributes and relating criteria and alternatives according to a hierarchical structure. It allows for subjective ranking of alternatives through pairwise comparison matrices: $n \times n$ matrix of values that represents the relative importance of each criterion or alternative to another. These values are usually assigned by the

DM, based on the relative importance of the parameters on a scale from 1 (equal) to 9 (very strong). The weights of the criteria or priorities of alternatives can be computed using the eigenvector computation. The numerical values assigned to the alternatives called 'priorities' are measured in percentage and represent the subjective evaluations made by DMs through pairwise comparisons considering the relative importance of criteria. The consistency of the pairwise comparisons is evaluated using the Consistency Ratio (CR). When CR is less than 0.10, class weights would be considered acceptable. If not, the relevant weights are reevaluated to prevent discrepancies.

AHP-related aggregation techniques in GDM

When many DMs are involved in a decision problem, AHP utilizes several techniques to aggregate their individual opinions and synthesize a group ranking of alternatives, as we will see in detail below.

I) The concepts of Aggregating Individual Judgments (AIJ) and Aggregating Individual Priorities (AIP)

AHP can be used in GDM by aggregating individual judgments or priorities. There are two basic ways to aggregate individual opinions into a group opinion, depending on whether the group wants to act together as a unit (e.g., a group of department heads meeting to set corporate policy) or as separate individuals (e.g., politicians) (Forman & Peniwati, 1998). Several researchers find agreement in applying the AIJ method in case a group is homogenous, while the AIP method is recommended when the group is heterogeneous. Srdjevic (2007), who goes through a GDM process by utilizing a group of experts, split into interest subgroups, having certain decisions made in the decision subgroups, and with the final decision made by the whole group of experts concerning the preferences of the subgroups, claims that AIJ is possible to apply only at the subgroup level. Among different subgroups, AIJ is not applicable since the information on individual judgments is generally not available or meaningful. At this level, only AIP is possible.

II) The Arithmetic Mean Method (AMM) and the Geometric Mean Method (GMM) in AHP

In the existing literature, two popular methods employed for the aggregation of individual judgments or priorities in AIJ and AIP respectively are the Arithmetic Mean Method (AMM) and the Geometric Mean Method (GMM). When calculating the geometric mean of the judgments (AIJ) or either the arithmetic or geometric mean of priorities (AIP) we often assume that the individuals are of equal importance. On the other hand, according to Forman & Peniwati (1998), and Bernasconi *et al.* (2014), when group members are not equally important, we may calculate the Weighted Geometric Mean (WGM) of the judgments (AIJ).

According to Forman & Peniwati (1998) in the case of AIJ where the group behaves as an individual DM, aggregation concerns judgments, not priorities thus the previous individual judgments concerning the relative importance of the criteria become irrelevant. Also, each individual may not even make judgments for every cluster of the hierarchy. Thus, they claim that the Pareto principle concerning priorities is inapplicable in the context of AIJ. Furthermore, when it comes to AIJ, it has been demonstrated that: WGMM is the only method that preserves the reciprocally symmetric structure of the judgment matrices and satisfies the Pareto Principle over judgments and the homogeneity condition, while the AMM does not (Aczél & Saaty, 1983; Forman & Peniwati, 1998; as cited in Bernasconi *et al.*, 2014). For the case of AIP, where one is concerned about each individual's resulting alternative priorities, Forman & Peniwati (1998) also prove that both the geometric and the arithmetic mean can be used for the aggregation of each individual's resulting priorities as neither of them violates the Pareto principle.

In conclusion, Forman & Peniwati (1998), claim that the GMM must be used in AIJ, while in AIP both AMM and GMM are meaningful. The latter is also supported by Srdjevic (2007). Furthermore, Aczel & Saaty (1983) proved that the only aggregation procedure that satisfies separability, unanimity, homogeneity, and the reciprocal property is GMM (or WGMM if the individuals are not equally important). In addition, if the indi-

viduals are experts, they may not wish to combine their judgments but only their final hierarchy outcome (Saaty & Vargas, 2013). In that case, again, they suggest that one should take the GM of the final individual priorities or WGM if the individuals have different priorities of importance.

Also, according to the bibliography, when trying to choose between GMM and AMM, one should consider that measurements in AHP do not occur on an interval but on a ratio scale. According to Bernasconi *et al.* (2014) and Forman & Peniwati (1998), AMM is typically preferable when measurements are on an interval scale. In the context of the ratio scale, Escobar & Moreno-Jiménez (2007) claim that the GMM is more suitable for aggregation since it directly satisfies homogeneity.

III) Understanding the Consistency of Aggregated Comparison Matrices

Duke & Aull-Hyde (2002) applied AHP, using survey respondents who were assumed to act as “one individual” towards the determination of a single policy. They used GMM to aggregate the individual comparison matrices and define the collective preferences. At the end of the process, they discovered that although all aggregated comparison matrices displayed acceptable levels of consistency, the majority of the individual comparison matrices did not. Based on that it is proved (Aull-Hyde *et al.*, 2006) that if AIJ is combined with WGMM, given a sufficiently large group size depending on the matrices’ dimensions, the aggregated comparison matrices can display acceptable levels of consistency, although the majority of the individual comparison matrices may not be of acceptable consistency.

3. Implementation results

3.1. Criteria performance calculation using AHP

Evaluation of the environmental criteria performance is based on evidence provided by the Metaponto pilot fields in Basilicata however measurements of relevant indicators should extend in time beyond the project horizon to provide precise values. Qualitative performance that was elicited from scientists involved on an

ordinal scale using the following Likert scale: --, -, 0, +, ++, resulted in ex aequo for the great majority of alternatives thus rendering the ranking among them impossible. Thus, we exploited expert knowledge by applying pairwise comparisons based on the AHP method 1-9 scale making it possible for the performances to be transformed into percentage priorities. The highest a percentage was the most preferable the option concerning the specific criterion. Thus, not only distinct ranking positions of alternatives were created but numerical values were also provided to populate the payoff matrix. This reasoning was applied to assign cardinal performance in land suitability subclasses. For instance, the ‘soil texture’ subclass, was distinguished into 5 qualitative categories (loamy, sandy-loamy, sandy clay, clay, and gravelly) ranked from the best to worst based on common scientific knowledge. The pairwise comparison of these categories concerning soil suitability for agriculture resulted in cardinal performance measures of 54%, 21%, 12%, 7%, and 5% respectively (Senapati & Das, 2024).

Regarding the environmental criteria, we asked the 3 agronomists involved in the pilot fields and with no conflicting attitude to apply AHP pairwise comparisons among the 6 alternatives, based on their knowledge, regarding each one of the 4 environmental criteria. The pairwise preference values were on the 1 to 9 scale suggested by Saaty. The priorities that resulted from this process were calculated along with the consistency index which was less than 0.10 based on individual responses. Subsequently, based on literature findings and since the 3 agronomists formed a consensus group, we aggregated their individual judgments for each one of the 4 criteria through GMM. E.g., in Table 4, we can see the aggregated pairwise comparison matrix that leads to the final weights of the 6 scenarios regarding NPK.

Similarly, we calculated the aggregated scenario weights regarding the other 3 environmental criteria. All those weights were injected into the performance table as percentages to substitute the missing performance values of the 4 environmental criteria (Table 5).

Regarding managerial difficulty, we asked 10

Table 4 - The aggregated pairwise comparison matrix and the elicited weights for the NPK criterion.

<i>AIJ</i>	<i>Sc1</i>	<i>Sc2</i>	<i>Sc3</i>	<i>Sc4</i>	<i>Sc5</i>	<i>weights</i>	<i>products</i>	<i>ratios</i>
<i>Sc1</i>	1	7.319	6	4.309	3.302	43.08%	2.848	6.611
<i>Sc2</i>	0.137	1	0.437	0.158	0.144	3.99%	0.197	4.938
<i>Sc3</i>	0.167	2.289	1	0.188	0.151	6.57%	0.306	4.663
<i>Sc4</i>	0.232	6.316	5.313	1	0.5	19.90%	1.032	5.188
<i>Sc5</i>	0.303	6.952	6.604	2	1	26.46%	1.504	5.685
							<i>CI</i>	0.088
							<i>CR=CI/RI</i>	0.084

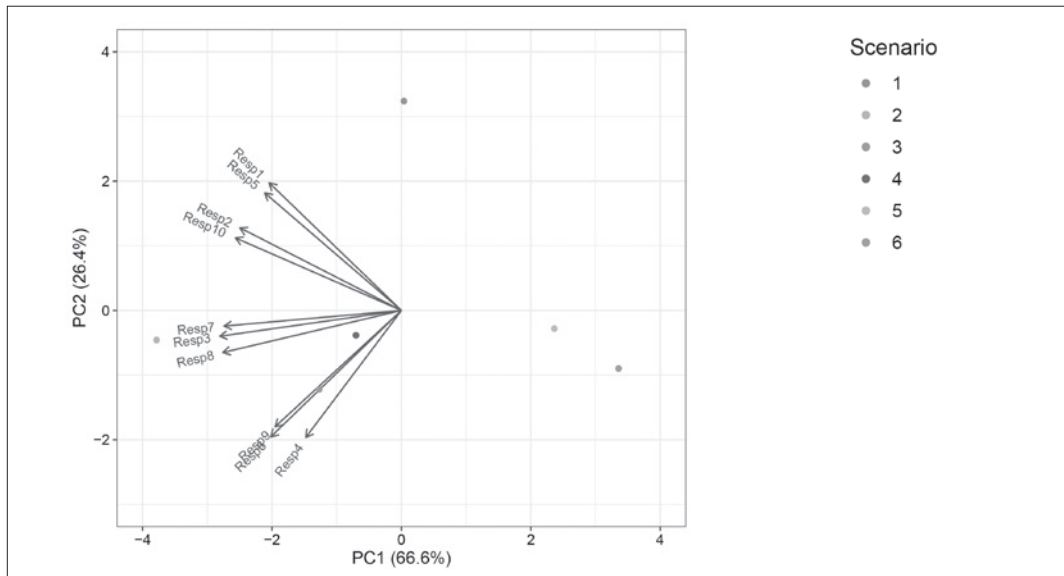
persons, agronomists, and practitioners, with experience in cereal cropping systems, to compare the alternative scenarios to conventional durum wheat after being informed in detail by the research team on the cultivation activity requirements of each one of them during a session of the workshop which took place in Basilicata in May 2024. The sample units were individual respondents participating in the workshop ($n = 10$ participants). Participants were selected to ensure (i) adequate knowledge and familiarity with durum wheat management at local scale (i.e. Basilicata context) as well as (ii) the ability to provide AHP pairwise judgements by covering complementary stakeholder categories, including research/technical advisory profiles, public administration and rural development, and farmers organisations. The panel comprised two Research Directors (ALSIA), one researcher from the Italian Centre for Agriculture and Environment Research (CREA), four additional ALSIA researchers, one representative of public administration and rural development (President of the local LAG START 2020 for rural development), and two representatives of farmers organizations. In the session, the participants revealed preference, comparing pairs of alternatives according to the AHP concept, as described above. Furthermore, this time we split the non-unanimous

group of 10 respondents into 4 subgroups each presumably demonstrating a unanimous attitude (respondents 1 & 5, respondents 2 & 10, respondents 3, 7 & 8, and respondents 4, 6 & 9), shown in Figure 2, by plugging the respondents' individual scenario rankings regarding this criterion into the Principal Component Analysis (PCA) method using online SRplot written in R and Python.

PCA is the general name for a technique that lies in the field of multivariate data analysis and transforms many (possibly) inter-correlated quantitative dependent variables into a smaller set of new uncorrelated, orthogonal variables called principal components (PC) (Abdi & Williams, 2010). Despite the dimensionality reduction, PCA assures an adequately good summary and variation of the data (patterns, trends, outliers, etc.). The 1st PC explains the largest percentage of this variation, the 2nd one explains the second largest percentage, and so on. The projections concerning the first two (or three) PCs can also be visualized.

To aggregate the individual judgments inside each consensus group, we used AIJ combined with GMM again but for the elicitation of the final scenario weights, as suggested in the literature review section, among the subgroups, we used AIP combined with GMM. An interesting finding, that is in agreement with the work of Aull-Hyde *et al.*

Figure 2 - PCA Biplot respondents' alliances.



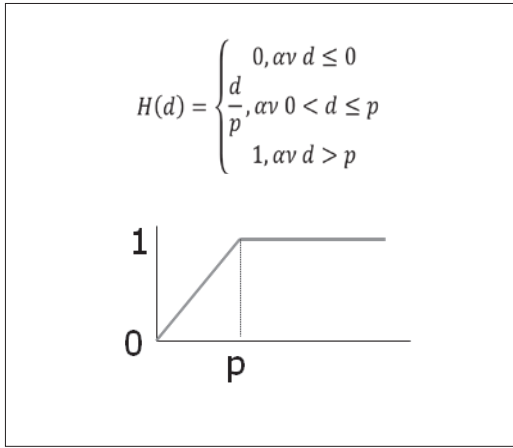
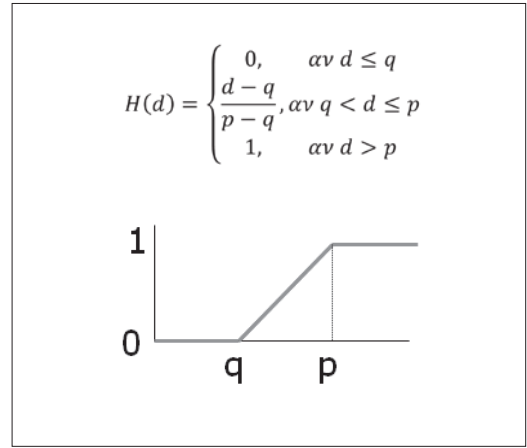
(2006), was that, although the overwhelming majority of the individual comparison matrices were not of acceptable consistency, all the aggregated comparison matrices of the subgroups displayed better, or even acceptable ($CR < 0,1$) levels of consistency (Saaty, 1977).

Finally, we normalized those weights and injected them too into the performance table, as

percentages, to substitute the missing performance values of the managerial difficulty criterion so that the complete evaluation matrix is ready, for the implementation of PROMETHEE (Table 5). Preference functions are selected for each criterion and shown in figures 3 and 4 along with formulae for calculation of the partial preference indices.

Table 5 - The final table that contains the performance values of all the scenarios on all the criteria.

Criteria	Labour (Hrs/ha)	Manag. Diff. (AHP)	Mon. Gr.Profit (Euros/ ha)	Yield risk stdev/ mean	NPK (AHP)	SOM (AHP)	Biodiversity (AHP)	Disease Risk (AHP)
Sc1	16	0.13	192.6	0.15	0.43	0.06	0.10	0.46
Sc2	12	0.48	15.8	0.27	0.04	0.06	0.04	0.19
Sc3	13.33	0.19	-3.2	0.18	0.07	0.18	0.28	0.20
Sc4	12	0.15	-8.4	0.11	0.20	0.34	0.12	0.06
Sc5	13.33	0.06	-60.8	0.11	0.26	0.36	0.45	0.09
direction	max	min	max	min	max	max	max	max
function	TYPE III - V shape	TYPE III - V shape	TYPE V - Linear	TYPE III - V shape	TYPE III - V shape	TYPE III - V shape	TYPE III - V shape	TYPE III - V shape
thresholds	$p=2.91$	$p=29\%$	$q=20$ $p=50$	$p=13.9\%$	$p=22\%$	$p=21\%$	$p=26\%$	$p=27\%$

Figure 3 - Preference function type III: Formula and graphical form ($p > 0, q = 0$).Figure 4 - Preference function type V: Formula and graphical form ($p, q > 0$).

Decision outcome from a public policy consultation process

Policy makers aspire to promote alternative practices improving socioeconomic and environmental conditions in agriculture. They prioritize job creation and maintenance, improvement of innovation and management capacities of farmers, food security, and environmental goals related to the soil fertility, climate change mitigation and resources efficient use. In the current decision process the criteria weights (Table 6) are arbitrarily set by the authors according to the aforementioned rationale.

In the case of cereals in Italy labour use gross margin and the environmental constraints are meant to maximization whereas yield variability and managerial difficulty should be minimized. Managerial difficulty score is based on pairwise

preference (higher priority denoting less difficulty) then the lower the priority value the higher the managerial difficulty of the alternative. From a public interest point of view capacity building of farmers is positively related to the effort they invest to learn and apply novel and environmental friendly techniques. Based on the above directions and weight values the PROMETHEE evaluation model resulted in the following outranking flows and subsequent ranking of alternatives are shown in Table 7.

We observe that Scenario 5 ranks first as with the exception of gross margin and risk of diseases it outperforms all other scenarios with conventional cultivation in the second position outranking the other alternative practices. The reason is the high performance of conventional cultivation

Table 6 - Preferences policy makers' viewpoint.

first level	socio-eco		financial		long_term_environmental			
weights	20%		20%		60%			
second level	Labour	managerial difficulty	gross margin	yield variability	nutrients	SOC	microbial diversity	diseases risk
weights	50%	50%	20%	80%	10%	30%	30%	30%
relative importance	10%	10%	4%	16%	6%	18%	18%	18%

Table 7 - Global preference values, outranking flows and ranking of alternatives (PROMETHEE I and II).

<i>Final</i>	<i>Sc1</i>	<i>Sc2</i>	<i>Sc3</i>	<i>Sc4</i>	<i>Sc5</i>	Φ^+	Φ	<i>P II rank</i>
<i>Sc1</i>		0.66	0.42	0.39	0.36	1.83	0.929	2
<i>Sc2</i>	0.00		0.00	0.10	0.11	0.21	-2.246	5
<i>Sc3</i>	0.23	0.53		0.25	0.11	1.12	-0.006	4
<i>Sc4</i>	0.24	0.54	0.26		0.04	1.08	0.026	3
<i>Sc5</i>	0.42	0.73	0.44	0.32		1.92	1.297	1
Φ^-	0.90	2.46	1.13	1.06	0.62			

Table 8 - Preference set from the farmer point of view.

sustainable_farming				econ_long_term_environmental			
Social Criteria		Economic Criteria		Environmental Criteria			
0.70				0.30			
Labour (Hrs/ha)	Manag. Diff. (AHP)	Mon. Gr.Profit (Euros/ha)	Yield Var. (stdev/mean yield)	NPK (AHP)	SOM (AHP)	Biodiversity (AHP)	Disease Risk (AHP)
0.20	0.25	0.30	0.25	0.25	0.25	0.25	0.25
14.0%	17.50%	21.0%	17.50%	7.50%	7.50%	7.50%	7.50%

in labour hours, yield variation and gross income generation at the first position among all. In our case for all weight sets it is desirable for policy makers that farmers switch to Scenario 5 (Durum wheat in intercropping with lentil and application of AMF inocula on durum wheat genotypes) instead of practicing the conventional way.

Decision making in farm business

Farmers decide the cropping plan after consideration of multiple often conflicting criteria after all aiming at attaining short-medium term sustainability of the farm. Thus not only the importance but also the direction of objectives may change comparing with policy makers' viewpoint, sometimes the objectives themselves too. In this exercise we keep the same criteria set, however we reconsider weights and also the opposite direction for criteria 1 and 2. In fact labour use and managerial difficulty the less the better whereas the weight allocated to environmental criteria is now minimal, if the farmers is concerned at all, in the sense of short to long term financial sustainability ratio of 4/1. The farmers'

opinions above are translated to the preferences shown in Table 8.

In Table 9, the PROMETHEE outcomes consist of positive, negative and net flows and ranking where conventional cultivation (with inorganic fertilizers) ranks first with the Scenario 4, namely 'Durum wheat cultivation in intercropping with lentil' to be selected very closely the second (Φ 0.4752 versus 0.381 respectively), followed by Scenario 3 (Durum wheat cultivation without inorganic fertilization). Then Scenario 2 Durum

Table 9 - PROMETHEE II complete ranks - farmer's point of view.

<i>Alternatives</i>	Φ^-	Φ^+	Φ	<i>PROMETHEE II rank</i>
Sc1	1.19	1.665	0.475	1
Sc2	1.50	1.260	-0.235	4
Sc3	1.14	0.928	-0.209	3
Sc4	0.82	1.199	0.381	2
Sc5	1.51	1.10	-0.413	5

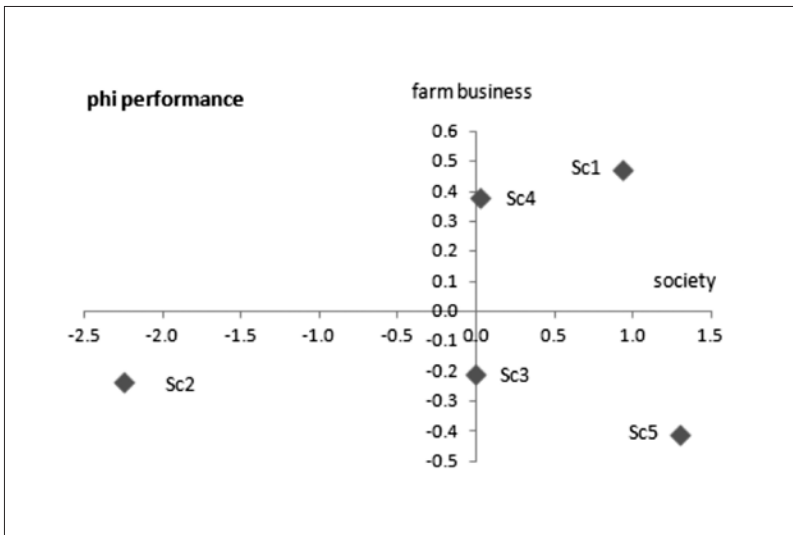


Figure 5 - Global performance for the societal viewpoint plotted against the farm business one.

wheat cultivation with the application of bio-based products (AMF inocula) comes next followed by Scenario 5 (Durum wheat cultivation in intercropping with lentils and the application of bio-based products (AMF inocula) on durum wheat genotypes) both with negative total flows. For strong preference to farm sustainability (from 80% or more for economic and social objectives) Scenario 4 outperforms conventional cultivation (Scenario 1) is explained by its higher performance in 3 out of 4 social and economic criteria (conventional cultivation largely outperforms regarding gross margin only).

In Figure 5 phi values for the societal and the business viewpoints are plotted on the horizontal and vertical axes respectively. The plot illustrates the different ranking positions with regard to the ideal point (upper right corner of the graph). Alternative Scenario 4, 1 and 5 are efficient whereas Scenario 3 and particularly Scenario 2 are dominated by the alternatives. Scenario 2 is penalized by high yield variability and poor environmental performance. Scenario 4 intercropping with lentil is suggested as the most satisfactory option for farmers practically in the same position with the conventional cultivation. This conforms with the estimation of Cimino *et al.* (2015) that for farms specialised in durum wheat, the green payments would cover the reduction of farm gross margin caused by the introduction of the new environmental obligations.

The intercropping with inocula application (Scenario 5) is the most environmentally friendly option at the expense of costs, labour input and significant managerial difficulty, so the question is how to make interesting for the farmers so that in their own evaluation it ranks on the top. This can be done through agricultural extension knowledge diffusion of the benefits and education for correct application of the method in conjunction to substantial financial support for sufficient time so that this practice to become familiar and profitable alike the conventional one.

4. Conclusions

In presence of environmental and scarcity problems in agriculture, research funding is largely oriented to devise alternative ways of conduct in the case of staple crops so that to mitigate adverse impacts of conventional practices in the farm towards a resilient and sustainable future. Presumably alternative practices suggested by the research community in agronomy and related sciences result in environmental friendly solutions. Nevertheless this should not be taken for granted but proven under scientific inquiry. Moreover for the benign scientific results to be adopted by practitioners, stakeholders' preferences need to be taken into account. It is important then to comprehensively evaluate the outcome of research to check whether it contributes

to better overall situation and explore the conditions of adoption by the farmers. For this purpose a two step approach can be implemented as the case of durum wheat in Italy has shown. Firstly to evaluate alternatives taking into account public welfare decision criteria then to see whether the optimal ranking from the public viewpoint is in line with the ranking outcome of the decision process simulating farm viewpoint.

Under the policy-maker perspective leading option is Scenario 5: Durum wheat–lentil intercropping with AMF inoculation is characterized by high soil organic matter, improved biodiversity indicators, reduced chemical inputs, lower gross margin and higher labour requirement. Under the farmer perspective Scenario 1 that is conventional cultivation that is the most profitable and sufficiently familiar to farmers with regular managerial difficulties as well as Scenario 4: Durum wheat–lentil intercropping (without AMF) that achieves good economic performance, lower yield variability, moderate labour requirements, and environmental improvement without severe profit penalty are the leading ones. For Italian farmers, the intercropping scenario (Scenario 4) represents a realistic transition pathway, offering improved income stability and reduced input dependency while maintaining economic viability. For more sustainability-oriented producers, the AMF-enhanced system (Sc5) may become attractive if supported by targeted policy incentives.

At the sectoral level, support for wider adoption of intercropping systems could be justified by positive externalities as they contribute to improved soil carbon sequestration, reduced nitrogen losses, and enhanced biodiversity, supporting national climate and environmental targets. Unlike traditional evaluation methods such as cost-benefit analysis, that require to quantify in monetary values of observed impacts of all kinds, our approach can capture trade-offs among profitability, risk, soil health and labour requirements thereby providing a comprehensive basis for sustainability oriented decision-making. Aggregation methods as the weighted sum method are often applied in decision making by non-specialists. From the farmer viewpoint the weighted sum method implemented in our problem ranks better Scenario 4 than conventional cultivation

(Scenario 1) due to its higher performance in 3 out of 4 social and economic criteria thus compensating for the large difference in gross margin. The PROMETHEE model's non compensatory reasoning takes into consideration the high importance of gross margin largely outperforming all alternative cultivation schemes, and ranks conventional scenario well aligned to the actual farmer behavior (Rozakis, 2011).

Beyond AHP and PROMETHEE, alternative MCDA methods such as ELECTRE (ELimination Et *Choix* Traduisant la REalité), TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), VIKOR (Compromise solution method) have been applied to rank cropping system alternatives. Arondel & Girardin (2000) used ELECTRE outranking logic to classify and rank cropping systems based on environmental impacts (particularly nitrate leaching). Based on the references of the seminal paper Opricovic & Tzeng (2004) both VIKOR and TOPSIS have been largely used in irrigation management evaluation, sustainable land-use planning, crop selection under competing stakeholder interests aiming at identifying a compromise solution. Similar trade-offs between environmental performance and farm profitability have been identified using alternative MCDA approaches such as ELECTRE and VIKOR. This demonstrates that our findings are robust across methodological families, the sustainability gap is structural, not methodological. Overall PROMETHEE is transparent, it handles mixed criteria types, it is well-suited for stakeholder weight comparison, it avoids strict compensatory assumptions, and produces interpretable ϕ -values.

Our study produces two distinct rankings namely policy-maker viewpoint: Scenario 5 (intercropping + AMF on wheat) ranked 1st and Farmer viewpoint: conventional Scenario 1 ranked 1st; Scenario 4 (intercropping with lentil) very close 2nd. Many studies perform sensitivity analysis and compare weight sets, but relatively few explicitly perform dual-Ranking Comparison (Policy vs Farmer) plotting Socially optimal against Privately ϕ -values (Figure 5). This dual ranking is a central contribution of our work. Our results that Scenario 5 dominates when environmental weights dominate

(policy-maker case). This is consistent with the literature showing that ecological innovations often outperform conventional systems under sustainability-oriented weighting schemes. As a matter of fact, environmentally advanced systems rank higher under public-interest weighting (Król *et al.*, 2018; Cano *et al.*, 2023; Abdallah *et al.*, 2018). Systems with reduced chemical inputs, higher biodiversity, improved soil parameters ranked higher when environmental weights were increased. On the other hand conventional systems perform strongly under profitability-focused weighting (Abdallah *et al.*, 2018; Nigussie *et al.*, 2018) often ranked high (or first) when gross margin weight was dominant, yield stability was highly valued, environmental criteria were weakly weighted. Our farmer-viewpoint ranking mirrors the literature: conventional systems remain highly competitive when financial viability dominates the objective function. Intercropping as a compromise solution is a particularly interesting difference suggesting that legume intercropping improves yield stability (low SD) keeping labour demand remains moderate, at the same time environmental benefits are achieved without excessive cost. This is consistent with agronomic findings as in Tosti *et al.* (2023), however the MCDA integration quantifies its systemic sustainability advantage.

The patterns emerging from our PROMETHEE-based ranking are consistent with broader evidence from Mediterranean cereal systems. In a recent socio-ecological systems (SES) assessment of Tunisian cereal production, Khamassi *et al.* (2026) highlight structural tensions between environmental sustainability, economic viability, and institutional constraints. Although their methodological approach differs from our multi-criteria outranking framework, their conclusions parallel our findings in several key respects. First, both studies identify a divergence between environmentally superior systems and those that are privately optimal for farmers. In our case, Scenario 5 (intercropping + AMF) achieves the highest ranking under policy-oriented weighting due to its environmental performance, yet it performs poorly under farmer-oriented weighting because of weak gross margins. Similarly, Khamassi *et al.* document that environmentally

improved cereal systems often face economic and structural barriers that limit farmer adoption, particularly in contexts characterized by market volatility and input dependence. Second, both analyses emphasize that sustainability gaps are not merely technical but institutional. Our dual-ranking framework explicitly quantifies the gap between socially optimal and privately optimal systems, while Khamassi *et al.* conceptualize this gap within a broader SES framework, linking it to governance structures, value chains, and policy support mechanisms. Taken together, the two studies reinforce the argument that agro-ecological transitions in Mediterranean cereal systems require coordinated policy instruments to realign private incentives with public sustainability objectives.

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Weight-loss drugs as disruptive force in the Mediterranean diet tradition: Economic and behavioral implications

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Abstract

The Mediterranean diet is commonly framed as a healthy eating pattern, yet it also constitutes a complex food system shaped by local agriculture, biodiversity, short supply chains, and deeply rooted social and cultural practices. Embedded in territorial knowledge and collective food traditions, it links consumption, production, and environmental sustainability across the Mediterranean region. Concurrently, the global surge in obesity and metabolic disorders has accelerated the adoption of pharmaceutical interventions, particularly glucagon-like peptide-1 (GLP-1) receptor agonists. These drugs, increasingly used for weight loss, modify food demand primarily through physiological appetite suppression rather than structural changes in diets or food environments. This paper examines how the rapid diffusion of GLP-1 therapies is reshaping food systems by altering consumption patterns, agri-food markets, agricultural production incentives, and cultural food practices. While recognizing their potential public-health benefits, the analysis highlights risks of decoupling nutrition from food systems, with implications for sustainability, rural livelihoods, and food heritage. The paper argues for an integrated food-systems perspective that situates pharmaceutical innovation within broader strategies for sustainable, culturally grounded, and resilient diets.

Keywords: Mediterranean Diet, Eating behavior, Agrifood supply chain, Sustainable diet.

1. Introduction

The Mediterranean diet has long been recognized not merely as a healthy eating pattern, but as a complex cultural, social, economic, and agricultural system deeply embedded in the Mediterranean basin. Rooted in shared meals, local food production, biodiversity, and intergenerational knowledge, it represents a holistic relationship between food, territory, and social cohesion.

At the same time, the global escalation of obesity and metabolic disorders has accelerated the

adoption of pharmaceutical responses, particularly GLP-1 receptor agonist weight-loss drugs. Originally developed for diabetes treatment, these medications are now widely used to manage obesity, profoundly altering eating behaviors through physiological appetite suppression rather than long-term dietary change.

This paper examines how the rapid diffusion of GLP-1 drugs is reshaping food consumption patterns, agricultural systems, cultural food practices, and geopolitical dynamics. It argues that while these therapies offer significant public-health benefits, they also challenge the

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foundations of the Mediterranean diet as a living system, raising critical questions about how medical innovation can be reconciled with cultural heritage, social cohesion, and sustainable food systems.

The paper makes three main analytical contributions. First, it frames the diffusion of GLP-1 drugs as a systemic shock to food systems rather than merely a clinical innovation. Second, it conceptualizes the Mediterranean diet as a policy-relevant socio-economic and agri-food system, extending beyond its nutritional dimension. Third, it integrates insights from health economics, food consumption behavior, and agri-food governance to assess the medium- and long-term implications of pharmaceutical-driven dietary change for sustainability and rural development.

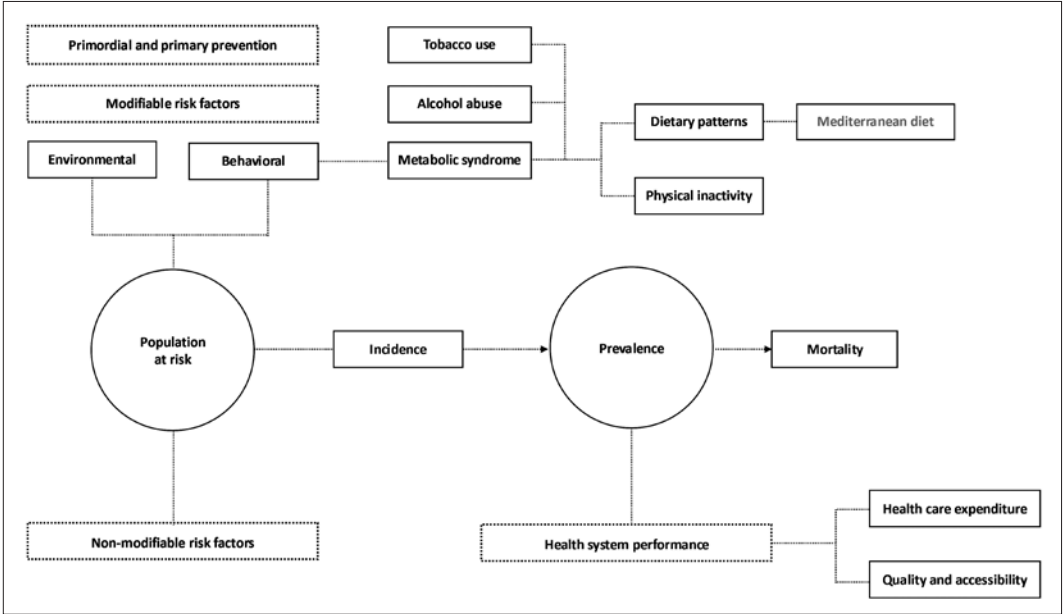
2. The Mediterranean diet: a complex cultural, social, economic, and agricultural system

For generations, the Mediterranean diet has represented far more than a healthy eating pattern. It constitutes a complex cultural, social,

economic, and agricultural system deeply embedded in the traditions of Southern Europe and the wider Mediterranean basin (FAO, 2010; HLPE, 2017). Characterized by a high consumption of fresh vegetables, fruits, legumes, whole grains, olive oil, fish, and moderate wine intake, this dietary model reflects an intimate relationship between food, territory, seasonal cycles, and local biodiversity (Willett *et al.*, 1995). It is the result of centuries of accumulated knowledge shaped by local ecosystems and sustained through collective practices of production, preparation, and consumption.

From a nutritional perspective, the Mediterranean diet is one of the most extensively studied dietary patterns worldwide. A substantial body of scientific evidence has consistently associated adherence to this diet with reduced risks of cardiovascular disease, type 2 diabetes, obesity, metabolic syndrome, and certain cancers, as well as with increased life expectancy and improved overall quality of life (Trichopoulou *et al.*, 2003; Sofi *et al.*, 2008; WHO, 2019). These benefits derive not only from the diet’s nutritional composition, but also from its emphasis on moderation, balance,

Figure 1 - Mediterranean-style diet and prevention of mortality from major non-communicable diseases.



Source: Reproduced from Ferretti, Capone, and Malorgio (2025).

and long-term dietary habits rather than short-term consumption patterns.

Recent macroeconomic research further underscores the protective role of the Mediterranean-style diet at the population level. An ecological analysis of 178 countries showed that stronger adherence to a Mediterranean-style dietary pattern is significantly associated with lower prevalence of metabolic syndrome, a central cluster of risk factors for major non-communicable diseases (NCDs), even after controlling for health system performance and implementation of WHO-recommended NCD prevention strategies. The study also highlighted a global drift away from traditional Mediterranean diets toward Westernized food patterns, underlining the urgent need to promote Mediterranean diet adherence as a public health priority (Ferretti, Capone & Malorgio, 2025).

In addition, socioeconomic determinants play a key role in shaping how individuals and populations adhere to Mediterranean diet principles. A national survey in Tunisia found wide variation in diet adherence across different socioeconomic groups: while a majority showed moderate adherence, only a small portion achieved high adherence. Higher adherence was positively associated with regular consumption of core Mediterranean foods such as olive oil, fruits, legumes, and fish, and negatively associated with low income or lower socioeconomic status. The results also revealed geographical differences within the country, with certain regions exhibiting better adherence patterns than others. These findings highlight the influence of income, professional status, and regional disparities on diet quality, and the need for targeted strategies to promote healthier eating habits and raise awareness of Mediterranean diet benefits (Gharbi et al., 2025).

Meals are traditionally shared, reinforcing family ties, community cohesion, and the intergenerational transmission of cultural knowledge (UNESCO, 2010). Food preparation and consumption function as social acts that promote dialogue, solidarity, and mutual care, thereby strengthening social capital and a shared sense of identity and belonging. In this

context, eating is not an individual or purely functional act, but a collective practice that contributes directly to social well-being and cultural continuity (FAO, 2018).

Central to the Mediterranean diet is its agricultural and production base, which plays a crucial role in the economic sustainability and social stability of Mediterranean regions. Agriculture, particularly small-scale and family farming, has historically been a cornerstone of local livelihoods. These production systems support rural economies, contribute to fairer remuneration when value chains remain locally anchored, and enhance food sovereignty. Moreover, Mediterranean agriculture acts as a stabilizing force in regions often exposed to environmental stress, market volatility, and geopolitical pressures (HLPE, 2017). By maintaining rural populations, preserving traditional knowledge, and promoting sustainable land-use practices, it helps counter rural depopulation and reduce socio-economic inequalities.

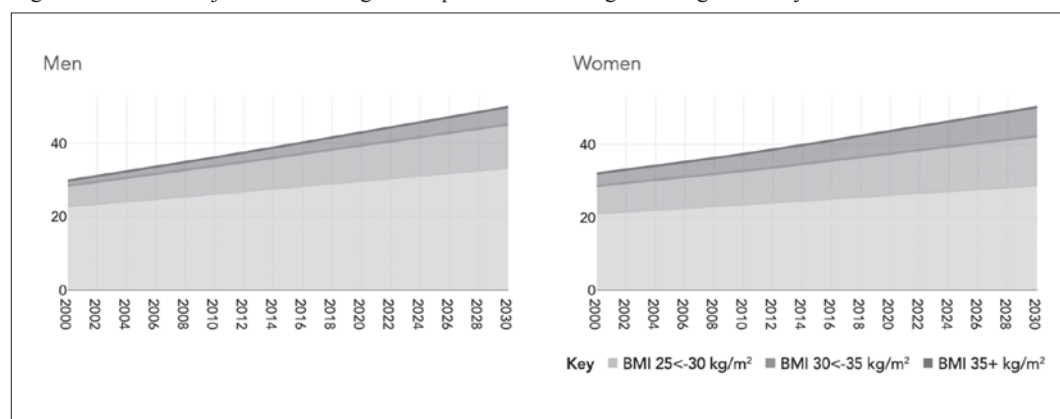
The Mediterranean diet represents a virtuous link between sustainable food systems, economic viability, environmental stewardship, and long-term social stability. Recognizing its multidimensional value (nutritional, cultural, social, and economic), UNESCO inscribed the Mediterranean diet on the Representative List of the Intangible Cultural Heritage of Humanity, acknowledging it as a living heritage that contributes not only to physical health, but also to sustainable development, social cohesion, and resilience in Mediterranean societies (UNESCO, 2010; UNESCO, 2013).

But today, at the height of its global recognition, the Mediterranean diet faces unprecedented pressure from a different kind of intervention: pharmaceutical weight-loss drugs that are rapidly reshaping how millions of people around the world relate to food, consumption, and health management.

3. GLP-1 drugs: a changing in eating behavior

Obesity is no longer merely a personal health issue. It has become a global epidemic with profound medical, economic, and social consequences. According to the World Health Or-

Figures 2 and 3 - Projected rise in high BMI prevalence among adults aged 20+ by 2030.



Source: Reproduced from NCD-RisC (2024) and World Obesity Federation projections.

ganization (WHO), the number of obese adults worldwide is projected to more than double, rising from 524 million in 2010 to 1.13 billion by 2030 (WHO, 2019; Lancet Commission, 2023). This sharp increase is placing unprecedented pressure on healthcare systems, two-thirds of which lack adequate policies to tackle obesity, and only 7% are fully equipped to manage it effectively. Overweight and obesity contribute to approximately 1.6 million premature deaths annually, primarily from non-communicable diseases such as diabetes, cancer, cardiovascular disease, and stroke, a toll that exceeds fatalities caused by

road traffic accidents. Amid this public health crisis, weight-loss drugs have emerged as a highly appealing solution. They promise rapid results, often within weeks, attracting individuals who seek to reduce body weight without committing to long-term dietary or lifestyle changes and transforming their habits in a short period of time.

The emerging class of GLP-1 receptor agonists, drugs originally developed to treat type 2 diabetes, is now widely used for weight loss. Ozempic, Wegovy, Mounjaro and more recently Zepbound have become mainstream. Their rising adoption is not just a medical trend; it

Table 1 - Global trends and projections of high BMI among adults aged 20+, by sex (2010, 2015, 2030).

Men	BMI 25-<30 kg/m ²		BMI 30-<35 kg/m ²		BMI 35+ kg/m ²		All high BMI	
2010	570m	26%	164m	7%	51m	2%	786m	36%
2015	665m	28%	203m	8%	69m	3%	936m	39%
2030	966m	33%	346m	12%	141m	5%	1,453m	50%

Women	BMI 25-<30 kg/m ²		BMI 30-<35 kg/m ²		BMI 35+ kg/m ²		All high BMI	
2010	518m	23%	203m	9%	106m	5%	826m	37%
2015	592m	24%	244m	10%	133m	5%	968m	40%
2030	834m	28%	299m	14%	244m	8%	1,477m	50%

Source: Reproduced from NCD-RisC (2024), UN population estimates (2024), and World Obesity Federation projections.

is a societal phenomenon (FDA, 2023-2024). According to growing estimates, millions of adults are now using these medications, and usage continues to climb year after year. In the United States, for example, the usage has more than doubled, with an estimated 12.4% of adults having taken a GLP-1 drug, a dramatic cultural shift that is already influencing food purchasing behavior, grocery consumption, dining patterns, and even broader lifestyle choices (*Washington Post*, 2025).

What makes this development particularly consequential is how weight-loss drugs affect not only individual bodies but entire food systems, economic sectors, and cultural traditions. As appetite wanes and calorie intake decreases, the Mediterranean way of eating, which thrives on shared meals, sensory appreciation, and cultural identity, is challenged by a new paradigm that treats food increasingly as fuel rather than an experience. But how this pharmaceutical revolution intersects with consumption patterns, industrial production, food cultures, and the future of Mediterranean dietary heritage?

The biological impact of GLP-1 medications is profound. These drugs mimic gut hormones that regulate appetite and satiety, leading users to consume substantially fewer calories without consciously restricting their diets (Nature Reviews Drug Discovery, 2023). Multiple studies, including consumer behavior research, suggest that average caloric intake among GLP-1 users can drop by up to 20-30%, with one analysis noting decreases of around 700 daily calories compared to pre-medication levels (Cornell SC Johnson College of Business, cited in *Washington Post*, 2025). This suppression of appetite and shift in food preferences has led to measurable changes in eating habits. Users report a significant decline in cravings for high-calorie, processed foods and an increased focus on nutrient-rich items such as lean proteins, vegetables, and foods higher in fiber. Therefore, grocery shopping transforms: households with a GLP-1 user often spend less overall and purchase fewer indulgent products like snacks, sweets, and sodas. A study from

the Cornell SC Johnson College of Business found that households cut grocery spending by about 5.5% within six months of adoption, with the largest reductions in ultra-processed, calorie-dense categories (Purdue University, 2025). Empirical evidence shows that GLP-1 users reduce caloric intake, alter grocery purchases, and modify meal patterns within weeks of starting the medication.

The motivations behind these changes are not the result of voluntary dieting alone but are primarily driven by profound physiological shifts induced by the medication. Appetite suppression and, in some, cases nausea, leads users to eat less not because of conscious restraint, but because their bodies register different hunger and satiety signals. This altered signaling produces cascading behavioral effects: reduced snacking, smaller portion sizes, fewer impulse food purchases, and a greater tendency to plan meals intentionally. Rather than spontaneously consuming calorie-dense snacks, individuals often opt for smaller, protein-rich foods or skip secondary meals altogether.

Observed behavioral changes include smaller portions, reduced snacking, and intentional meal planning. Clinical and observational evidence also shows a marked reduction in alcohol craving and consumption, improvements in fertility outcomes, and potential neuroprotective effects, including a lowered risk of neurodegenerative diseases such as Alzheimer's (*Food & Wine*, 2025; IQVIA, 2023). As a result, weight reduction is no longer the sole or primary motivation behind GLP-1 use, which is increasingly perceived as a broader metabolic and neurological regulator (Lancet Commission, 2023). If these trends continue, traditional Mediterranean food rituals may be disrupted, potentially affecting collective meals, culinary practices, and the broader agri-food system. The reduction in appetite induced by GLP-1 drugs fundamentally alters the eating experience, making some cultural practices less comfortable or desirable (UNESCO, 2013). While these outcomes are plausible, they are projections based on observed short-term behavioral changes rather than fully realized structural shifts.

4. Consequences for agricultural production and supply chains

Changes in consumption patterns naturally trickle back to agricultural production. Economic analyses suggest that reduced demand for calorie-dense, processed food inputs, such as corn for snack manufacturing or sugar for sweetened products, could shift cultivation priorities. If consumers increasingly favor fresh produce, lean proteins, and nutrient-rich items, agricultural supply chains may need to reallocate resources accordingly. Projections show that foods traditionally associated with indulgence—sugary drinks, creamy dairy products, and high-fat staples—could experience real declines, while crops and livestock geared toward protein quality and freshness may see stronger demand. Dairy researchers, for example, have observed that GLP-1 users tend to move away from heavy, processed dairy items toward lean protein options like cottage cheese and plain yogurt, influencing production strategies from farm to retail (FAO, 2018).

Supermarket and grocery sales data show that increased use of weight-loss injections correlates with declining sales volumes for snacks like crisps, biscuits, and chocolate. In a recent analysis, grocery volumes in the UK fell by 0.4% year-on-year, partly attributed to households with GLP-1 users cutting back on such purchases. Across the Atlantic, analysts report shifts in U.S. grocery spending as well, with consumers taking these medications spending less on dining out and more on cooking at home, a trend that reflects a combination of reduced appetite and deliberate food choices. Fast-food sales have declined, and consumers are substituting pizza and other high-calorie options with salads or lean protein entrées. These observed changes reflect short-term behavioral adaptations among GLP-1 users. Furthermore, this consumption change may become structural rather than temporary. As GLP-1 adoption spreads, many households are reducing total food intake and reshaping their grocery lists. This slowdown in food purchasing exerts downward pressure on sales of high-volume items, traditionally the backbone of supermarket revenues, and pushes producers to

rethink their product portfolios (*Reuters*, 2025; *Washington Post*, 2025).

If these trends continue, structural changes may occur in agricultural production and supply chains. Crop diversification may become more important, with farmers cultivating more vegetables, legumes, and nuts rather than commodity grains destined for processed food supply chains. Closer alignment between agricultural outputs and evolving dietary preferences could shorten supply chains, increase local production, and potentially reduce environmental impacts associated with long-distance transport, a trend that resonates with the sustainability ethos of the Mediterranean diet.

In response to rapidly evolving consumer demand, major food companies are already innovating. A growing trend within the food and beverage sector focuses on products tailored to consumers taking GLP-1 medications. For example, companies are introducing high-protein whey drinks designed to help individuals losing weight preserve muscle mass. Similarly, some brands are launching or rebranding products with “GLP-1 friendly” positioning, emphasizing higher protein content, smaller portions, and greater nutrient density. Restaurants are also adapting by offering GLP-1 friendly meals, sometimes serving reduced portions at a lower price. These initiatives reflect an industry-wide pivot away from high-calorie comfort foods toward healthier, functional products that cater to the evolving needs of a growing consumer segment. Specialty food makers are positioning themselves as well, leveraging the trend toward lean proteins, leaner snacking alternatives, and whole food ingredients as potential growth areas in a market that may see 10-20% of adults on GLP-1 medications by 2030 (*Food & Wine*, 2025).

While some adaptations are already underway, the full impact on food companies and agricultural systems will likely unfold over several years. These potential structural impacts represent medium- and long-term projections, based on current consumption trends and expected GLP-1 adoption rates. While demand for nutrient-dense and smaller-portion products grows, traditional high-volume categories such as salty

snacks, baked goods, and sugary beverages may face eroding markets. Reduced consumption of ultra-processed foods, alcohol, and sugary beverages threatens powerful agri-food and beverage industries, which have historically exerted significant political influence (OECD, 2023). As consumption patterns shift, so too will lobbying strategies, regulatory pressures, and national economic calculations, particularly in countries where these industries represent major employers or export sectors.

5. The Geopolitics Behind Weight-Loss Drugs

It is also important to underline the geopolitical dynamics surrounding GLP-1 weight-loss drugs, which are increasingly emerging as a new arena of global power struggle. Denmark, home to Novo Nordisk, the world leader in medications such as Ozempic and Wegovy, has transformed a single pharmaceutical company into a strategic national asset. Despite Denmark's small size, Novo Nordisk contributes significantly to GDP, exports, and stock market capitalization, giving the country an important influence over a major public health trend (*The Economist*, 2023-2024; Danish Ministry of Industry, 2023). The United States, in contrast, represents the largest and most profitable market for these drugs. High obesity rates, strong purchasing power, and a fragmented insurance system allow for premium pricing, but also create structural dependence on a foreign supplier. American patients and insurers rely heavily on Novo Nordisk for drugs that are increasingly framed not merely as lifestyle treatments but as long-term therapies for chronic disease management. This dependence, coupled with domestic pressures over soaring healthcare costs, limited insurance coverage, and periodic drug shortages, has amplified political attention and regulatory scrutiny in Washington (*Financial Times*, 2023-2024; U.S. Senate HELP Committee, 2023-2024). The GLP-1 segment is a rare instance where European industrial leadership constrains American negotiating power, demonstrating how pharmaceutical innovation can translate into geopolitical leverage even for small states. Supply shortages have further

intensified tensions. When demand surged, Novo Nordisk and its main competitor, Eli Lilly (USA), were forced to ration supplies and prioritize certain markets. Although commercially motivated, these decisions have geopolitical implications: uneven access sparked debates on domestic pharmaceutical manufacturing capacity, strategic stockpiling, and the risks of overreliance on foreign producers. Consequently, GLP-1 drugs are increasingly discussed in the United States within the broader framework of strategic autonomy, as a geopolitical weapon (the case of Greenland), alongside critical sectors like semiconductors and vaccines (OECD, 2023).

China, meanwhile, is emerging as a potential disruptor in the generics and biosimilars space. While no western health institution approved generics exist yet for semaglutide or tirzepatide, Chinese companies have already launched liraglutide biosimilars and are aggressively developing semaglutide equivalents, anticipating patent expirations around 2026. China's strategy leverages domestic production capacity, rapid scale-up, and regulatory positioning to capture markets where affordability and access are critical. Despite significant regulatory and market-entry barriers in the US and EU, China is positioning itself to become a major global supplier of GLP-1 generics, particularly for the Global South, highlighting the interplay between innovation, industrial policy, and geopolitical influence (WHO, 2023; *Nature Reviews Drug Discovery*, 2023; Brookings, 2023).

Weight-loss drugs are emerging as instruments of soft power and global influence. Countries that lead in pharmaceutical innovation, clinical research, and production capacity gain not only economic advantage but also diplomatic leverage. Offering access, partnerships, or technology transfer can strengthen bilateral relations, while restricted access can fuel resentment and political friction (CFR, 2023; WTO/TRIPS Council, 2023).

6. Conclusion

The rise of GLP-1 weight-loss drugs represents more than a medical innovation: it marks a profound societal, cultural, and economic shift.

While these medications offer significant benefits in combating obesity and metabolic disorders, their widespread adoption is reshaping how individuals relate to food, challenging the core principles of the Mediterranean diet. What has long functioned as a holistic system, integrating nutrition, social cohesion, cultural heritage, and sustainable agriculture, now faces disruption as appetite suppression and altered consumption patterns increasingly prioritize efficiency over enjoyment, individual convenience over collective ritual, and pharmaceutical intervention over centuries of dietary knowledge.

These behavioral changes may also have some implications for the food system, although their broader effects on agriculture and food production remain uncertain. The growing use of GLP-1 drugs could contribute to shifts in purchasing habits and meal practices, particularly through reduced calorie intake and changing preferences for certain food products. However, these developments represent only one among many factors shaping agri-food markets, and their impact on agricultural production and supply chains is likely to vary considerably across sectors and regions. Rather than driving a structural transformation of agriculture, GLP-1 adoption may therefore reinforce existing trends toward smaller portions and more nutrient-dense products. At the same time, the rapid expansion of the GLP-1 market introduces broader geopolitical considerations, as pharmaceutical leadership, access to medicines, and long-term treatment costs may become increasingly relevant sources of economic leverage and strategic dependency.

Taken together, these developments suggest that GLP-1 drugs may have implications that extend beyond their clinical use and deserve consideration from a broader policy perspective. For policymakers, an emerging question is how the increasing adoption of these therapies may interact with dietary habits, food systems, and wider public health objectives. In this context, the Mediterranean diet can be understood not only as a nutritional model, but also as part of a broader socio-economic and cultural system linking health, local food production, social practices, and territorial development. Changes in appetite, meal frequency, and approaches to weight manage-

ment associated with GLP-1 use could potentially influence some of these dimensions, including eating practices and food preferences. However, the scale and direction of these effects remain uncertain and are likely to depend on multiple economic, social, and cultural factors beyond the diffusion of GLP-1 therapies.

From a governance perspective, an overreliance on pharmaceutical solutions may reinforce an individualized approach to obesity, diverting attention from prevention, food environments, and nutrition education. Health policies that emphasize access to medication without parallel investment in culturally grounded dietary models risk accelerating the erosion of collective food practices and widening social inequalities in diet quality, particularly in Mediterranean and lower-income contexts where access to healthy diets is already uneven.

Policy responses must therefore be explicitly cross-sectoral. Health authorities should frame GLP-1 treatments as complementary to, rather than substitutes for, dietary and lifestyle interventions. Public information strategies are needed to ensure that individuals using these medications receive clear guidance on maintaining nutritionally adequate and culturally meaningful diets, consistent with Mediterranean principles. Nutrition education policies should also be updated to reflect the physiological effects of appetite-suppressing drugs, helping to prevent unintended outcomes such as under-nutrition, reduced dietary diversity, or disengagement from shared meals.

Agricultural and food policies must likewise anticipate structural shifts in demand. Supporting local production, short supply chains, and diversified Mediterranean agriculture will be essential to prevent further concentration of food systems around standardized, “functional” products designed primarily for medical or weight-loss purposes. Without targeted support, small producers and traditional food sectors risk marginalization, with broader implications for rural employment, landscape management, and food sovereignty.

GLP-1 weight-loss drugs represent a powerful but inherently ambivalent policy instrument. Their long-term impact will depend on gov-

ernments' ability to integrate pharmaceutical innovation into coherent strategies that protect healthy dietary models, sustain local food systems, and preserve the social and cultural dimensions of eating. The challenge for policymakers is not to choose between medical innovation and food culture, but to govern their interaction in a way that strengthens both public health and societal resilience.

Policy implications

- Health policy: integrate GLP-1 treatments with preventive strategies, nutrition education, and culturally grounded dietary counseling rather than relying exclusively on pharmaceutical management.
- Agricultural policy: support small-scale and diversified Mediterranean producers to adapt to changing demand patterns and prevent further concentration of the agri-food system.
- Food system governance: promote short supply chains and local food environments that sustain fresh, minimally processed products consistent with Mediterranean dietary principles.
- Education and social policy: reinforce food literacy, shared meals, and intergenerational transmission of culinary practices to preserve the social dimension of eating.
- Rural development policy: protect employment and income in traditional agri-food sectors potentially affected by reduced food consumption and portion sizes.

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Participatory co-design for youth entrepreneurship support in agrifood sector: Evidence from initiatives in the Mediterranean and Africa

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Abstract

Participatory approaches are increasingly recognised as key to designing effective interventions for youth entrepreneurship in agrifood sector, particularly in complex and heterogeneous contexts such as the Mediterranean and Africa. This paper analyses a co-design methodology developed and implemented by CIHEAM Bari across 17 countries within agrifood innovation ecosystems. The approach integrates ecosystem mapping, co-design services and capacity building of Business Support Organisations (BSOs), tailored startup support, and open innovation mechanisms linking startups with firms. Drawing on both implementation experience and selected literature on open innovation and innovation ecosystems, the paper shows how participatory co-design enhances the relevance, ownership, and effectiveness of interventions. A relevant aspect of this process is the Mediterranean Innovation Agrifood Week (MIA Week), organized by CIHEAM Bari yearly and gathering innovation ecosystem actors from Mediterranean and African countries, is discussed as a collective reflection space where methodological insights are consolidated and refined. The paper contributes to the operationalisation of participatory approaches in youth entrepreneurship support, moving beyond theoretical frameworks towards practice-oriented evidence.

Keywords: Participatory co-design, Youth entrepreneurship, Innovation ecosystems, Open innovation, Agrifood.

1. Background and objectives

Youth entrepreneurship in agrifood sector and rural areas has become a strategic priority in development policies, particularly in regions characterised by strong demographic pressure and limited labour market absorption capacity (Yami *et al.*, 2024). In the Mediterranean region,

this has prompted growing attention to food systems transformation through data, policy, investment and innovation (Valls Bedeau *et al.*, 2021). However, conventional support programmes often adopt standardised and top-down approaches, limiting their effectiveness in diverse and dynamic contexts.

In response, participatory co-design has emerged

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as a promising approach, enabling the alignment of interventions with local ecosystem dynamics and the actual needs of young entrepreneurs (Portuguez-Castro, 2023). Despite increasing recognition in academic literature, the practical operationalisation of such approaches remains underexplored.

This paper addresses this gap by analysing the methodology developed by CIHEAM Bari through international cooperation projects in the agrifood sector. Rather than focusing on theoretical constructs alone, the paper provides an empirical account of how participatory co-design can be structured and implemented across different contexts.

2. From Entrepreneurial Behaviour to Innovation Ecosystems: A Conceptual Framework

Entrepreneurial behaviour is widely recognised as a key driver of innovation and economic development. Building on the Schumpeterian tradition, entrepreneurs are not merely creators of new ventures but agents of change who mobilise resources, assume risk, and introduce novel combinations into the economic system (Kochetkov, 2023).

However, contemporary research emphasises that entrepreneurial behaviour cannot be understood solely as an individual attribute. Rather, it emerges from the interaction between individual capabilities and structural conditions, including access to finance, quality of education, institutional frameworks, and sociocultural norms (Arunkumar *et al.*, 2025). This is particularly relevant for youth entrepreneurship, where individual initiative is often constrained by systemic barriers such as limited access to finance, land, markets, skills, and technologies, as well as weak social and professional networks. Hence, fostering entrepreneurial behaviour requires interventions that go beyond skills development and address the broader environment in which young entrepreneurs operate. Participatory co-design of entrepreneurship support programmes can help reduce these constraints, provided that policymakers, business support organisations (BSOs), financial institutions, educational institutions, and entrepreneurs themselves are involved in

shaping interventions around local needs and ecosystem dynamics.

The systemic nature of entrepreneurial behaviour is closely linked to how innovation processes are governed. The literature on innovation governance highlights the role of multi-actor interactions in shaping innovation outcomes. The Triple Helix model conceptualises innovation as the result of interactions between universities, industry, and government (Etzkowitz & Leydesdorff, 2000). This framework has been expanded into the Quadruple Helix, which incorporates civil society as a key actor contributing knowledge, values, and creativity to innovation processes (Carayannis & Campbell, 2009) and quintuple helix, introducing ecological sustainability as key element of innovation (Carayannis & Campbell, 2010).

For youth entrepreneurship, this perspective is particularly significant, as it recognises young people and community-based organisations as active participants in innovation, rather than passive beneficiaries. At the same time, the literature highlights a persistent gap between these conceptual models and their practical implementation, pointing to the need for approaches that operationalise multi-actor collaboration in concrete intervention settings (Leydesdorff & Lawton Smith, 2022).

The concept of innovation ecosystems further develops this perspective by focusing on the interdependencies among actors, resources, and institutions. An innovation ecosystem can be understood as a configuration of interconnected actors, resources, and institutions that shapes innovation processes and the conditions under which entrepreneurs develop and bring innovations to market. Within such systems, entrepreneurial behaviour both shapes and is shaped by ecosystem dynamics, through opportunity recognition, risk-taking, experimentation, collaboration, and resource mobilisation.

Ecosystem conditions such as access to knowledge, finance, networks, support organisations, enabling policies, and entrepreneurial culture shape young entrepreneurs' capacity to identify opportunities, take risks, innovate, collaborate, mobilise resources, and launch or scale ventures. Access to early-stage finance reduces uncer-

tainty around venture creation; participation in networks strengthens opportunity recognition, knowledge exchange, and access to resources and markets; and supportive policies and institutional frameworks lower entry barriers and facilitate business development. Conversely, weak coordination or fragmentation across these elements can constrain entrepreneurial action, regardless of individual capabilities.

Moreover, the relationship between innovation ecosystems and entrepreneurial behaviour is not unidirectional. Entrepreneurs also shape innovation ecosystems through the development of new products and services, employment generation, knowledge diffusion, investment attraction, and the creation of linkages among actors. Their activities can stimulate further innovation, reinforce networks, and encourage new entrepreneurial initiatives. This reciprocal relationship highlights the co-evolution between entrepreneurial action and ecosystem conditions and reinforces the relevance of co-creation as an approach to ecosystem development.

Recent contributions emphasise that the performance of innovation ecosystems depends on the quality of these interactions, as well as on the alignment between different components such as services, talent, funding, and industrial actors (Zhou *et al.*, 2025). Weak coordination or fragmentation within the system can significantly limit innovation outcomes, particularly for more vulnerable actors such as young entrepreneurs.

In this context, the role of intermediary organisations, such as Business Support Organisations (BSOs), becomes critical, as they facilitate connections, translate knowledge into practice, and support the development of entrepreneurial initiatives.

Open innovation provides an analytical and operational framework to understand and structure these interactions. Defined as a distributed process based on purposively managed knowledge flows across organisational boundaries (Chesbrough & Bogers, 2014), it emphasises the importance of collaboration and knowledge exchange in innovation processes. Empirical studies show that engaging with diverse external partners enhances innovation performance, particularly in contexts characterised by uncer-

tainty and resource constraints (Portuguez-Castro, 2023; Bagherzadeh *et al.*, 2021). For young entrepreneurs, who often lack internal resources, access to external knowledge and networks becomes a fundamental enabling condition. Open innovation therefore reinforces the idea that effective support to entrepreneurship must be embedded in collaborative and network-based environments, rather than focusing solely on individual capacities.

Within these frameworks, youth entrepreneurship is shaped by structural barriers. Limited access to finance, land, skills, and networks remains a major constraint, particularly in rural and peri-urban contexts, often compounded by gender inequalities and institutional weaknesses (Yami *et al.*, 2024). In North African countries, these challenges intersect with specific dynamics in agricultural and food innovation systems that require tailored analytical frameworks and policy responses (Ben Hassen & El Bilali, 2021).

Building on the above strands of literature, participatory co-design can be understood as an operational approach that integrates entrepreneurial behaviour, innovation governance, and ecosystem dynamics. Co-design involves structured processes in which multiple stakeholders jointly identify problems, develop solutions, and implement actions.

From an open innovation perspective, co-design represents a form of coupled innovation, combining knowledge inflows and outflows (Bagherzadeh *et al.*, 2021). From an ecosystem perspective, it facilitates the activation of relationships and complementarities among actors, contributing to system effectiveness (Zhou *et al.*, 2025).

As such, participatory co-design provides a practical mechanism to translate complex theoretical frameworks into concrete interventions, particularly in contexts where coordination failures and resource constraints limit the potential of youth entrepreneurship.

Building on these theoretical perspectives, the following section examines how these principles can be operationalised in practice through a structured participatory co-design methodology. Drawing on the experience of CIHEAM Bari across Mediterranean and Af-

rican agrifood ecosystems, the paper analyses how multi-actor governance, open innovation, and ecosystem approaches can be translated into concrete interventions to support youth entrepreneurship.

3. Innovation ecosystem methodological approach for youth entrepreneurship support

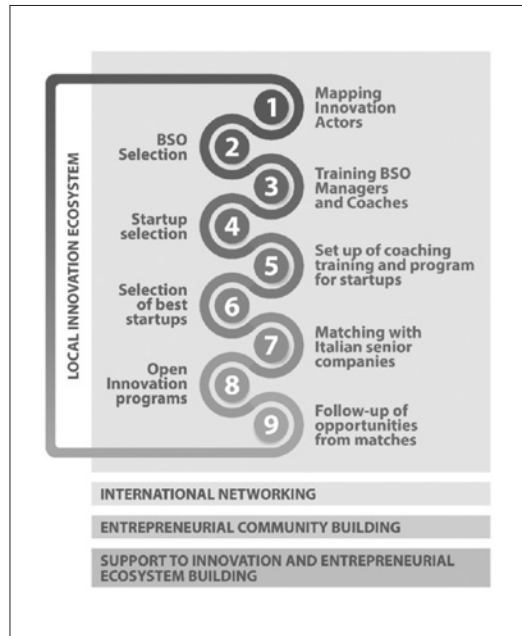
The CIHEAM Bari approach is grounded in an ecosystem perspective, consistent with the literature on innovation systems emphasising the interaction between multiple actors. It also reflects principles of open innovation, in which knowledge flows across organisational boundaries enhances innovation outcomes (Chesbrough, 2006).

The methodology follows a progressive logic combining ecosystem development, intermediary strengthening, and direct support to entrepreneurs along their journey. The *entrepreneur's journey* refers to the sequence from initial exposure to entrepreneurship, through idea generation, validation, launch, and early growth. The *entrepreneurship support value chain* (ESVC) refers to the support actions and services provided within local ecosystems, identifying what guidance, tools, partnerships, and services are needed at each stage.

The journey typically begins with outreach and stimulation activities encouraging entrepreneurial initiative, then moves into a pre-start phase where potential entrepreneurs aspire to achieve proof of concept, proof of business, proof of technology, and proof of delivery, followed by launch and early growth phases focused on market entry, customer acquisition, operational structuring, and revenue generation. All phases of the methodology are therefore designed around the real progression of entrepreneurs and their changing challenges and needs. Ecosystem actors are therefore “coordinated enablers” providing different forms of value along the entrepreneurial path according to their specific role and capacities.

The methodology is guided by five cross-cutting principles: all phases revolve around the entrepreneurs’ constraints and opportunities

Figure 1 - CIHEAM Bari methodological framework for strengthening agrifood innovation ecosystems.



along the journey (*Entrepreneur-centered*); the methodology emphasises cooperation and complementary roles rather than one-stop-shop solutions (*Ecosystem-based*); close engagement with local players is required to understand informal relationships, institutional sensitivities, and practical bottlenecks, increasing chances of sustainability (*Co-design*); the mapping in Phase 1 anchors the intervention in the specific characteristics of each context, making actions realistic and relevant (*Place-based*); each BSO works with different types of entrepreneurs with distinct needs and ambitions, making standardised pathways insufficient (*Custom-based*).

The methodology is structured into four main interconnected phases that guide the process of strengthening the local innovation ecosystem in support of youth entrepreneurship (Figure 1).

Phase 1: Ecosystem Mapping

The methodology begins with a comprehensive mapping exercise combining desk review, stakeholder interviews, and workshop-based validation, designed to produce an actionable

understanding of the agri-food entrepreneurial ecosystem. The mapping identifies the main actor categories and analyses each one's contribution to entrepreneurial development:

The first phase aims to develop a systemic understanding of local agrifood ecosystems through desk research, stakeholder interviews, and participatory workshops.

This process allows the identification of key actors: *public institutions* (defining the enabling environment and sometimes directly running support services); *research organisations, universities, and technical centres* (generating and transferring knowledge, providing scientific expertise and laboratories); *Business Support Organisations* (translating ecosystem resources into concrete services through coaching, business advisory, mentoring, and market linkages); *financial actors* (providing the different forms of capital entrepreneurs require at different stages); and *private sector SMEs* (providing market information, supply chain linkages, and open innovation opportunities). The process allows each typology of actor within the entrepreneurial support value chain to understand their role (Devaux *et al.*, 2018).

Empirical evidence from CIHEAM Bari projects shows that ecosystem mapping frequently reveals:

- fragmentation among support actors,
- gaps in growth-oriented services,
- weak linkages between research and market actors.

For example, in several partner countries, mapping exercises highlighted the limited coordination between universities and incubators, constraining technology valorisation pathways.

This is further illustrated by the case of Sudan (Kassala and Red Sea States) in *MIPRO-Sud program*¹, where ecosystem mapping revealed a fragile but evolving entrepreneurial environment characterised by the predominance of informal activities and strong dependence on

agriculture-based livelihoods. Public institutions, particularly the Ministry of Production and Economic Resources, play a central coordinating role, often through project-based collaborations with international partners. However, the analysis highlighted significant structural constraints, including weak coordination between national and regional levels, limited access to finance, underdeveloped value chains, and a strong mismatch between production and market integration. Entrepreneurship is largely small-scale and community-based, with limited innovation orientation, although donor-supported initiatives have contributed to capacity building and the inclusion of youth and women in value addition activities. This case confirms the importance of ecosystem mapping in identifying systemic bottlenecks and informing context-specific intervention design.

Phase 2: Strengthening BSOs

The second phase focuses on reinforcing the capacity of BSOs as key intermediaries within the ecosystem.

In line with findings on the importance of intermediary organisations in innovation systems (Zhou *et al.*, 2025), the approach combines:

- co-design workshops to develop services and entrepreneurship support programmes (incubation, seed and/or growth acceleration),
- targeted training activities,
- peer-to-peer coaching mechanisms.

A distinctive feature is the participatory development of incubation models, ensuring that programmes reflect local constraints and opportunities rather than adopting pre-defined templates.

This process contributes to building *institutional ownership*, which is widely recognised as a critical factor for sustainability (Reed *et al.*, 2025).

¹ MIPRO-Sud program aims to improve the living conditions of small-scale producers and increase food production in the fisheries, agriculture, and livestock health sectors in the states of Kassala and the Red Sea. The interventions are designed to strengthen the resilience and sustainability of local communities by addressing everyday challenges and promoting economic development.

Table 1 - BSOs involved in CIHEAM Bari initiatives.

<i>University-based Incubation Centres</i>	Agricultural University of Tirana
	Incubatore Valona
	University “Fan S. Noli” of Korçë
	Nilepreneurs -Nile University
	University of Jordan Innovation & Entrepreneurship
	Innovation and Incubation Center at USIU Africa (Nairobi)
	Bahir Dar Uni. Entrepreneurship Dev. and Incubation Center (EDIC)
	Dire Dawa University Business and Technology Incubation Center
<i>Public</i>	TIEC
	Momentum Incubator for Lebanese Startups
	APIA Agricreation
	APIA Kef
	APIA Foodtech
<i>Private</i>	CERD
	LiNK
	Athar
	The Venture X
	Asher Center for Innovation and Entrepreneurship (USEK)
	Berytech
	SOTE HUB
	EAEA (East African Entrepreneurs Association)
	Leancubator

This approach is exemplified by the STARTUP10 initiative², implemented across ten countries in the Mediterranean and Africa, where 22 selected BSOs were engaged in a structured capacity-building pathway combining training, co-design, and coaching. The methodology was applied to different types of BSOs. A total of 13 public BSOs were involved, 10 of which were university-based, as well as 9 private BSOs (Table 1).

Through participatory workshops, BSOs developed tailored incubation programmes aligned with the needs of local agrifood entrepreneurs,

while peer-to-peer exchanges and mentoring by experienced coaches supported their practical implementation. The initiative demonstrated that strengthening BSOs through co-design not only improves the quality of services provided to startups but also enhances the long-term sustainability of support mechanisms by embedding methodologies within local institutions. In addition, STARTUP10 contributed to fostering stronger linkages among ecosystem actors, reinforcing the role of BSOs as coordinators and facilitators of innovation processes at local level.

² STARTUP10 is a MAECI funded initiative aiming at promoting food security and youth employment in 10 partner countries of Italian cooperation (Albania, Algeria, Bosnia and Herzegovina, Egypt, Ethiopia, Jordan, Kenya, Lebanon, Tunisia, Uganda) through the strengthening of business incubators to foster the development of local startups that present innovative solutions in the green and blue economy sectors with a focus on digitalization.

Phase 3: Startup Support Programme

Startup support is delivered through structured coaching programmes targeting early-stage or post-revenue ventures.

The approach emphasises:

- selective identification of startups through ecosystem actors,
- iterative coaching processes,
- continuous interaction between local and international experts.

Experience has shown that open calls have significant limitations in identifying ventures with the strongest readiness and market potential; more proactive headhunting practices have therefore been developed, mobilising ecosystem actors — including investors — with direct visibility on promising enterprises.

Evidence from the STARTUP10 initiative further illustrates these dynamics. While open calls enabled the mobilisation of a large pool of applicants, reaching over 740 applications across ten countries, the subsequent support phase revealed significant heterogeneity in terms of startup maturity and readiness. Many ventures, although promising, were not yet sufficiently structured to fully benefit from intensive, market-oriented coaching programmes or to engage in more advanced exchange and collaboration opportunities, including access to Italian or European markets. This highlighted the need to complement open calls with more targeted selection mechanisms, ensuring better alignment between the level of maturity of startups and the objectives of structured support programmes.

A complementary perspective emerges from the SUSTLIVES project in Burkina Faso and Niger, implemented in partnership with university incubators (BTi-UJKZ in Ouagadougou and CIUAM-UAM in Niamey). In contexts where incubators are still at an early stage of development and startups present relatively low levels of maturity, the support model prioritised capacity building and progressive structuring of entrepreneurial skills. Two open calls led to the selection of 32 startups across two cohorts, which benefited from a structured training programme covering pitching, team management, sales strategy, and financial plan-

ning, followed by individual coaching adapted to local realities.

The programme also incorporated pitch competitions to stimulate engagement and reward performance, providing financial support for selected ventures to consolidate their business models. Additional support focused on communication and visibility, including the development of tailored promotional materials for each startup, facilitating interactions with partners, investors, and potential clients. Finally, thematic workshops on agrifood transformation, biodiversity, collective action, and women's empowerment contributed to embedding entrepreneurs within a broader collaborative innovation ecosystem.

This experience highlights how, in low-maturity ecosystems, startup support programmes need to combine capacity building with exposure to markets and access to finance, confirming the importance of adapting intervention models to the specific characteristics of each context.

Generally, support takes the form of a structured coaching programme of approximately four months, typically organised around eight to ten sessions helping entrepreneurs address strategic and operational challenges, refine business models, strengthen market positioning, and prepare for growth decisions. Experienced coaches accompany local coaches throughout, observing sessions and providing feedback to enhance the capacity of the local coaches. Across projects, observed outcomes include:

- improved business model definition,
- enhanced market orientation,
- increased readiness for investment and partnerships.

Phase 4: Connecting with European Agri-Food Businesses

The fourth phase aims to connect startups with concrete market opportunities, translating entrepreneurial support into concrete business development opportunities, operationalising open innovation principles.

Two main instruments are used:

- *challenge-based programmes*, which identify concrete problems faced by European or

local SMEs and invite startups to propose solutions

- *opportunity-based networking* (venture clienting), which focuses on understanding the operational and market needs of companies and facilitating targeted interactions with relevant startups.

In practice, the structuring of the open innovation program, as implemented in STARTUP10 project, requires a preliminary phase of in-depth analysis aimed at identifying firms' innovation needs. This is conducted through dedicated meetings, interviews, and structured discussion sessions with participating companies. The objective is to gather detailed insights into their specific challenges and opportunities, both from a technological and organisational perspective. This process enables the definition of an "innovation profile" for each company and the identification of priority areas to be addressed through subsequent open innovation activities. The evidence collected serves as the basis for the development of tailored intervention pathways, including the preparation of customised reports summarising key needs and outlining potential development trajectories. This approach allows for a more precise *matching* between corporate demand and startup solutions, thereby increasing the effectiveness of open innovation mechanisms and the likelihood of generating concrete collaboration outcomes. Within the STARTUP10 initiative, this approach resulted in 21 matchings between startups and Italian companies, generating diverse outcomes, including the co-development of new products and the exploration of new market opportunities and the identification of innovative solutions aligned with firms' strategic needs. In addition, startups benefited from high-level and tailored mentorship provided by corporate partners, contributing to the strengthening of their business models and overall performance.

These mechanisms address a common limitation of incubation programmes, namely the weak integration with real market demand. By directly involving firms in the innovation process, they create concrete opportunities for interaction between supply and demand of innovation. As a result, evidence from implementation suggests that such engagement significantly enhances the

scalability and sustainability of startup solutions.

Overall, the four-phase methodology highlights how participatory co-design can be operationalised as a structured, ecosystem-based approach to supporting youth entrepreneurship. By combining systemic analysis (Phase 1), strengthening of intermediary actors (Phase 2), targeted support to startups (Phase 3), and integration with real market demand through open innovation mechanisms (Phase 4), the approach ensures alignment between entrepreneurial capacities and ecosystem opportunities.

The following section builds on this framework by analysing how these methodological principles are collectively reflected, discussed, and refined within the Mediterranean Innovation Agrifood Week (MIA Week), which serves as a participatory platform for validation, knowledge exchange, and consolidation of lessons learned across countries and projects.

4. The Mediterranean Innovation Agrifood Week as a participatory validation platform

The Mediterranean Innovation Agrifood Week (MIA Week) represents a key component of the approach, functioning as a collective reflection and validation space between actors involved in the CIHEAM Bari initiatives and other innovation players. It acts as a platform where insights from different projects are shared, compared, and refined.

This function is consistent with the concept of innovation ecosystems as dynamic learning systems characterised by continuous interaction among actors (Zhou *et al.*, 2025).

Across five consecutive editions, MIA Week has become a key platform for sharing diverse local experiences and initiatives. By convening Business Support Organizations, startups, policymakers, international institutions, and companies, it transforms collective insights into meaningful support, including policy development. At once a space for gathering and nurturing, MIA Week collects knowledge while generating new connections, project ideas, and future business opportunities.

It is structured around three pillars: *Meet* (connecting innovation leaders through B2B sessions

and showcases), *Share* (exchanging ideas, models, and practices), and *Empower* (strengthening skills through masterclasses and mentoring).

It operates as a living laboratory for co-creation and methodological advancement, placing people at the centre as active protagonists in co-designing future strategies. Participatory co-design is not a peripheral methodological preference in this context: it is the structural condition for ensuring that opportunities are genuinely owned by those they are meant to serve. The 2025 edition brought together 60 startups, 25 BSO managers, 14 representatives of international organisations, and 50 experts from 12 countries, producing some *Collective Takeaways*, many of them highlighting recurring themes directly linked to the methodological framework presented in the present paper.

Collective Takeaways refer to the insights that MIA Week participants can take back with them: recommendations to improve approaches and interventions supporting youth entrepreneurship and innovation in the Mediterranean and Africa, to which they themselves contributed during the event. This reflects the essence of the participatory approach: analyzing past experiences, jointly designing future pathways, co-creating commitments, and envisioning the most prosperous future together, all of which are captured in these *Collective Takeaways*.

Innovation as a collective process, confirming the need for ecosystem-based approaches (Chesbrough, 2003). Fragmentation remains a principal barrier to progress, making stronger cross-sector connections and collaborative governance essential. In agrifood systems, innovation must be built with local actors, not for them, and co-design, co-creation, and shared learning, including learning through failure, are indispensable, particularly in addressing structural challenges such as water scarcity and climate adaptation.

Youth entrepreneurship as a strategic imperative: Youth entrepreneurship in agrifood systems lies at the heart of development across Africa and the Mediterranean. With a large share of the population under 35 in Africa, the potential for transformative growth is significant, but so are the risks of exclusion. Persistent barriers (limited

access to land, finance, technology, and markets, compounded by social and cultural constraints) continue to hinder young entrepreneurs. The agrifood sector offers diverse opportunities beyond primary production, spanning processing, logistics, digital services, and renewable energy. Unlocking this potential, demands investment in education, digital skills, market access, and tailored financing.

Local ownership of processes: Sustainable impact depends on local ownership. Initiatives imposed from outside often generate dependency rather than empowerment, whereas innovation flourishes when communities actively shape and lead processes. The guiding principle is clear: innovation must originate within territories, not be transferred into them. Cooperation should foster mutual learning rather than one-way knowledge transfer.

Cultivating creative ecosystems as drivers of innovation: Innovation is closely tied to creativity, which thrives in environments that encourage experimentation and exchange. Building such ecosystems requires investment in both physical and social infrastructure, where ideas can circulate freely and interdisciplinary collaboration can emerge. Creative hubs, labs, and communities are critical for transforming ideas into viable projects, and effective innovation also depends on communication: shaping narratives around innovation is as important as developing the innovations themselves.

Dignity as the ultimate horizon of innovation and cooperation: Underlying all these themes is a shared conviction: innovation and cooperation must ultimately serve human dignity. This principle reshapes how success is defined, shifting focus from outputs to meaningful improvements in people's lives. It demands recognition of individuals, especially young people, not as beneficiaries but as active agents of change, and requires that initiatives be assessed in terms of real impact on livelihoods, opportunities, and social inclusion.

Frugal Innovation, a necessity: in specific contexts characterized by scarcity and instability, innovation frequently takes the form of frugal solutions — practical, resource-efficient responses built on local ingenuity. Meaning-

ful solutions do not always require advanced technologies, but rather the capacity to adapt, improvise, and make effective use of available resources.

5. Conclusion

The analysis confirms that participatory co-design represents a relevant and effective approach for supporting youth entrepreneurship in complex and heterogeneous contexts.

Three main conclusions emerge:

First, participatory approaches improve the relevance and effectiveness of interventions by aligning them with local needs and ecosystem dynamics. Participatory co-design enables a shift from standardised, top-down programme design towards context-sensitive interventions grounded in local realities. Through the active involvement of entrepreneurs, BSOs, public institutions, investors and private actors in the design phase, interventions are better able to capture informal dynamics, hidden constraints, and opportunities that are often not visible through desk analysis alone.

This alignment enhances both relevance, ensuring that services respond to real needs of the local entrepreneurial communities, and effectiveness, as stakeholders are more likely to engage with and sustain initiatives they have helped shape. Moreover, participatory processes foster trust and mutual understanding among ecosystem actors, which are essential for long-term collaboration.

Evidence from CIHEAM Bari projects confirms that co-designed programmes tend to achieve higher uptake, stronger engagement from participants, and greater continuity beyond project cycles, as local actors progressively internalise and adapt the methodologies.

Second, an ecosystem perspective is essential: interventions targeting individual entrepreneurs are insufficient without strengthening intermediary organisations and system-level interactions. Entrepreneurial performance is strongly influenced by the quality and structure of the surrounding ecosystem. Isolated support to startups, for example through standardized training or coaching, often fails to generate sustainable

outcomes if systemic constraints remain unaddressed. An ecosystem perspective highlights the importance of intermediary organisations, particularly BSOs, which play a critical role in translating resources, knowledge, and opportunities into accessible services for entrepreneurs. Strengthening these actors contributes to building a more coherent and functional support infrastructure.

In addition, fostering interactions among ecosystem actors, including research institutions, financial actors, and private firms, is essential to create the conditions for innovation and growth. The CIHEAM Bari experience shows that interventions are significantly more effective when they combine direct support to entrepreneurs with capacity building of BSOs and mechanisms that enhance coordination and collaboration within the system.

This systemic approach allows for cumulative and multiplier effects, whereby improvements in one component of the ecosystem generate positive spillovers across others.

Third, the integration of open innovation mechanisms is critical to ensure that entrepreneurial support translates into concrete market opportunities. A recurrent limitation of entrepreneurship support programmes is the disconnect between capacity building activities and actual market access. The integration of open innovation mechanisms addresses this gap by directly linking startups with firms, value chains, and real demand.

Through instruments such as challenge-based programmes and venture clienting, startups are embedded in direct innovation processes with established companies, allowing them to validate solutions, access markets, and generate revenue opportunities.

This approach shifts the focus of support from knowledge acquisition to application and market integration, which is essential for ensuring business sustainability. It also benefits firms, which gain access to innovative solutions and new technologies, reinforcing a mutually beneficial relationship.

The experience across CIHEAM Bari initiatives demonstrates that when open innovation is integrated into support programmes, startups

show higher levels of growth potential and are better positioned to scale, while ecosystems become more dynamic and interconnected.

Overall, the contribution of this paper lies in demonstrating how participatory co-design can be operationalised through structured methodologies and applied across diverse contexts. Future research should further investigate the long-term impact of such approaches, particularly in terms of job creation, business sustainability, and ecosystem transformation.

Ultimately, it's important to emphasize how methodologies are a collective act in constant evolution, where the exchange between different types of actors, different experiences in different territories, and local innovation ecosystems represents a crucial value-building factor.

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Much more than an alternative source of income: Participation in women's producer groups in rural Tunisia

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Abstract

Women's producer organisations (WPOs) have been promoted for their potential to empower women in patriarchal contexts. However, there has been limited research on the interactions, in such contexts, between women's capacity to generate individual income and the changes made possible through their participation in WPOs. This study explores the socio-economic changes experienced by women engaged in three WPOs in Siliana Governorate, Tunisia. It assessed the economic benefits and collected women's narratives about changes in social relations at community and family level, in social skills, and in self-perception. The financial gains were generally modest, especially compared to alternative sources of income. Women nevertheless valued their participation in WPOs. First, the work aligned better with their domestic responsibilities and was less physically demanding than farm labour. Second, women reported significant social and psychological benefits. The majority of women reported these changes, even when their economic gains were particularly small. Third, many women used their WPO experience to launch their own small-scale businesses. Thus, Tunisian WPOs offer more than financial benefits: they foster social support, personal development, and a way towards empowerment.

Keywords: Collective action, Tunisia, Women's empowerment, Women's producer organisations.

1. Introduction

In many places where patriarchal norms formerly constrained women's autonomy, gendered disparities in access to entrepreneurship have diminished significantly in recent decades. The trend is particularly clear in urban areas in North Africa (Metaiche and Bendiabdellah,

2016; Chaker and Zouaoui, 2023). However, in many other parts of the world, women continue to have limited opportunity to become entrepreneurs (Semkunde *et al.*, 2022). For instance, in many rural areas, women mostly stay at home, only working on the family farm or they find paid work as farm labourers outside the household (Akram-Lodhi, 2024; Islam *et al.*, 2021).

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Women's entrepreneurship has attracted attention for its perceived potential to empower women, not only by improving their economic conditions but also by transforming relationships within families and communities, and by contributing to the social cohesion of rural societies (Iakovidou *et al.*, 2012). However, women's ability to become entrepreneurs faces many barriers in patriarchal contexts, where women often have limited access to the resources – such as land ownership – and support systems – such as credit facilities – they need to start a business (Mwobobia, 2012). Cultural factors may also be restricting; for example, social norms may dictate that only men are responsible for meeting family needs (Tlaiss, 2015). Additionally, women may struggle to participate even in officially gender-neutral producer organisations (Meinzen-Dick *et al.*, 2017).

In such patriarchal contexts, development practitioners have promoted Women's Producer Organisations (WPOs), formal or informal collectives which provide support in production and marketing to their women members (Semkunde *et al.*, 2022). WPOs can facilitate entrepreneurial initiatives, whether pursued individually or collectively. The activities they organise are led by women; they may take place at home or on group premises and sometimes involve support from spouses, but it is the women themselves who carry out the activities and take the decisions. WPOs are part of a broader category of women's Self-Help Groups (SHGs); more specifically, they belong to a subset called livelihood SHGs (Brody *et al.*, 2017).

There is now a substantial body of experience with WPOs and SHGs in rural areas shaped by patriarchal norms. Numerous studies have examined the trajectories of these organisations, the challenges they face, and the extent of empowerment they facilitate. In the past decade, a comprehensive list of the wide-ranging impacts of WPOs and SHGs has been compiled thanks to several meta-analyses (e.g., Brody *et al.*, 2017; Castiblanco-Moreno and Pineda Duque, 2022). These meta-analyses propose a broad structuring of impact pathways. However, research on the impacts of women's SHGs shows that women's empowerment is highly context-specific. First,

the meaning of women's empowerment needs to be defined locally, following a constructivist approach (Kabeer, 1999). Second, the types of changes triggered by participation in WPOs differ significantly across studies. There is neither a guaranteed outcome nor a standard pathway to follow for change to occur. For instance, in some contexts, patriarchal norms exist but only have a marginal impact on women's mobility in public spaces (Semkunde *et al.*, 2022), whereas in other contexts, women face major problems accessing public spaces on their own (Bouzid *et al.*, 2024).

Women's empowerment processes is thus deeply embedded in local contexts. One key dimension of this context, which has received limited attention to date, concerns how, in patriarchal settings, women's capacities to generate individual income interact with the changes enabled thanks to their participation in WPOs. One of the three situations prevails at the point in time the WPO is launched: 1) the women have no prior individual source of income (Ferguson and Kepe, 2011); 2) the women are already engaged in entrepreneurial activities, such as producing and selling agricultural or food products (Baden, 2013a; Benkhallouk, 2021; Mwambi *et al.*, 2021; Serra and Davidson, 2021); 3) the women have access to paid work and may already have some individual entrepreneurial activities. Considering this dimension entails examining the extent to which the socio-economic changes brought about by participation in WPOs make a difference for women who already have a prior source of income, and the extent to which women can mobilise the resources gained through participation in WPOs to pursue individual income-generating activities. In the literature on the economic impacts of SHGs, considerable attention has been devoted to credit and savings groups, while far less focus has been placed on WPOs (Kumar *et al.*, 2021; Brody *et al.*, 2017). Studies on the impacts of WPOs generally addressed economic benefits in a qualitative way (Cinar *et al.*, 2021; Mayoux, 1995). In the few studies that quantified economic benefits (e.g., Baden *et al.*, 2013b; Dohmworth and Hanisch, 2018), the latter were generally not compared with alternative individual sources of income.

Besides, most research on the impacts of

SHGs and WPOs has focused on South Asia and sub-Saharan Africa (Brody *et al.*, 2017). Much less attention has been paid to these organisations in rural areas of North Africa. These regions have been conspicuous for their strong patriarchal norms, which limit opportunities for women to develop their own entrepreneurial activities (Bouzid *et al.*, 2024; Maayoufi *et al.*, 2023; Kerras *et al.*, 2023; Benabdallah *et al.*, 2020). However, in parallel in these rural areas, women's employment, chiefly as agricultural labourers, has increased in recent decades (Bouzidi and Faysse, 2024; ONAGRI, 2016), although, in this context, agricultural labour is typically informal, demanding, risky, and poorly paid. While it helps women meet their basic needs in challenging conditions, it rarely advances their empowerment in a meaningful way (Bouzidi and Faysse, 2024; Azim *et al.*, 2025). Another source of income in these rural areas is individual, usually informal, entrepreneurial activities. These activities are often not directly linked to agriculture as women usually lack formal access to land. Instead, typical entrepreneurial activities are handicrafts or food products (Bouzid *et al.*, 2024).

In the past two decades, public development actors, NGOs and international donors have actively promoted WPOs in rural areas of North Africa (Hanafi *et al.*, 2024; Hamamouche *et al.*, 2023). In Tunisia, since 2010, the government has supported the creation of Agricultural Development Groups whose members are all women or in which women represent a significant proportion of the members. Hereafter, these groups are referred to Women's Agricultural Development Groups (WADGs). Their number increased rapidly to 164, with over 5,000 registered members in 2022 (Hanafi *et al.*, 2024). These WADGs are involved in a wide range of income-generating activities, including livestock breeding, food production, handicrafts, and collecting and distilling medicinal and aromatic plants. Despite the increase in their number, the groups still face many constraints, thus limiting their capacity to flourish (Hanafi *et al.*, 2024). To date, no studies have been conducted of the changes these WADGs triggered in their members in Tunisia,

and only two studies have focused on WPOs in other North African countries (Faysse *et al.*, 2015; Montanari and Bergh, 2019).

The present article analyses the socio-economic changes that have occurred as a result of participation in three WADGs in Siliana governorate. The study provides a quantitative assessment of the economic benefits of participating in WPOs, alongside an analysis of women's narratives concerning social and psychological changes. In doing so, it seeks to address the two research gaps identified above: first, the limited examination of how changes associated with participation in WPOs both shape and are shaped by women's individual access to income-generating activities; and second, the lack of evidence on the economic and non-economic impacts of WPOs in rural areas of North Africa.

2. Women's producer organisations in environments shaped by patriarchal norms

We now review studies of the impacts of WPOs on their members in environments shaped by patriarchal norms. Patriarchy is generally defined as "a societal structure that is male dominated, male identified, and male centred" (Jonhson, 1997). In studies of WPOs in environments shaped by patriarchal norms, these norms usually comprise the following elements: 1) men are the official representatives of the households in public, as well as in matters external to the households; 2) men are the decision-makers when it comes to managing productive resources (e.g. land and water); 3) few women have economic activities outside their household, and even when they do, they often have limited or even no control over their personal earned income.

Some studies underline that becoming a member of a WPO was an issue *per se*. Membership of WPOs may be limited to women who already have sufficient resources to start producing and become an entrepreneur (Castiblanco-Moreno and Pineda Duque, 2022). In a study on WPOs in Ethiopia, Mali and Tanzania, Baden (2013b) reported that members of WPOs were generally older, married women who had more time to undertake entrepreneurial activities outside

their daily household responsibilities. In another study, Ugur-Cinar *et al.* (2024a) highlighted cases where women joined WPOs later in life after completing family obligations. These women had few opportunities to build a life project around their entrepreneurial activity and therefore received only limited benefits from their involvement in the WPO.

Some studies identify a wide range of impacts of participating in WPOs. First, WPOs can play a crucial role in enabling women to access essential resources for production and marketing, for example, through collective purchasing of inputs, securing credit, obtaining necessary production training, or organising collective access to the market (Baden, 2013a and 2013b; Elbehri and Lee, 2011; Messonyat *et al.*, 2022). Baden (2013b) and Serra and Davidson (2021) reported that members of WPOs were able to obtain higher prices for their products than non-members.

Second, participation in WPOs can help women acquire new skills, including those related to entrepreneurship. In Morocco, Faysse *et al.* (2015) found that WPOs helped women improve existing production skills and learn how to manage collective action, although learning opportunities were not always evenly distributed among members of the group. Studies conducted in India (Mayoux, 1995), Turkey (Ugur-Cinar *et al.*, 2024a), and Morocco (Benkhallouk, 2021) reported that membership of an WPO enabled women to learn how to run a business. Many members of WPOs later applied this knowledge and the resources they accessed through these organisations (e.g. networks) to start their own business, either by leaving the WPO or while remaining an active member.

Third, participation in WPOs can boost women's self-confidence (Baden, 2013a). Through their involvement, women are seen and perceive themselves as economic actors, not only as members of a family (Cuellar-Gomez, 2009). Additionally, WPOs can foster a sense of collective identity (Manzanera-Ruiz and Lizárraga, 2016).

Fourth, research has explored how WPO participation fosters social empowerment. Several authors have reported that women's involvement in WPOs can help challenge gender norms within households, encouraging a more equitable

sharing of responsibility and decision-making between men and women (Majurin, 2012; Manzanera-Ruiz and Lizárraga, 2016). For instance, in a case study conducted by Ravichandran *et al.* (2021), women became more able to decide independently how to use their earnings, and men took on household tasks traditionally assigned to women. However, these outcomes are not guaranteed. Other studies in patriarchal contexts report that WPO participation did not alter household dynamics, with husbands insisting that women's cooperative work should not affect their traditional domestic roles (Ugur-Cinar *et al.*, 2024b). In Morocco, Montanari and Bergh (2019) described WPOs that were, in reality, controlled by men, in which women's participation amounted to being a low-paid labour with no empowerment. Similarly, in studies of women's cooperatives in Morocco's argan sector, some cooperatives were reported to function like investor-owned private companies. Presidents managed them unilaterally and members served as paid workers with no decision-making power (Perry *et al.*, 2019). Some of the changes reported may also take place at the level of the community. Participation in WPOs facilitates access to public spaces, such as market places. WPO members also feel more confident speaking at meetings (Baden, 2013b; Ferguson and Kepe, 2022; Othman *et al.*, 2021).

Changes at household or community level do not always take place without friction. For instance participation in WPOs may motivate women to challenge gendered norms within households, leading to increased tensions between genders (Alemu *et al.*, 2018). Likewise, Dohm-wirth and Hanisch (2018) argue that supporting women-only producer organisations in a way that excluded men may limit gains in terms of women's empowerment at the level of the household.

These studies also underlined that the connection between economic changes and psychosocial ones may take various forms. In some cases, WPOs have been able to challenge social norms even when financial gains were limited (Baden, 2013a; Cinar *et al.*, 2021; Oberhauser and Pratt, 2004); whereas in others, participation in WPOs did have financial benefits but the social transformation it brought about was negligible

(Mayoux, 1995; Baden, 2013b; Ugur-Ceinar *et al.*, 2024a and 2024b).

On the other hand, the same authors often also underline the fact that the impacts they identified were in no way guaranteed. First, many WPOs were fragile and some stopped operating. Second, the benefits of participating in a WPO depend to a great extent on the specific local context. Notably, none of the above-mentioned studies specifically considered whether the fact a woman had access to an individual source of income influenced their level of involvement in WPOs and the benefits they had and continue to derive from it.

3. Method

3.1. Women's Producer Organisations studied

The present study builds on a analysis conducted by Hanafi *et al.* (2024) that included a comprehensive diagnosis of the WADGs in Siliana Governorate in Tunisia. The mapping of women's organizations in Siliana Governorate underscores both the vitality of collective initiatives and the sustainability challenges they face (Hanafi *et al.*, 2024). Between 2012 and 2023, 18 WADGs were created in the governorate. However, by 2023, seven had ceased operations, reflecting structural, financial, managerial, or

market-related constraints that compromised their viability. Moreover, two WADGs had been created but had not yet initiated activities in 2023. As a result, only nine WADGs were active in Siliana Governorate at the time of the study.

The present study focused on three active WADGs: El Wifak, Borj Massoudi, and Zidi Kesra (Figure 1). The three GDAs were selected for the diversity of their situations: they had varying sizes, from 25 to 300 members, and undertook diverse activities, e.g. food production and handicrafts (see details in Hanafi *et al.*, 2024).

All the members of El Wifak and Borj Massoudi WADGs are women. In the Borj Massoudi WADG, some women are not members but are nevertheless allowed to use the WADG's equipment: they are referred to as beneficiaries. Zidi Kesra WADG is a mixed-gender agricultural development group. Apart from the 32 women members of this group, 248 farmers – usually men – grow figs they sell to the group. In this WADG, men's and women's activities are clearly separated.

Since their inception, these three WADGs have gradually diversified their activities, either independently or with the support of development partners. They often sell their products collectively through trade fairs, by selling their products in local villages, and occasionally, online. Some groups have also developed their own sales networks. However, these three WADGs face sever-



Figure 1 - Location of the Women's Agricultural Development Groups (WADGs) included in the present study.

al challenges, mainly due to limited financial resources, inadequate equipment and facilities, and marketing problems (Hanafi *et al.*, 2024).

3.2. Analytical framework and data collection

Hereafter, women's empowerment is understood using Kabeer (1999)'s definition as a process through which women enhance their ability to make life choices, in a context where this ability is limited. It means the capacity of women to define and implement livelihood strategies, i.e., their choice of a combination of activities to maintain, secure, and improve their livelihoods (de Haas, 2010). We considered dimensions of this empowerment that are commonly used to study the impact of collective actions among women in rural areas (Brody *et al.*, 2017): economic gains, social relations and self-perception. The social dimension concerns women's social resources and social status (Kabeer, 1999). It refers to the changes in relations taking place within communities, at home and with development actors but also in terms of the way women consider that they are viewed and considered by other actors. The self-perception dimension relates to the confidence in oneself and in one's capacity to pursue self-defined goals (Rowlands, 1997; Yount *et al.*, 2020).

We used a constructivist approach to analyse these dimensions. First, instead of a preidentified set of indicators, we identified and used indicators of social changes adapted to the local context (Richardson, 2018), based on preliminary open-ended interviews. Second, we encouraged interviewees to narrate their own experiences of change brought about by their involvement in WPO. Following on Kabeer (1999), we paid importance to the meaning given by women to the economic and social indicators used. We also chose a mixed-methods approach, combining quantitative and qualitative elements. We deliberately used the term "change" rather than "impact," as the WADGs had only been established eight years or less prior to the interviews.

We interviewed women who were members or beneficiaries of El Wifak, Borj Massoudi,

and Zidi Kesra WADGs. During the interview, we first asked about the interviewee's involvement in the WADG, focusing on their daily activities and participation in decision-making processes. Then in collaboration with each interviewee, we jointly examined three main categories of change. The first was the net financial benefits women gained from participating in the WADG, calculated over a one-year period. The second category covered social and psychological changes, assessed first through open-ended questions about how women perceived the effects of their participation in four areas: social relationships, relations within the family, social skills, and self-perception.

Twelve possible changes related to these four areas had been identified before the interviews. Concerning social relationships, the potential changes were making new friends, escaping loneliness and having distracting activities, exchanging ideas (e.g. on project opportunities and on production practices), establishing a relationship of mutual respect with the administration, and being better respected by the community. Concerning relations within their family, identified potential changes were stronger involvement in household decision-making and family pride in one's accomplishment. Concerning social skills, identified potential changes were better leadership skills and improved communication skills. Finally, concerning self-perception, the preidentified potential change was enhanced self-confidence. If the interviewee did not mention any one of these changes spontaneously, follow-up questions were asked to determine whether she had in fact experienced those changes.

The third category of change focused on how women's involvement in the WADG fits their wider livelihood strategies. Interviewees were asked about any other individual sources of income they had before joining, whether they maintained or initiated new ones, and how they balanced WADG activities with their household responsibilities. With the interviewees' permission, interviews were recorded and subsequently transcribed.

We interviewed 33 members of WADGs (Table 1). The sample was chosen to ensure a di-

Table 1 - Distribution of the rural women interviewed in the three WADGs.

WADG	<i>Female members of the management committee</i>		<i>Female members</i>		<i>Female beneficiaries</i>		<i>Total</i>
	<i>Total number</i>	<i>N° interviewed</i>	<i>Total number</i>	<i>N° interviewed</i>	<i>Total number</i>	<i>N° interviewed</i>	
Zidi Kesra	2	1	32	11	-	-	12
El Wifak	6	1	25	9	-	-	10
Borj Massoudi	4	2	30	7	30	2	11

versity of cases according to three dimensions: (1) age: the ages of the interviewees ranged from 24 to 83; (2) marital status - the sample included single, married, divorced women and widows; and (3) activities carried out under the auspices of WADGs: each of these activities was taken up by some of the interviewees.

4. Results

4.1. *How the WADGs function*

Activities

The Zidi Kesra group emerged from an informal group of women who, in 2012, decided to work together to produce and sell jam and handicrafts. In 2015, the regional rural women's office (part of the regional office of the Tunisian Ministry of Agriculture) helped the group formalise their activities by merging with a previously inactive agricultural development group which had previously managed a small-scale irrigation scheme. Women collectively produce and sell food products, most of which are based on figs purchased from farmer members. The group provides training for its members: the training focuses on marketing and media skills for non-farming women members, and on irrigation and agroecology for farmers.

El Wifak WADG was established in 2017 thanks to a joint initiative by members and supporting organisations. This women-only group collectively carries out a variety of seasonal activities, including processing agricultural products, making traditional pastries, drying

medicinal plants, and handicrafts. The involvement of some members is limited due to time constraints or lack of skills. While the wide range of activities reflected the goal of diversifying existing sources of income, it also created challenges related to time management and mastering different production skills.

Borj El Massoudi WADG was created in 2019 at the initiative of its women-only members. Group members engaged in collective poultry breeding and distillation of medicinal plants. They also produced ingredients for traditional dishes on the group's premises. Members benefitted from both training and from being able to use the group's equipment. In 2024, in addition, there were 12 beneficiaries, women who already had their own business: they had their own produce and their own sales channels. Beneficiaries do not pay a membership fee and are thus not official members, but can nevertheless follow the training sessions. However, to use the group's equipment, beneficiaries are required to pay a fee set by the management committee.

Women's involvement in collective action

Women are actively involved in the management of the El Wifak and Zidi Kesra WADGs. Every member has a voice in decisions that affect the functioning of the group. The president of Zidi Kesra WADG holds regular meetings to discuss members' needs and expectations. For example, following a suggestion from members, the president introduced a daily wage of 12 Tunisian Dinar (TND)¹ per day during the fig jam making season in 2023. This measure

¹ In 2023, on average 1 TND = 0.30 euro.

meant the women could receive regular payment for their work, even before the products were sold. This measure was made possible thanks to the sufficient financial resources of the WADG, whose capital amounted to 30,000 TND in 2023.

The El Wifak WADG has faced challenges related to its members' lack of motivation and collective participation. In some cases, development projects were a source of small financial incentives during events held to promote collaboration. However, this approach led some members to rely on external support rather than actively contribute to group activities. One member remarked: "Some women complain without doing anything. They want to receive an income without working. When there is work to be done in the group, they say they have family commitments and cannot come. And when there is no work, they complain too." This lack of engagement has disrupted the group dynamics, and the president occasionally struggles to organise collective tasks aimed at holding the group together. In contrast, in the Borj El Massoudi WADG, the interviewees emphasised the reciprocal trust between the members and the president. However, some members told us the president consults members but then makes decisions alone.

In all three groups, the women's involvement in WADG activities has enabled them to increase their technical and managerial skills. In the three WADGs we studied, participation enabled women to acquire the skills they need to transform locally available natural resources into value-added products. As one 50-year-old member explained: "Before joining the group, I had no idea that medicinal plants like chamomile could provide an income. In fact, my nieces used to pick the plants to play with. Now, thanks to the training I received on drying medicinal plants, which was organised by the group with the support of a development project, these chamomile plants have become my main source of income in spring." When a WADG received equipment—such as tools for the distillation of aromatic plant - training is generally provided to ensure members are able to use it properly. In addition, members of the management committee receive

training in group governance, including financial management, and how to organise and document meetings.

4.2. *Economic changes*

Direct financial benefits

Members reported a range of benefits resulting from their involvement in WADGs, including the ability to produce a wider variety of products (30 responses), participation in trade fairs (29), access to new markets (13), reduced production costs (13), access to funding opportunities (5), and online marketing opportunities (1).

Between February 2023 and January 2024, the average annual income earned by interviewees from activities carried out directly with their WADG was 570 TND for women in the El Wifak WADG, 322 TND in the Borj Massoudi WADG, and 204 TND in the Zidi Kesra WADG. This corresponds to an average monthly income of approximately 28 TND across the three groups. When asked to evaluate this income, respondents described it as insufficient (17 responses), average (8), or satisfactory (8). Indeed, this income is low: According to Decree No. 2024-419 of 9 July 2024, the official minimum monthly wage for a farm labourer was 450 TND per month in 2024 in Tunisia. In Siliana Governorate, in 2024, female farm labourers could expect to earn between 10 to 20 TND per day. However, the work in WADG was usually not full time but was limited to a few hours a week or a month.

For women with no prior income, earnings from the WADG were particularly important. As one member admitted: "I didn't have a job, I wasn't married and I had no money. The group gave me a source of income". In particular, women underlined its stability. Another member pointed out: "The group enabled members to receive a minimum income all year round. This is an important step forward for us, as it provides a certain level of financial stability. However, the income is low, it's not enough to cover all our expenses. To supplement this income, we also work as farm labourers, mainly during the pea harvest. That extra work is indispensable to be able to cover our daily needs". Women mainly use the money they earn to cover their daily household expenses,

Table 2 - Annual net income from activities undertaken as part of the WADG (calculated over the period from February 2023 to January 2024).

<i>Annual net income</i>	<i>Members' age in years</i>			<i>Total</i>
	<i>25-31 (N = 8)</i>	<i>32-49 (N = 10)</i>	<i>Over 50 (N = 15)</i>	
Less than 200 TND	0	3	13	16
Between 200 and 400 TND	4	4	2	10
Between 400 and 1 400 TND	4	3	0	7

health-related costs, and their children's education. Only two women reported being able to save part of their earnings.

Table 2 shows the income obtained by members based on age categories, which, in turn, is based on: (1) the fact that the average age of women when they marry in Tunisia was 30 in 2024 (National Statistical Institute of Tunisia, 2025); (2) women older than 50 could be expected to have fewer duties in terms of taking care of children. The income actually earned by members varied significantly, with younger women generally earning more than their older counterparts. Younger women are typically more willing and more able to dedicate the time and energy required to participate actively in collective entrepreneurial projects. They also usually have the level of formal education necessary to be actively involved in managing these initiatives. In contrast, women over the age of 50 tend to earn substantially less. Many have faced challenges when starting entrepreneurial activities, they often have only a limited formal education, and sometimes struggle to carry out physically demanding tasks.

One factor that strongly influences women's participation and income is marital status. Single women are more flexible and have more free time, meaning they can engage in personal development and in entrepreneurial ventures. The four women aged between 25 and 31 who earned more than 400 TND per month, were all single at the time of the interview. On the other hand, the 21 married women needed to find a balance between their family obligations and the time they dedicated to WADG activities: six of them prioritize family obligations and only participate in WADG activities when they have the time, while four of the interviewees chose to undertake production early in the morning or late at night,

so that these activities did not affect their daily domestic chores. As the president of Zidi Kesra WADG pointed out: "Some members have family responsibilities, and the time they are available to work in the group is very limited. They are mainly involved in making jam, and since jam sales are limited, they only earn 50 dinars a month during the months of production".

Constraints limiting income generation

The financial benefits obtained by members of the WADGs remained modest, reflecting a combination of constraints at both organisational and household levels. At the organisational level, the groups encountered structural and operational difficulties, including cash flow shortages, inadequate premises, and insufficient shared equipment to increase production capacity. Marketing posed a further major challenge. Several women engaged in individual production intentionally kept output low due to uncertainty about their ability to sell their goods. The marketing of collectively produced items was equally problematic. Before the Covid-19 crisis, the Zidi Kesra WADG used to produce food products all year round. However, the pandemic disrupted sales and resulted in the loss of stored products. The group consequently decided to limit production to a few months each year when sales are guaranteed. As one member of the Borj Massoudi WADG explained: "We have a large quantity of products, but we lack the technical and commercial skills required to market them effectively. We need support from decision-makers to help us access larger-scale markets".

Members of the Zidi Kesra and El Wifak WADGs also emphasised that administrative and legal barriers further constrained

their ability to undertake income-generating activities. In particular, regulatory provisions prevented them from developing e-commerce initiatives, thereby considerably limiting the diversification of their marketing channels. As the president of the Zidi Kesra WADG explained: “I tried to set up a social media page and a website to promote our products more effectively, and it worked very well in terms of sales. I was even working with delivery agencies. However, the head of the administration told me that we were not permitted to engage in e-commerce or online sales, as this is prohibited by law. When I asked how we were expected to market our products, he replied that we should simply wait for customers to come to us directly or sell at fairs, which is very restrictive”.

At the household level, income generation was further limited by prevailing gender norms embedded within a patriarchal social context. Women’s restricted access to productive resources, such as land and capital, meant that WADGs tended to concentrate on activities requiring minimal investment, which consequently often generated modest returns. Moreover, women’s participation in economic activities remained shaped by intra-household power relations, with decision-making authority and control over time frequently exercised by male family members. One member explained: “Handicrafts require a great deal of sacrifice. My husband never allows me to spend the whole day working in the workshop”. Women were therefore expected to carry out WADG-related activities in addition to their domestic responsibilities, leaving them with limited time to devote to income-generating work. As another woman stated: “If my husband does not find a meal ready and the house as clean as it should be, he will argue with me. That’s why I decided to prioritise my family obligations”. These gender norms also restricted women’s mobility. As one participant noted, “Husbands [of WADG members] are strict and do not allow us to travel far from home—particularly to urban centres such as Tunis—to commercialise our products”. Such gendered constraints curtailed women’s capacity to fully invest in productive activities, even when collective organisational structures were in place.

Connection between activities undertaken in the WADG and other income-generating activities

About half the women interviewed (18 out of 33) already had a personal income prior to joining their WADG. Of these, 12 ran their own business—handicrafts, food production, poultry farming, or a small shop; while 7 (one of whom also had her own business) worked as farm labourers, factory workers, or cashiers in stores. Their monthly income from these activities typically ranged between 50 TND and 400 TND, (average approximately 250 TND). This income was thus much higher than the average direct income (28 TND a month) they earned working in their WADG. However, the other sources of income were often unstable due to the irregular demand for labour at factories and farms, or to problems they met selling their products. WADG members also underlined the fact that farm labour is physically hard. Consequently, even though the income they receive from the WADG is modest, it is nevertheless valued as a supplement.

Among the 18 women who already had another source of individual income, 8 stopped doing the activities concerned when they joined the WADG. They decided their previous work was either not sufficiently profitable or too difficult to organise alongside their household responsibilities. In some cases, factories simply did not offer stable employment opportunities, and the three women who had previously worked as farm labourers stopped doing so after joining the WADG. On the whole, women preferred the working conditions of the WADG to paid labour, which meant they could work closer to their home or even at home and were often able to fit their schedule around their family commitments. As one 42-year-old member explained: “Before, the women of our community worked as farm labourers in difficult conditions with no real prospects for improving their lives. Now, thanks to our group, we have the opportunity to work from home, in a comfortable environment”.

Seventeen of the interviewees had started their own business thanks to the experience and the skills they had acquired by participating in the WADG and the resulting networks. They

ran their business but continued to be active in the WADG. One interviewee told us: “I started a handicraft business at home after taking the group’s training courses. I produce my own items with my own tools and sell them directly to customers. I also benefit from the fairs organised by the group”.

4.3. Social and psychological changes

Twenty-eight of the 30 interviewees reported that participation in the WADGs improved their social relationships by helping them build new friendships and by creating networks based on solidarity and mutual support (Table 3). Being

part of the group also helped women overcome feelings of loneliness, release negative energy, and find positive distractions, all of which enhanced their sense of well-being. As one interviewee told us: “I’ve made new friends in the group. I’m from Kef not Siliana, so I didn’t have any friends here”. A 52-year-old interviewee described how her ties with the community had been strengthened: “Since I joined the group, my social relations have improved a lot, especially with my neighbours. We exchange knowledge, share ideas, and support each other in our activities”. Another member added: “One of the members took a pastry-making course and then trained us; we are all united”. A widowed mem-

Table 3 - Social and psychological changes linked to participating in WADGs according to interviewees.

Category	Change	Distribution by age			Women having previous individual source of income (N = 18)	Women that had earned less than 200 TND over one year (N = 12)	Total (N=33)
		Between 25 and 31 (N = 8)	Between 32 and 49 (N = 10)	Age 50 and over (N = 15)			
Social relations	Making new friends	7	8	13	15	11	28
	Escaping loneliness and finding distracting activities	6	7	11	13	10	24
	Exchanging ideas (e.g. on project opportunities and on production practices)	7	8	12	15	9	27
	Establishment of a relationship of mutual respect with the administration	3	3	6	6	6	12
	Receiving more respect from the community	7	5	9	11	7	21
Relations within the family	Increased involvement in household decision-making	7	4	11	11	6	22
	Family pride in one’s accomplishment	4	8	5	14	7	17
Social skills	Better leadership skills	2	0	0	1	0	2
	Better communication skills	2	2	2	3	1	6
Self-image	Increased self-confidence	7	7	12	16	9	26

ber highlighted the value of community support, explaining that, thanks to the president of her WADG, she had contacted an association from which she subsequently received monthly financial assistance.

Before the WADGs, the women we interviewed had played no leadership roles and had not had the opportunity to take initiatives at the level of the community as men were the only official representatives of households in public spaces. Through the WADGs, the women were starting to play active roles in collective actions and negotiations, such as purchasing inputs and marketing their own products. New opportunities also arose to travel to other regions—and occasionally abroad—as recognised economic actors. These developments significantly increased the respect and recognition women received within their communities.

Members also reported feeling on a more level playing field and more respected in their interactions with local administration. A 42-year-old interviewee noted: “When I attend meetings, I now exchange ideas with the administration, and mutual respect has developed between myself, as a rural woman, and the administration. I also pay more attention to my appearance and dress in neat, presentable clothes when I go to a meeting with them”. Two-thirds of the women interviewed reported that participating in the WADG had significantly boosted their self-perception and their self-confidence. One member told us: “Before, I was shy, but thanks to the meetings and exchanges, I now participate actively and I’m not afraid to express my opinion”.

Additionally, interviewees reported that joining the WADGs had brought about positive changes in family relationships. Some interviewees mentioned that men’s attitudes had become more positive since women had started contributing to household expenses. One member explained: “Now, with the group, I have my own income, which makes me independent. I no longer have to ask my husband for an allowance, which has made our relationship less stressful”. Another told us: “Before, my husband would not let me attend training sessions, especially those held a long way away from our area without being accompanied. But after see-

ing that thanks to these training sessions, I can help with family expenses, he has been encouraging me to take on even more”. A 52-year-old member of the WADG described her changing family dynamics: “My husband is very proud of me. Although he is allergic to chili peppers himself, he lets me produce harissa [a highly spiced condiment] and to continue to do so with the group. This helps us meet the family needs”. Similarly, a 42-year-old interviewee told us: “Since I became more active, my husband sees me as independent and is proud of me because I contribute to daily household expenses and I can do administrative tasks. Thanks to this income, I’ve gained the confidence to support myself without having to financially rely on my husband”.

Table 3 also shows that these social changes do not depend on age. Although older women often earned significantly less than younger members, they reported similar psychological and social benefits. The table also indicates that reported social changes were substantial for the 18 women who had previously engaged in individual income-generating activities and for the 12 women who had earned less than 200 TND over the course of a year.

5. Discussion

5.1. *Opening new horizons*

In our study, the direct monetary gains to be had from participating in a WADGs appeared to be limited because of several internal constraints within the WADGs, many of which were in turn related to the patriarchal environment. Moreover, the regulatory environment limited their development. WADGs are chiefly considered as associations and face difficulties acting as small-scale companies. For instance, the Tunisian Law No. 2004-24 prevents agricultural development groups from distributing profits to their members (Hanafi *et al.*, 2024).

Women criticised the limited monetary gains but also pointed out that the core benefit was often elsewhere. This result is similar to findings made in other studies (Brody *et al.*, 2017; Baden, 2013a; Castiblanco-Moreno and Pine-

da Duque, 2022). First, as mentioned in Baden (2013a), participation in WADGs enabled access to new resources and opportunities, such as training sessions, travel, production equipment, and connections with development actors. For instance, Zidi Kesra WADG had previously collaborated informally in jam making, but formalising their group enabled them to create valuable links and to receive support from various development organisations. Second, participation gave women recognition as economic actors taking decisions on their own for income generation, rather than being seen as “mere” housewives, farm workers or employees. Each of the social and psychological changes identified in this study had already been identified in previous research on SHGs and WPOs. For instance, Alemu *et al.* (2018) also reported that members of WPOs had started sharing more information among themselves.

The present study produces a more original result. The most active members were generally the younger ones, not only because many were not yet married but also because they were interested and felt able to engage in a collective entrepreneurial project. This result contrasts with a study conducted by Baden (2013a) in Mali, where the women who were the most active in the WPOs were older married women who were able to spend less time on family duties than younger women. However, even though there were differences in the level of engagement and in the monetary benefits obtained by participating in the group, social and psychological changes were mentioned by a large majority of members. As pointed out by Ferguson and Kepe (2011), this result confirms the need not only to avoid evaluating WPOs by focusing solely on their economic impacts.

A question is whether reported changes are reversible, in particular in the context of the economic and organisational fragility of WADGs. The data obtained does not allow to provide definite answers to this question – this would need a longitudinal study. As mentioned by Kabeer (1999), understanding empowerment as a process entails it is open-ended and depends on evolving circumstances. However, the example of Zidi Kesra WADG shows that

psychological changes may be sustained even after the group enters a phase of crisis. The reason behind these sustained changes is that WADGs play a major role in terms of building connections and building capacities, even though the direct income that may be derived from producing with the group is low. Moreover, the study identified several changes that were not dependent on a possibly negative future evolution of WADGs. Some members reported improved skills. Moreover, a majority of interviewed WADG members had initiated private entrepreneurial activities based on their experience in the group.

5.2. Pushing many — not all — walls set by patriarchy

The reported changes enabled to increase intrinsic, instrumental and collective dimensions of women’s agency (Yount *et al.*, 2020). Women increased their intrinsic agency, as they increased their self-confidence and their motivation to pursue their own goals. Their instrumental agency increased, in the sense that they enhanced their capacities to take initiatives. Finally, collective agency increased thanks to the sustained functioning of WADGs. However, this study did not consider the wide range of dimensions of empowerment proposed by the Women’s Empowerment in Agriculture Index (Quisumbing *et al.*, 2018). Some indicators such as work balance or changes in the control over the use of income were not systematically assessed.

The changes reported took place in a patriarchal environment that was not directly challenged. Empowerment took place “within the walls” of patriarchy, pushing some of these walls rather than attempting to break them. The activities in the WADGs did not explicitly challenge the traditional gender relations, for instance, they were organised so that women could keep on taking on their traditional household duties. The entrepreneurial activities did not challenge the control that men have officially on land use. Women did not officially call for an increased public role, which is traditionally the prerogative of men. These findings

correspond well to many studies on the impact of WPOs in a patriarchal environment, which identified changes in income, in autonomy in decision-making but which generally reported no changes relative to the inequality of the control of resources, of the distribution of care tasks (Castiblanco-Moreno and Pineda Duque, 2022; Ugur-Cinar *et al.*, 2022).

Yet, in order to undertake the entrepreneurial activities of the WADG, women travelled on their own, and more generally obtained a more autonomous role in public spaces. Some social norms concerning the role of women changed but this change was not claimed by the women as an objective in itself. It was taking place beneath the surface of official traditional norms. Still, this transformation was limited and many “walls” remained untouched. Thus promoting female entrepreneurship should not be viewed as sufficient to challenge the entrenched patriarchal norms that operate at a broader societal scale (Murray Li, 2007). As already noted by Mayoux (1995), while WPOs are a promising development tool, supporting their growth alone is unlikely to bring about widespread empowerment unless accompanied by initiatives that enhance women’s economic capacities along with deeper interventions aimed at transforming social norms.

Providing more effective support to WADGs requires acknowledging the diversity of profiles among their members in terms of the differing expectations and life projects, especially depending on their age, marital status, and level of formal education. This calls for a tailored approach that addresses the specific needs of each group. For example, younger women may benefit most from training in entrepreneurship, innovation, and digital tools, as well as targeted assistance—such as access to credit—to help them launch their own initiatives in partnership with the WADG. Married women might prefer support for activities that offer flexible schedules, allowing them to better balance work with their household responsibilities. Meanwhile, elder women could receive support to enhance the packaging and marketing of products that leverage their traditional skills, particularly in crafts and food processing.

6. Conclusion

At international level, SHGs addressing a broad range of issues—such as social development, health, credit, and savings—have been widely promoted. In rural areas of Tunisia, limited efforts have been made to promote SHGs across these diverse topics. Rather, Tunisian development actors have promoted one main form of women’s groups: WPOs focused on creating collective businesses. The underlying planned empowerment pathway is as follows: WPOs are groups in which women work collectively, share income, and then bring their individual shares back to their households, thereby driving change at individual and family level. In practice, the empowerment pathway in the three studied WADGs is quite different. Although the economic benefits observed remain limited compared to alternative sources of income, participation in WPOs is associated with significant social and psychological changes. WPOs appear to function as platforms for capacity-building, the strengthening of social networks, and enhanced self-confidence. Thanks to these wide-ranging roles, WPOs appear valuable even for women who had already individual income-generating activities, but also for many women who made use of their participation in WPOs to establish their own individual businesses. This complexity highlights the challenge of defining a straightforward causal pathway triggered by the creation of a WPO. Rather than a linear process, WPOs allow women to discover new opportunities, envision different futures for themselves, and take concrete steps towards turning opportunities into projects.

The study provides in-depth insights into the social and economic changes that took place within three WADGs in Siliana Governorate. However, these three WADGs do not cover the diversity of WADGs in this governorate, and much less at national level. Patriarchal norms, resource availability, and women’s engagement into entrepreneurial activities may differ in other rural regions of Tunisia or even North Africa. Therefore, the pathways to empowerment and the balance between economic and

social outcomes observed in this study may not fully reflect experiences in other settings. Future research involving a larger number of groups and more diverse contexts could help validate and extend the patterns identified here, while building on the contributions of this study.

The study also underlines that women often combine collective group activities with individual business initiatives. One crucial role of the WADGs is fostering connections—not only among their own members but also between members and external actors who provide training, equipment, marketing support, and links with other groups. These connections can be sized by women for both collective and individual trajectories. In Tunisia, WADGs currently perform a role to support women's empowerment imperfectly due to limited resources and the inherent difficulties of sustaining collective action. Yet, WADGs provide numerous “windows of opportunity” in rural areas that are strongly shaped by patriarchal norms and where such opportunities were previously rare if not non-existent. As such, they play a valuable and meaningful role in advancing the empowerment of rural women in Tunisia.

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Shifting axis in global olive oil trade: A comparative RCA and CMS analysis of Mediterranean vs. New World producers

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Abstract

This study analyzes export specialization and market-share dynamics among ten selected olive oil exporting countries during 2005-2023 using the Revealed Comparative Advantage (RCA) index and Constant Market Share (CMS) analysis. Drawing on ITC Trade Map data for HS 1509, it compares six Mediterranean producers with four New World exporters. To capture changes over time, the CMS decomposition is applied across five successive three-year transition windows. The results reveal a clear divergence between structural specialization and market-share performance. Tunisia records the highest specialization in the sample ($RCA = 75.67$) but a negative overall CMS residual share (-36.5%). By contrast, Portugal shows the most sustained improvement, with RCA rising from 6.50 to 18.02 and about 89.0% of export growth associated with positive residual gains. Chile emerges as the most dynamic New World producer, increasing its RCA from 0.15 to 1.01 and reaching a CMS residual share of 97.9%. Overall, the findings show that high export specialization does not automatically translate into sustained market-share gains.

Keywords: Olive oil trade, Revealed comparative advantage, Constant market share analysis, Mediterranean producers, New World exporters, Export competitiveness.

1. Introduction

Olive oil is one of the most characteristic agricultural products of the Mediterranean Basin, with a production culture spanning millennia, and has historically played a central role in shaping regional identity, dietary culture, and trade networks. In the early 2000s, countries of the Mediterranean Basin accounted for about 95% of world production and 85% of world

consumption (Mili, 2006). Over the last two decades, however, climate change, rising production costs, and the liberalization of global agri-food trade have progressively reshaped this traditional framework (Leal Filho et al., 2026).

In the post-2000 period, producers referred to as the ‘New World’ such as Chile, Argentina, Australia, and the United States have emerged as alternative supply hubs to traditional Mediterranean producers. By adopting modern Su-

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per High Density (SHD) planting systems, these countries have established a production structure characterized by high efficiency and reduced labor dependency through large-scale mechanization. Furthermore, Southern Hemisphere producers within this group have leveraged the counter-seasonality advantage to optimize market timing (Mili and Zúñiga, 2001; Vilar and Pereira, 2018). Consequently, global competition parameters have expanded from a mere focus on volume toward dimensions of cost-effectiveness, export specialization, and market share dynamism.

The academic literature on olive oil trade competitiveness has evolved considerably since the early 2000s. Mili (2006) provided a foundational analysis of the international market structure, highlighting the oligopolistic nature of the retail and distribution sector and the growing role of private-label products in reshaping trade flows. Türkekel *et al.* (2010) applied RCA indices to Mediterranean producers, documenting the persistent dominance of traditional exporters during the pre-2010 period but noting early signs of competitive divergence among them. More recently, Kashiwagi *et al.* (2020) employed a gravity model to demonstrate the increasing prominence of intra-industry trade within the EU, particularly Italy's extensive import-processing-reexport activity, while Nilsson *et al.* (2007) provided a broader comparative framework for assessing Mediterranean agricultural export competitiveness. Pehlivanoglu *et al.* (2021) used panel data analysis to identify factors affecting olive oil export competition across selected countries, finding that production volume, exchange rates, and agricultural value added were significant determinants. Mavrommati *et al.* (2024) extended this econometric perspective by analyzing leading producers' export competitiveness through gravity and panel approaches, though their sample was limited to major Mediterranean countries.

A parallel strand of country-specific research has examined the competitiveness trajectories of individual producers. Arfaoui *et al.* (2022) analyzed Tunisia's export performance within the context of shifting world demand, finding that despite strong specialization, the country's

dependence on a limited number of destination markets rendered its exports vulnerable to demand-side shocks. Sönmüş and Aslan (2021) measured Türkiye's comparative advantage in olive oil, reporting gains relative to certain competitors but noting the constraining effect of production volatility. In the New World context, Boza *et al.* (2023) compared Spain and Chile through the lens of governance and sustainable practices, concluding that Chile's export-oriented institutional framework provided structural advantages, while Guevara *et al.* (2023) mapped the commercial positioning of Latin American producers without directly comparing them to Mediterranean counterparts. Klonaris and Agiangkatzoglou (2018) demonstrated that Greek extra virgin olive oil maintained a quality-based competitive position in key European markets. Meanwhile, the structural transformation of production systems has emerged as a critical theme: the rapid expansion of SHD orchards in Portugal and Chile has fundamentally altered cost structures and yield levels (Vilar and Pereira, 2018), while climate change has been increasingly recognized as a structural risk factor for olive-producing regions, with projections of greater yield variability and production threats across the Mediterranean basin (Fraga *et al.*, 2021; Brito *et al.*, 2019; Kaniewski *et al.*, 2023).

Despite this growing body of work, three significant gaps persist in the literature. First, existing studies predominantly evaluate export performance through either static specialization indices (RCA) or dynamic market share decompositions (CMS) in isolation, without jointly examining how changes in specialization relate to competitive dynamics over time. Second, the few CMS applications in this domain most notably Türkekel *et al.* (2010) relied on single-period endpoint comparisons based on narrow pre-2008 timeframes, thereby missing both the post-2010 emergence of New World competitors and the period-specific volatility that a multi-window decomposition would reveal. Third, no study to date has provided a systematic Mediterranean–New World comparative framework that simultaneously incorporates both RCA-based specialization

trajectories and temporally disaggregated CMS residuals across the full range of established and emerging producers.

This study aims to fill these gaps by providing a holistic comparative analysis of the Mediterranean and New World producers over a nearly two-decade period (2005-2023). Utilizing the Revealed Comparative Advantage (RCA) index to measure structural specialization and the Constant Market Share (CMS) analysis to decompose export growth into “world demand” and “competitiveness” effects, this research seeks to reveal the strategic divergence between the aggressive market entry of New World producers and the market defense strategies of traditional Mediterranean powers.

2. Methodology

In this study, quantitative research methods were employed to comparatively analyze the competitive structures and market dynamics of Mediterranean and New World producers in the global olive oil trade. The methodological framework of the research consists of three stages: the creation of the dataset, the determination of the scope, and the calculation of quantitative trade performance indicators.

2.1. Data Source and Scope

The primary data source for this research is the TradeMap database provided by the International Trade Centre (ITC). The analysis period is defined as 2005-2023 (19 years) to encompass structural changes in the olive oil sector and recent market fluctuations. The product coverage is restricted to the Harmonized System (HS) code 1509 (Olive oil and its fractions), which is the standard classification for international olive oil trade.

Product Classification: In this study, export data under the code “1509 - Olive oil and its fractions” according to the Harmonized System (HS) classification were utilized. Since this code encompasses both virgin and refined olive oil categories, it possesses the capacity to represent the total trade volume of the sector (Guevara *et al.*, 2023).

Country Sample: The study focuses on two main producer blocs that collectively represented approximately 93% of global olive oil exports during the study period (ITC Trade Map, 2024).

Mediterranean Group (Traditional Producers): Spain, Italy, Greece, Tunisia, Türkiye, and Portugal.

New World Group (Emerging Producers): Argentina, Chile, the United States, and Australia.

Data Standardization: To ensure consistency in cross-country comparisons, export values were utilized in terms of United States Dollars (USD). Furthermore, the “Total Agricultural Exports” data used as the denominator in the RCA analysis were retrieved based on the aggregate of “HS 01-24: Food and Agricultural Products”. This standardization facilitates a uniform analytical framework for evaluating the relative specialization of each country within the broader agricultural sector.

2.2. Methods of Analysis

To measure the international competitiveness and market performance of the countries, two fundamental indices widely accepted in the literature were employed: Revealed Comparative Advantage (RCA) and Constant Market Share (CMS) Analysis.

2.2.1. Revealed Comparative Advantage (RCA) Index

To measure country level export specialization in olive oil, the export-based RCA index proposed by Balassa (1965) was employed. In order to reduce denominator bias for diversified economies with very large merchandise export baskets (e.g. the USA and Australia), total agricultural exports (HS 01-24) were used in the denominator instead of total merchandise exports, following the sectoral adjustment approach suggested by Nilsson *et al.* (2007). Accordingly, the RCA was calculated as:

The formula used is as follows:

$$RCA_{ij} = \frac{X_{ij}/X_{it}}{X_{wj}/X_{wt}}$$

RCA_{ij} : the revealed comparative advantage of country i in product j (olive oil),

X_{ij} : the export value of olive oil (HS 1509) of country i (USD),

X_{it} : the total agricultural export value of country i (HS 01–24),

X_{wj} : total world exports of olive oil,

X_{wt} : total world agricultural export value.

Countries with an index value greater than 1 ($RCA > 1$) are considered to exhibit a revealed export specialization in olive oil above the world average.

2.2.2. Constant Market Share (CMS) Analysis

To reduce annual fluctuations arising from the alternate-bearing (“on”/“off” year) cycle in olive production, the CMS analysis was based on three-year averages rather than single-year observations (Türkekul *et al.*, 2010). The decomposition was then implemented across five successive three-year transition windows T1 (2005/07→2008/10), T2 (2008/10→2011/13), T3 (2011/13→2014/16), T4 (2014/16→2017/19), and T5 (2017/19→2020/22) together with an overall comparison between 2005/07 and 2020/22, reported for summary purposes. While the RCA analysis covers annual data through 2023, the CMS decomposition based on three-year averages extends through the 2020/22 window due to the averaging structure.

The mathematical representation of the model applied in this study is presented in Equation (2):

$$\Delta X_j = (X_j^1 - X_j^0) = (r \cdot X_j^0) + [(X_j^1 - X_j^0) - (r \cdot X_j^0)] \quad (2)$$

The two main components included in the equation are defined as follows:

$(r \cdot X_j^0)$: World Growth Effect. It represents the hypothetical increase in exports that would arise solely from the growth in world demand, assuming that the country’s market share remains constant.

$[(X_j^1 - X_j^0) - (r \cdot X_j^0)]$: Competitiveness Effect. It is defined as the difference between the actual increase in exports and the world growth effect.

ΔX_j : The absolute change in country j ’s total exports,

X_j^0 : Initial-period exports,

X_j^1 : Final-period exports,

r : World growth rate.

Since the analysis focuses on a single product group (HS 1509) and utilizes aggregate world export data rather than destination-specific bilateral trade flows, the CMS decomposition is implemented in its two-component form, distinguishing only between the ‘World Growth Effect’ and the ‘Competitiveness Effect’ (Leamer and Stern, 1970).

3. Results

In this section, in light of the data covering the 2005–2023 period, the competitive structures of Mediterranean and New World countries in olive oil exports are presented through the dimensions of static specialization (RCA) and dynamic market share changes (CMS).

3.1. Changes in Specialization Levels: RCA Analysis Results

To reveal the comparative advantages of countries in olive oil exports and the evolution of these advantages over time, the analysis period was divided into three sub-periods: 2005–2010, 2011–2016, and 2017–2023. The periodic average RCA values obtained from the analysis are presented in Table 1.

Table 1 reports period-average RCA values as an export-based indicator of revealed export specialization ($RCA > 1$), rather than direct competitiveness. Across all subperiods, Mediterranean producers consistently remain above the specialization threshold, pointing to a persistent concentration of olive oil within their agricultural export baskets relative to the world benchmark. Tunisia stands out as the most specialized exporter in every period; its

Table 1 - Period-Average RCA Values and P1–P3 Percentage Change by Country.

Country	Period 1 Avg (2005–2010)	Period 2 Avg (2011–2016)	Period 3 Avg (2017–2023)	Change (P1→P3, %)	Export specialization class (RCA-based)
Tunisia	61.68	60.81	75.67	22.7	Strong specialization
Portugal	6.50	14.09	18.02	177.2	Strong specialization
Greece	13.68	17.98	16.29	19.1	Strong specialization
Spain	11.98	13.77	12.37	3.3	Strong specialization
Italy	7.67	8.20	5.92	-22.8	Strong specialization
Türkiye	2.41	1.32	2.18	-9.5	Medium specialization
Chile	0.15	0.80	1.01	573.3	Weak specialization
Argentina	0.37	0.38	0.58	56.8	No revealed specialization
Australia	0.13	0.10	0.07	-46.2	No revealed specialization
USA	0.03	0.05	0.05	66.7	No revealed specialization

Source: Authors' calculations using ITC Trade Map data. $RCA = (X_{ij}/X_{it})/(X_{wj}/X_{wt})$. RCA indicates revealed export specialization ($RCA > 1$), not direct competitiveness. Export-specialization classes follow a common four-level interpretation (Hinloopen & van Marrewijk, 2001): $0 < RCA \leq 1$ (no), $1 < RCA \leq 2$ (weak), $2 < RCA \leq 4$ (medium), $RCA > 4$ (strong).

2017–2023 average RCA of 75.67 indicates an exceptionally high olive-oil share in Tunisia's agricultural exports compared with the corresponding global share.

Within the Mediterranean bloc, Portugal exhibits the most pronounced strengthening in specialization. Its period-average RCA rises from 6.50 in 2005–2010 to 18.02 in 2017–2023 (+177.2%), placing it above Spain (12.37) and Greece (16.29) in the most recent period in terms of revealed export specialization. Spain and Greece, in turn, maintain consistently high RCA values, reflecting stable and strong specialization patterns across the sample.

Italy shows the opposite direction: its period-average RCA declines from 7.67 to 5.92 (-22.8%), suggesting a relative weakening of olive-oil export specialization within Italy's overall agricultural exports over time. Türkiye follows a non-linear trajectory (2.41→1.32→2.18), ending the sample with a clear position above the $RCA=1$ threshold; the annual RCA value ob-

served in 2023 further signals a recent strengthening, although RCA alone does not identify the underlying drivers of this change.

In the New World group, Chile demonstrates the most notable convergence toward specialization by moving from 0.15 to 1.01, i.e., from below the threshold to a near-threshold level of revealed export specialization. Argentina increases but remains below $RCA=1$ (0.58), while Australia (0.07) and the USA (0.05) continue to exhibit very limited revealed specialization.

3.2. Sources of Export Growth: Findings from the CMS Analysis

The CMS framework decomposes each country's change in olive oil export value (ΔX) into two components: (I) the world growth effect, i.e., the increase that would occur if the country maintained its initial market share while the world market expanded, and (II) a CMS residual (often labelled the "competitiveness

Figure 1 - RCA Evolution of Mediterranean Countries (2005-2023).

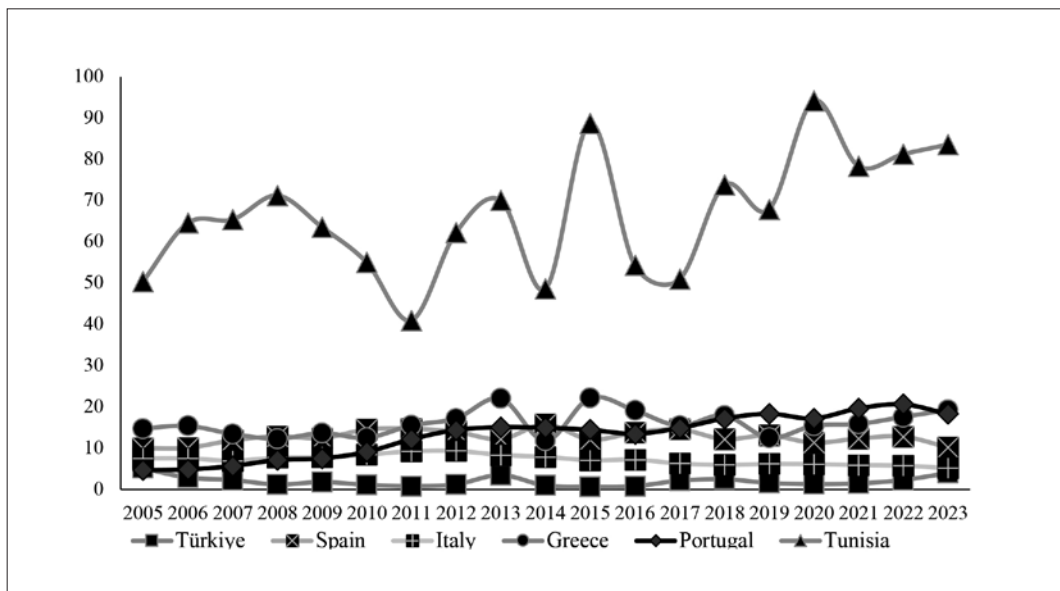
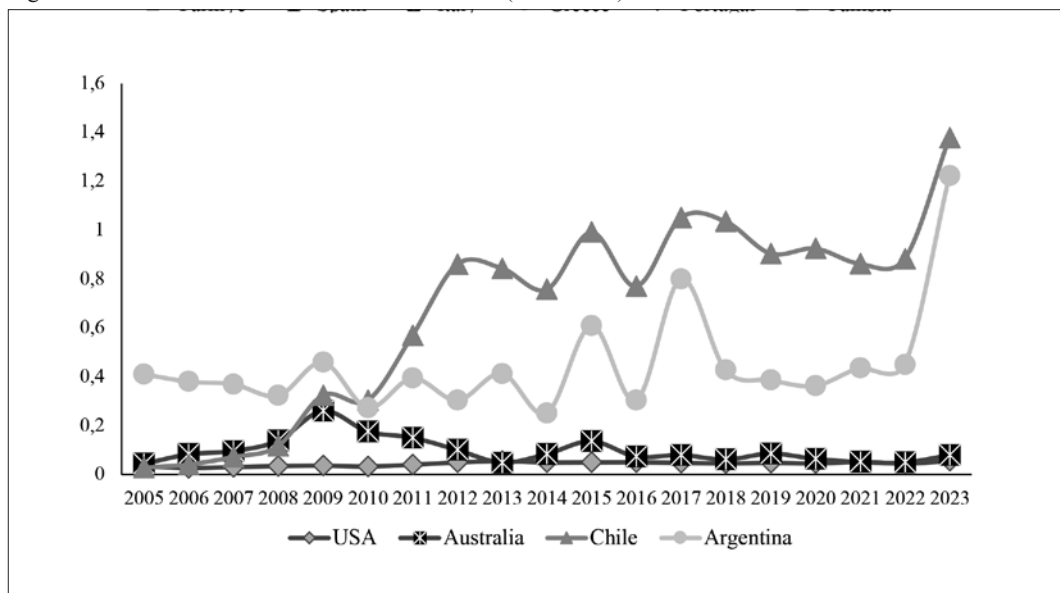


Figure 2 - RCA Evolution of New World Countries (2005-2023).



effect”), which captures the portion of export change not explained by world growth alone. In line with the study’s objective of tracking the evolution of trade dynamics over 2005-2023, the CMS decomposition is implemented using successive three-year

transition windows rather than a single end-point comparison. Specifically, Table 2 reports the residual share for five consecutive transitions based on three-year averages: T1 (2005/07→2008/10), T2 (2008/10→2011/13), T3 (2011/13→2014/16), T4 (2014/16→2017/19),

Table 2 - CMS Residual Share (%) Across Successive Transition Periods.

Country	T1 2005/07→ 2008/10	T2 2008/10→ 2011/13	T3 2011/13→ 2014/16	T4 2014/16→ 2017/19	T5 2017/19→ 2020/22	Overall 2005/07→ 2020/22
World Growth (r, %)	-0.9	10.79	20.8	8.66	10.63	59.42
Chile	100.2	95.4	50.8	68.3	393.1	97.9
Portugal	101.5	86.3	33.6	75.4	60.7	89.0
USA	104.6	79.7	15.9	316.7	8.4	59.1
Spain	108.2	-158.9	36.1	1.6	-284.0	16.8
Greece	94.8	68.1	-27.6	316.9	62.1	-1.6
Tunisia	93.5	189.9	48.5	-592.7	68.1	-36.5
Argentina	82.9	38.3	-162.5	76.2	170.9	-51.6
Italy	39.0	-2.7	-708.9	298.1	-14.9	-256.4
Australia	100.8	132.6	-25.4	143.7	150.4	-980.7
Türkiye	98.6	86.8	143.4	94.8	-13.4	-1424.7

Source: Authors' calculations. Residual Share (%) = CMS residual / Total Export Change $\times$ 100. Values $>100\%$ or $<0\%$ indicate that the residual component either exceeded or moved against the direction of ΔX .

and T5 (2017/19→2020/22). The row “World Growth (r, %)” reports the global market growth rate for each transition. Because the decomposition is conducted in current USD values, the residual component should be interpreted as an indicator of relative export performance that may also reflect unit values and exchange-rate movements; it does not identify causal determinants.

The window-by-window CMS results reveal substantial heterogeneity in the timing and persistence of residual gains and losses across countries. Chile and Portugal display consistently high and positive residual shares across most transitions, suggesting that their export expansion was frequently associated with gains beyond those attributable to world market growth. By contrast, several large Mediterranean exporters exhibit more variable outcomes across windows, indicating that long-run changes were shaped by period-specific conditions rather than a uniform trajectory throughout the sample period. For countries with strongly negative overall residual shares, the results suggest that the residual component often moved against total export change over the full horizon. These magnitudes should be interpreted cautiously, particularly when total export change is small in absolute value.

4. Discussion

The results of this study paint a picture of an olive oil trade landscape in the midst of a fundamental, though uneven, realignment. Over the 2005–2023 period, the competitive structure that had long favoured Mediterranean incumbents has begun to shift, not through a single dramatic rupture but through a series of incremental adjustments that the multi-period CMS decomposition conducted across five successive three-year transition windows brings into sharp relief. While the aggregate patterns are broadly consistent with earlier work on olive oil trade (Türkekul *et al.*, 2010; Arfaoui *et al.*, 2022; Boza *et al.*, 2023), the present analysis extends the literature by offering a holistic Mediterranean-New World comparison and a temporally disaggregated perspective that captures the trajectory, not merely the endpoints, of competitive change.

Before discussing the country-level results, two methodological considerations should be noted. First, since the CMS decomposition is based on current USD values, the competitiveness residual is a composite indicator that captures volume and price effects simultaneously and should not be read as a pure measure of productive efficiency (Ahmadi-Esfahani, 2006).

Second, the RCA index reflects revealed patterns of export specialization but does not directly capture underlying determinants such as production costs, product quality, or the influence of trade policy (Balassa, 1965; Yeats, 1985).

Perhaps the most striking finding concerns the heterogeneity within the Mediterranean Basin itself. Tunisia, despite recording by far the highest RCA values in the sample (P3: 75.67), nevertheless exhibits a negative overall CMS residual share (-36.5%), pointing to a highly specialized but unstable export trajectory. Periods of strong residual gains partly associated with domestic production surges and supply shortfalls in Southern Europe appear to alternate with sharp reversals (Arfaoui *et al.*, 2022). In this sense, Tunisia illustrates a specialization-fragility paradox, in which hyper-specialization coexists with limited market diversification, bulk-export dependence, and vulnerability to external shocks. Portugal, by contrast, represents the clearest case of sustained strengthening. Its RCA increased by 177.2% over the study period, and the CMS results associate 89.0% of total export growth with positive residual gains, with favorable values observed across all five transition windows. This trajectory is consistent with the literature on the diffusion of super-high-density and mechanized olive systems in Iberia, as well as with descriptive evidence showing the expansion of large, irrigated, technology-intensive olive farms in Portugal, particularly in Alentejo (Tous, 2011; Vilar and Pereira, 2018; Lo Bianco *et al.*, 2021).

The remaining Mediterranean producers occupy different positions along this spectrum. Spain, the world's largest producer, displays stable but largely stagnant specialization (RCA around 12 across all periods) and an overall positive but modest CMS residual share of 16.8%, despite substantial period-to-period volatility, including a sharply negative outcome in T5. This pattern is broadly consistent with the growing climate-related pressures documented for Mediterranean olive systems (Fraga *et al.*, 2021; Kaniewski *et al.*, 2023). Pehlivanoğlu *et al.* (2021) argue that high domestic consumption may weaken revealed export performance, a view that is not inconsistent with Spain's modest overall residual. Italy presents the most pronounced case of ero-

sion in relative export performance: even after accounting for re-export-related distortions, its overall CMS residual share of -256.4% indicates that export growth fell far short of world demand. This outcome is consistent with the growing relevance of intra-industry trade in Mediterranean olive oil markets, particularly within the EU, where simultaneous import and export flows have become increasingly prominent (Kashiwagi *et al.*, 2020). Greece maintains a relatively resilient, though unspectacular, position with a near-neutral overall residual share (-1.6%) and a stronger reliance on differentiated quality attributes (Klonaris and Agiangkatzoglou, 2018). Türkiye, by contrast, shows a U-shaped RCA trajectory and a reversal of its previously positive residual trend in T5, highlighting the sensitivity of its export performance to production shocks. This vulnerability is reinforced by the sharp decline in 2023/24 output (IOC, 2025) and by the continuing need for stronger institutional capacity in branding, marketing, and value chain development (Sönmüş and Aslan, 2021).

The New World producers, though still marginal in absolute specialization, tell a different story. Chile stands out as the most dynamic entrant: its RCA increased by 573.3%, and the overall CMS residual share of 97.9% indicates that nearly all of its export growth was associated with positive residual gains, with positive values in every transition window. The particularly strong outcome in T5 may be related to Chile's ability to expand exports during a period of tighter Mediterranean supply. More broadly, Chile's trajectory is consistent with the literature describing its emergence as an export-oriented olive oil producer, supported by rapid planted-area expansion, super-intensive production systems, mechanization, and a strong focus on high-quality extra virgin olive oil (Boza *et al.*, 2023; Guevara *et al.*, 2023). Argentina's trajectory is more erratic, with positive residual shares in some periods offset by sharp reversals in others, while the United States and Australia remain weakly specialized exporters, with RCA values far below unity.

Taken together, these country-level findings point to what is perhaps the central insight of the study: the disjunction between export speciali-

zation and dynamic export performance. Tunisia and Portugal occupy opposite ends of this spectrum: the former is highly specialized yet competitively fragile, whereas the latter combines rising specialization with consistently positive residual gains. Chile and Spain offer a parallel contrast among low and high RCA exporters, respectively. This pattern is consistent with the broader literature suggesting that export specialization and competitive dynamism are not identical and may reflect partly different underlying mechanisms. While specialization tends to capture longer-term structural features of sectors and economies, dynamic export performance is more sensitive to technological change, market conditions, policy environments, and other non-price factors (Latruffe, 2010; Bojnec and Fertő, 2012). In this respect, the consistently positive residual trajectories observed for Portugal and Chile are broadly consistent with the literature on structural transformation, technological upgrading, and the spread of intensive and super-high-density production systems, whereas the more volatile or negative trajectories of Tunisia, Spain, and Türkiye align with recurrent challenges related to climate exposure, market concentration, and incomplete value-chain upgrading (Tous, 2011; Vilar and Pereira, 2018; Lo Bianco *et al.*, 2021; Boza *et al.*, 2023; Guevara *et al.*, 2023).

The global context adds further complexity. The world olive oil market expanded substantially over the study period, with the cumulative world growth component in the CMS framework reaching 59.4%. The global olive oil market was valued at approximately USD 23.2 billion in 2023 and is projected to grow at a CAGR of 5.2% through 2030 (Grand View Research, 2024). Yet the sustainability of this growth is increasingly threatened by climate change. Mediterranean orchards face rising temperatures and water scarcity (Brito *et al.*, 2019; Fraga *et al.*, 2021), and world olive oil production declined from 2.76 million tonnes in 2022/23 to 2.56 million tonnes in 2023/24 (IOC, 2024). The negative CMS residual shares recorded by Spain, Türkiye, and Tunisia in T5 may partly reflect this asymmetric climate shock. Conversely, the positive residual trajectories of countries invest-

ing in modernized production systems (Portugal, Chile) suggest that capital-intensive approaches may offer a degree of resilience, although the rapid expansion of super-high-density systems also raises concerns regarding water demand, biodiversity, and cultivar concentration (Fraga *et al.*, 2021; Lo Bianco *et al.*, 2021).

These findings carry differentiated policy implications. For mature Mediterranean producers, sustaining export performance will likely require continued investment in quality upgrading, agricultural modernization, and production stability, while managing the constraints associated with strong domestic consumption and pricing pressures (Mavrommati *et al.*, 2024; Pehlivanoglu *et al.*, 2021). For Türkiye, the positive CMS residual shares observed in T1–T4 point to latent competitive potential, but the T5 reversal underscores the urgency of climate adaptation together with stronger branding, marketing, and broader value-chain upgrading. For New World producers, the results are consistent with the effectiveness of export-oriented strategies, technological upgrading, and supportive governance structures, particularly in Chile (Boza *et al.*, 2023; Guevara *et al.*, 2023). Across all producer groups, adaptation to climate change emerges as a common policy priority.

Several limitations should temper the conclusions drawn here. The RCA index captures revealed export specialization rather than product quality, unit-value heterogeneity, or other non-price dimensions of export performance. Moreover, like other trade-based specialization measures, it may be affected by policy distortions and preferential trade arrangements (Yeats, 1985; De Benedictis and Tamberi, 2004). The CMS decomposition, applied in its two-component form to a single commodity, does not permit further disaggregation into product-composition or market-distribution effects of the kind that bilateral trade-flow data would allow. Since all values are denominated in current USD, the CMS residual incorporates price movements, exchange-rate fluctuations, and inflation that cannot be separated from volume changes without complementary constant-price analysis (Ahmadi-Esfahani, 2006). Future research could address these limitations through quality-adjusted unit-value anal-

ysis, bilateral CMS decompositions incorporating destination-market effects, and panel-data models integrating climate variables, policy indicators, and complementary trade measures such as the Grubel Lloyd or Lafay indices.

5. Conclusion

This study examined the evolution of export specialization and market-share dynamics in the global olive oil trade between 2005 and 2023 by combining the Revealed Comparative Advantage (RCA) index with a Constant Market Share (CMS) decomposition framework for a selected panel of ten exporting countries. The findings reveal a clear divergence between structural specialization and dynamic export performance. Among Mediterranean producers, Portugal represents the most notable structural transformation, increasing its RCA from 6.50 to 18.02 (+177.2%), while approximately 89% of its export growth is associated with positive competitiveness effects. In contrast, Tunisia, despite recording the highest specialization level in the sample (RCA=75.67), exhibits a negative competitiveness contribution (-36.5%), indicating that strong export specialization does not necessarily translate into market-share gains. Spain, although remaining the dominant exporter in absolute terms, displays relatively limited competitiveness gains, while Italy shows a gradual decline in export performance despite maintaining high specialization levels. Among New World producers, Chile emerges as the most dynamic competitor, increasing its RCA from 0.15 to 1.01 and achieving a competitiveness contribution of 97.9% of total export growth. Overall, the results highlight a specialization-competitiveness paradox in the olive oil sector, suggesting that long-term export success increasingly depends on technological modernization, production-system transformation and strategic market diversification, rather than on inherited comparative advantages alone. From a policy perspective, the findings imply that Mediterranean producers need to strengthen innovation capacity, value-chain upgrading and climate adaptation strategies, while emerging producers may consolidate

their competitive gains through export-oriented institutional frameworks and continued investment in modern production systems.

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Green management and innovative strategies for sustainable business development

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Abstract

This study analyses green management and its role in shaping innovative strategies aimed at fostering sustainable enterprise development. The research applies methods of analysis and synthesis of scientific literature, a comparative approach, and a systems perspective, combined with an analytical review of selected corporate sustainability practices. Theoretical and practical aspects of environmental management are examined, alongside an evaluation of the impact of eco-innovations on business performance. The paper also synthesises the experiences of leading global companies in implementing sustainable development strategies, reinforcing the relevance of transitioning towards environmentally focused business models. The results indicate that integrating green initiatives with innovation-oriented strategies can strengthen economic performance, enhance corporate reputation, and improve long-term competitiveness. The implementation of eco-innovations contributes to the optimisation of production processes, reduction of carbon emissions, and improvement in energy efficiency. These findings highlight practical implications for enterprises seeking to integrate environmental responsibility into strategic management, while also demonstrating broader societal benefits related to resource efficiency, emission reduction, and sustainable economic development.

Keywords: *Costs, Production processes, Environmental challenges, Eco-innovation, Competitiveness.*

1. Introduction

Global trends such as climate change, the depletion of natural resources, and increasing environmental regulations are reshaping the operational landscape for businesses. Enterprises that fail to adapt to these shifts risk losing their competitive edge. In response to these challeng-

es, a new management approach has emerged, one that emphasises sustainable development through the integration of environmentally oriented solutions into business operations. Green management is no longer merely an ethical expectation of modern society; it is also a substantial factor in the formulation of innovative growth strategies.

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Implementing green management enables companies to transition towards sustainable business models that combine economic efficiency with environmental responsibility. Within this transformation, innovative approaches play a decisive role by creating new opportunities for optimising production processes, reducing carbon footprints, adopting energy-efficient technologies, and advancing towards a circular economy. Such strategies are vital for ensuring business development. They contribute to enhancing competitiveness, streamlining production with reduced environmental impact, and shaping a positive image of a responsible enterprise.

Theoretical, methodological, and practical aspects of green management, including its conceptual foundations and potential integration pathways into business strategy, were examined by Bukreeva *et al.* (2023). The fundamentals of green business and the factors influencing its development in Ukraine and globally amidst intensifying economic, environmental, social, energy, and humanitarian crises were explored by Rosokhatska *et al.* (2022).

Dewi *et al.* (2024) identified strategic priorities for the advancement of green management and proposed innovative approaches to support enterprise development within the framework of a green economy, aiming to ensure sustainable societal progress. Wang *et al.* (2024) highlighted the importance of a comprehensive approach to green management, incorporating innovative development strategies. The study by Tran (2023) emphasised the necessity of a holistic strategy for the effective implementation of green management, encompassing technological innovation, stakeholder engagement, corporate responsibility, and transparent reporting. Al Karim *et al.* (2023) underscored the importance of an integrated approach that not only includes technological advancements but also social responsibility, stakeholder participation, and support from public policy. Successful implementation of such strategies contributes to sustainable business development and improved economic and environmental outcomes.

The study by Naseer *et al.* (2023) reinforced the notion that the success of green management

depends on an integrated strategy involving innovation, strategic leadership, social responsibility, and active stakeholder engagement. Liu and Zhang (2022) stressed the importance of a comprehensive framework for green management, one that encompasses the adoption of eco-friendly technologies and practices, shifts in corporate culture, government support, and proactive collaboration with stakeholders.

The study by Novitasari and Agustia (2021) emphasised the importance of implementing green management as a key element for ensuring the sustainable development of enterprises. Riaz *et al.* (2024) examined how green human resource management influences corporate sustainability performance.

Thus, the relevance of the subject under examination is strongly supported by numerous studies. The studies consistently highlight the importance of integrating ecological practices into business strategies, introducing innovative technologies to reduce environmental harm, and advancing corporate social responsibility. Enterprises that actively engage in green management gain economic advantages, enhancing both their competitiveness and market reputation. These findings confirm that sustainable development through environmentally oriented strategies is essential for the successful and long-term functioning of businesses.

Given the relevance of these challenges, the objective of this study is to analyse the role of green management in shaping innovative strategies for sustainable enterprise development. To achieve this objective, the study addresses several tasks:

- to systematise existing theoretical approaches to green management;
- to examine the role of eco-innovations and sustainable practices in contemporary business strategies;
- to synthesise the experience of leading companies in implementing environmentally oriented development strategies.

2. Materials and Methods

This study is based on a comprehensive approach to examining green management and in-

novative strategies for enterprise sustainability, conducted over the period 2022-2024, which was selected to capture recent developments in green management practices and eco-innovation strategies discussed in contemporary academic literature and corporate sustainability reports. Analytical and synthetic methods were applied to the scientific literature to generalise the theoretical foundations of green management. The analysis focused primarily on recent peer-reviewed publications and reports addressing green management, eco-innovation, sustainable supply chains, and corporate environmental strategies. A comparative method was also employed to identify differences in sustainability approaches depending on enterprise scale and regional characteristics.

The initial stage involved identifying the main concepts, approaches, and methods used in the field of sustainable enterprise development based on recent studies on green management, eco-innovation, and sustainable corporate governance (Liu and Zhang, 2022; Al Karim *et al.*, 2023; Wang *et al.*, 2024). The subsequent analysis focused on the theoretical basis of green management, particularly its core principles, including ecological efficiency, energy conservation, waste recycling, and the use of renewable energy sources. The role of innovation in supporting sustainable development was examined in detail.

Further stages involved the examination of innovative strategies contributing to sustainability, including technological innovations, new approaches to resource management, and strategic planning. Based on the analysis of theoretical and methodological aspects of green management and innovative strategies, a synthesis of the key findings was conducted. This involved formulating recommendations for enterprises on the implementation of effective innovation strategies for sustainability and identifying the critical success factors. Within this approach, environmental, economic, and social dimensions of enterprise activity were analysed jointly in order to assess the broader effects of green initiatives on organisational performance and sustainability outcomes.

The study also employed methods of analytical review and data synthesis from various

sources, which allowed identifying trends in the development of green management at both global and local levels including sustainable supply chains, resource efficiency practices, and corporate environmental reporting. Alongside theoretical analysis, attention was directed towards examining the influence of new innovative strategies on business processes and the environmental performance of enterprises.

Case analysis was conducted on selected enterprises to assess the practical effectiveness of innovative strategies. The companies included in the analysis were selected because they represent widely cited international examples of corporate sustainability practices and provide publicly available sustainability reports describing the implementation of green innovations. The study examined the example of Amazon (2024), which set an ambitious target of achieving net-zero carbon emissions by 2040. The company is also actively investing in the development of renewable energy sources, demonstrating its commitment to environmental sustainability and climate action.

The experience of Kering (2023) was also analysed; the company is pursuing a sustainability strategy focused on reducing greenhouse gas emissions, enhancing environmental responsibility within its supply chains, and supporting eco-innovations in the fashion industry. City Developments Limited (2023) places considerable emphasis on environmental strategy in the real estate sector by implementing energy-efficient solutions, green building certification, and long-term decarbonisation plans to foster sustainable urban environments.

The study further considers Microsoft's (2024) approach, with the company committing to becoming carbon negative by 2030 and to removing all historical emissions since its founding in 1975 by 2050. Microsoft is investing in artificial intelligence and digital tools to monitor and reduce climate impact. L'Oréal (2022) is implementing its "L'Oréal for the Future" strategy, aiming to reduce the carbon footprint of its factories and distribution centres by 100% by the end of 2025. The company is investing in clean technologies and developing products with minimal environmental impact.

The analysis of green innovations adopted by the companies discussed in the study allowed identifying key trends in environmental management, evaluating the effectiveness of applied technologies, and outlining prospects for sustainable enterprise development. These companies were selected as illustrative case studies because they represent different economic sectors and publish detailed sustainability reports describing the implementation of green innovation strategies.

3. Results

The contemporary world is undergoing drastic changes related to environmental challenges that threaten the sustainability of economic, social, and environmental systems. In this context, green management has become a key component of enterprise governance for businesses seeking to combine economic efficiency with environmental stewardship. The implementation of innovative strategies aligned with sustainable development lays the foundation for the emergence of new competitive advantages and long-term business resilience.

Green management is founded on the principles of ecological responsibility, energy efficiency, prudent resource use, and the adoption of environmentally safe technologies. This approach integrates environmental criteria across all levels of enterprise operations, from strategic planning to day-to-day activities. It emphasises the inclusion of ecological principles within enterprise management strategies to support sustainable development. This includes the efficient use of natural resources, the minimisation of environmental harm, and the improvement of production processes through innovative technologies and management methods. The primary aim of green management is to establish harmony among the economic, social, and environmental dimensions of corporate activity. The concept places emphasis on the adoption of innovative strategies. Environmental innovation encompasses the development of new products and processes designed to minimise negative environmental impacts. Digitalisation of business processes plays an equally important role, ena-

bling more efficient resource management and reducing ecological strain.

Green management is gradually gaining precedence over conventional economic models. It addresses contemporary challenges by demanding a balanced integration of economic growth and environmental responsibility. Conventional economic models, with their focus on continuous expansion and profit maximisation, often lead to overexploitation of natural resources and environmental degradation. This undermines sustainable development and endangers both planetary health and the well-being of future generations.

In contrast, green management calls for a paradigm shift, encouraging enterprises to adopt responsible practices regarding resource use and environmental considerations. This approach involves embedding inclusive practices across all areas of enterprise activity, including production, supply chain management, energy efficiency, and the execution of social initiatives. Enterprises adopting green management actively reduce emissions, transition to renewable energy sources, utilise environmentally friendly materials, and seek more rational approaches to resource consumption. The inclusive nature of green management lies in its attention not only to environmental concerns but also to social and economic interests. Business becomes part of a broader ecosystem in which the needs and expectations of employees, customers, suppliers, local communities, and governments are considered. Transparency and accountability play a critical role, with companies publicly reporting their achievements in sustainable development. This fosters trust in the brand and contributes to the growth of an environmentally oriented market.

In the implementation of green management, particular importance is attributed to quantitative indicators that allow for the evaluation of the actual outcomes of environmental initiatives. Such measurements provide compelling evidence in support of business greening and facilitate evaluation of its impact on resource conservation, environmental safety, and the economic performance of enterprises. Table 1 summarises key quantitative indicators of green management effectiveness derived from

Table 1 - Quantitative indicators of effectiveness in the context of green management.

<i>1. Resource savings</i>
1. Energy conservation: According to the International Energy Agency (IEA), the adoption of energy-efficient technologies enables enterprises to reduce electricity consumption by 15-30%. 2. Reduction in water usage: In industrial contexts, the use of water recirculation systems can lower water consumption by up to 50%. 3. Decreased raw material use: Application of circular economy principles may reduce reliance on primary raw materials by 20-40%.
<i>2. Pollution reduction</i>
1. CO₂ emissions reduction: Studies by the European Environment Agency indicate that the adoption of energy-saving solutions can reduce CO₂ emissions by 10-25%. 2. Carbon footprint reduction: Enterprises transitioning to renewable energy sources record reductions in carbon footprints ranging from 20% to 60%. 3. Waste minimisation: In certain sectors, the shift towards closed-loop production reduced solid waste generation by up to 70%.
<i>3. Enterprise performance indicators</i>
1. Operating cost reduction: Certification under International Organization for Standardization (ISO) 14001 standards contributes to a decline in operational costs by 8-20%. 2. Increased consumer loyalty: According to research by Nielsen, 66% of consumers are willing to pay more for products from environmentally responsible brands, driving sales growth by 25-35%.

Source: compiled based on IEA (2022), United Nations Educational, Scientific and Cultural Organisation (UNESCO, 2021), Ellen MacArthur Foundation (2021), European Environment Agency (2022), International Renewable Energy Agency (2021), Kaza et al. (2018), Whelan and Fink (2016), ISO (2023).

international analytical reports and studies on sustainable resource management.

The quantitative data presented demonstrate that green management is not solely a socially responsible strategy but also a financially advantageous model. It enables enterprises to reduce resource-related expenditures, lower environmental risks, improve profitability, and enhance market reputation.

Quantitative evaluation of the outcomes associated with ecological approaches serves as a crucial tool for managerial decision-making and the formulation of long-term sustainability strategies. The growing relevance and proliferation of this concept confirm its effectiveness not only as a practical strategy for businesses but also as an integral element of a global economy striving to balance economic growth with environmental preservation. Green management is thus becoming a prerequisite for enterprises aiming to re-

main competitive in a world increasingly shaped by sustainability and ecological accountability. The development of enterprises through green management tools requires renewed approaches to collaboration among businesses, governments, and society. Establishing environmental standards, introducing incentive-based tax systems, and allocating grants for innovative projects contribute to the wider adoption of sustainable practices. Consumers are becoming more discerning regarding the ecological credentials of products, prompting businesses to prioritise environmentally responsible solutions.

One of the first researchers to highlight the need for integrating environmental considerations into business models was Elkington (2007), who introduced the Triple Bottom Line. This framework proposes evaluating a company's success not only through economic indicators but also by considering its environmen-

tal impact and social responsibility. Building upon this idea, Yavorska (2020) emphasised that green management should not be seen as a collection of isolated environmental measures, but rather as a systematic approach to enterprise governance. This approach entails the strategic integration of ecological factors into all levels of management processes. In a similar vein, Mazraani and Tucci (2025) noted that implementing green management requires a comprehensive mechanism for greening economic activities, involving a range of economic, organisational, and informational tools.

In light of the above, the study presents an original interpretation of green management, developed through analysis of contemporary scientific concepts, synthesis of best practices from leading companies, and reflection on current environmental challenges. Within the context of sustainable enterprise development, green management is defined as a strategic management approach that integrates environmental, economic, and social dimensions into all aspects of a company's operations and de-

cision-making processes. Its aim is to reduce harmful environmental impacts, conserve natural resources, and achieve both economic benefits and social responsibility. This includes the adoption of environmentally friendly technologies, efficient resource use, reduction of harmful emissions, and the promotion of innovations that support sustainable business development and the preservation of natural ecosystems.

The implementation of green management and innovation strategies remains a considerable challenge for many enterprises, particularly small and medium-sized ones, due to limited resources and restricted access to advanced technologies. These obstacles can be addressed through collaboration within strategic partnerships, clusters, and networked structures, which enable knowledge sharing and the dissemination of technological innovations. Enterprise innovation strategies under the green management framework are directed towards building environmentally oriented businesses that minimise ecological impact while ensuring economic viability. Figure 1 illustrates the key innovation

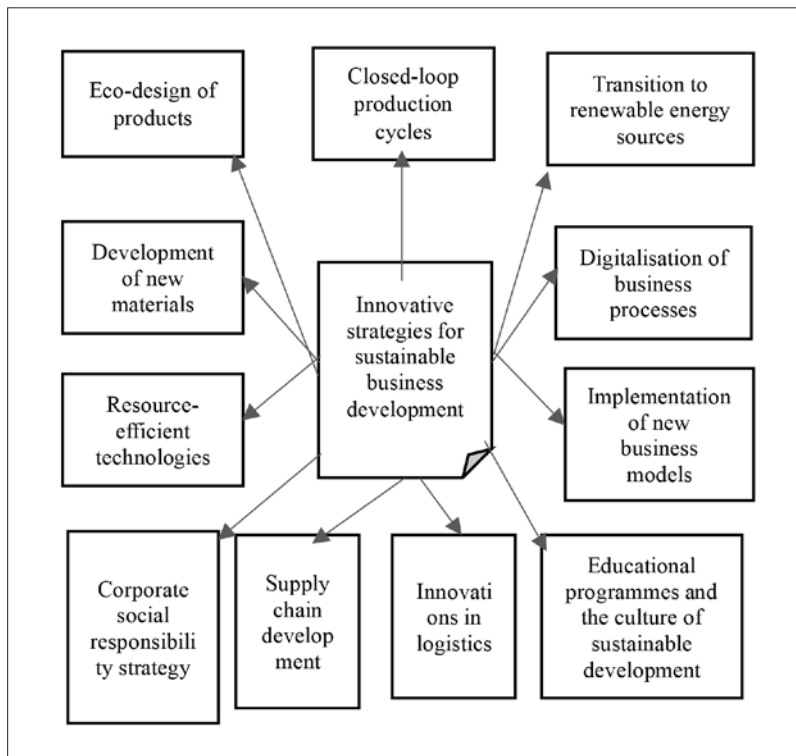


Figure 1 - Innovative strategies for sustainable business development in the framework of green management.

Source: compiled by the authors.

strategies that enterprises may adopt within the sustainable development framework.

Innovative strategies adopted by enterprises within the framework of green management have become a crucial tool for achieving sustainable development and enhancing companies' competitiveness in the modern market. Green management entails the integration of environmental and social factors into business strategies, reducing harmful environmental impacts while improving financial performance.

One of the key innovative strategies involves the implementation of green technologies, including renewable energy sources, energy-efficient production processes, environmentally friendly materials, and waste recycling. These technologies not only reduce pollution levels but also create new opportunities for business growth.

Another noteworthy aspect is the development of a green brand, which includes creating prod-

ucts and services with environmental value that meet the demands of sustainability-conscious consumers. This approach not only attracts new customers but also strengthens trust in the company. Innovative strategies further encompass the integration of sustainable supply chain management, which reduces the negative environmental impact by optimising supply processes and lowering emissions at various stages of production.

Analysis of the results of implementing green innovations by leading global companies, based on their official sustainability reports, is presented in Table 2. The table includes five international enterprises (Amazon, City Developments Limited, Microsoft, Kering, and L'Oréal) selected because their sustainability reports provide detailed and comparable information on the implementation of green innovations across different sectors.

Amazon prioritises renewable energy and electric transport. Its 2022 report highlights

Table 2 - Results of green innovation implementation in leading global companies.

<i>Company</i>	<i>Results of implementing green innovations</i>
Amazon: Ecological transformation of logistics and energy	In its 2022 sustainability report, Amazon announced plans to achieve net-zero carbon emissions by 2040, ten years ahead of the Paris Agreement target. The company invests in renewable energy sources, including wind and solar power plants, and introduces electric delivery vehicles.
City Developments Limited (CDL): Leader in green construction	Singapore-based CDL actively implements green management principles. It was the first in the region to install energy-saving lifts, which reduce energy consumption by up to 50%. In 2009, CDL constructed 11 Tampines Concourse, Asia's first carbon-neutral commercial building. The company also issued green bonds to finance environmental projects.
Microsoft: Comprehensive environmental strategy	In its 2022 report, Microsoft outlined its strategy to achieve carbon neutrality by 2030. The company is implementing carbon, water, and waste management initiatives and invests in ecosystem restoration projects.
Kering: Reducing emissions in the fashion industry	The French luxury group Kering, owner of Gucci and Saint Laurent, achieved a 23% reduction in greenhouse gas emissions in 2024 compared with 2022. The company also invests in renewable energy and the use of sustainable materials in production.
L'Oréal: Energy efficiency in manufacturing	L'Oréal reported achieving 97% use of renewable energy sources across its production sites. The company also implements programmes to reduce water consumption and waste in its manufacturing processes.

Source: compiled based on Hurst (2023), Kering (2023), Smith (2024), IEA (2022), UNESCO (2021).

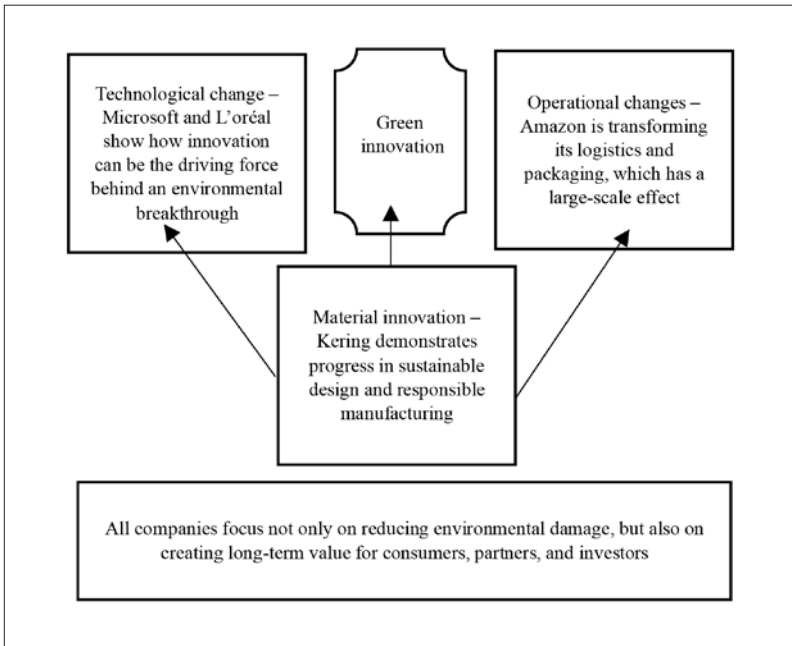


Figure 2 - Analysis of implemented green innovations.

Source: compiled based on Hurst (2023), Kering (2023), Smith (2024), IEA (2022), UNESCO (2021).

progress: 90% of its energy consumption now comes from green sources, and more than 145 million deliveries have already been conducted using electric vehicles. The company also reduced plastic usage by 11.6% through packaging optimisation.

The French fashion group Kering (Gucci, Saint Laurent) demonstrates a long-term commitment to sustainable development. Over several years, the company has reduced emissions by 71% (Scopes 1 and 2), fully transitioned to renewable electricity, and introduced sustainable materials, including Lunaform™ – a vegan and bio-based innovation. Microsoft, in turn, not only outlines but actively implements a comprehensive environmental policy. The company is building water-free cooling data centres, recycling 89% of its technical infrastructure, and significantly reducing plastic packaging. L'Oréal, a leader in the cosmetics industry, focuses on reducing its carbon footprint and investing in water-saving technologies. Through partnerships with startups, the company is developing new solutions for more efficient resource use (Figure 2).

Green innovations have become a strategic necessity. Leading global companies demonstrate that combining technological develop-

ment, environmental awareness, and transparent reporting delivers not only positive impacts on the planet but also sustainable business success. These companies set benchmarks for small and medium-sized businesses, governments, and educational institutions worldwide. The innovative strategies for sustainable business development aim not only to preserve the environment but also to improve economic efficiency and corporate social responsibility. Implementing green management supports the development of resilient businesses capable of adapting to contemporary challenges and ensuring the well-being of future generations.

Integrating innovations into the green management system changes not only the environmental policy of an enterprise but also its overall structure, strategy, and relationships with its environment. Table 3 summarises the key organisational, economic, and strategic outcomes of implementing innovative strategies within green management systems, synthesised from the analysed academic literature and sustainability studies.

Innovations in green management foster a radical transformation of enterprises, making them more resilient, responsible, and competitive. These changes form the foundation for harmo-

Table 3 - Outcomes of innovative strategies in the green management system.

<i>Outcome</i>	<i>Result</i>
Transformation of business models	Innovations encourage enterprises to transition from conventional business models to environmentally oriented ones. This transformation enables more efficient resource use, cost reduction, and the creation of sustainable production systems.
Reduction of environmental impact	Through the adoption of modern technologies, enterprises reduce waste generation, lower water and energy consumption, and minimise greenhouse gas emissions.
Increased investment in research and development	Innovations drive companies to increase investment in research, development, and the implementation of new technologies. This allows enterprises to develop unique, environmentally friendly products and services, enhancing competitiveness.
Changes in cost structure	Implementing innovations may initially require substantial capital investment; however, in the long term, they help reduce operating costs.
Changes in consumer preferences	By adopting innovations, enterprises can shape new consumer expectations regarding the environmental credentials of products and services. This enables businesses to influence consumer behaviour, encouraging the selection of sustainable alternatives.
Long-term economic benefits	Enterprises that actively implement innovations in green management create conditions for long-term economic growth. Cost reduction, enhanced reputation, increased market share, and attracting investors form the foundation for stable development.
Emergence of new market opportunities	Innovations open access to new market segments, such as environmentally conscious consumers or companies seeking suppliers with green certifications. The development of environmentally friendly products can become a competitive advantage.
Stimulation of partnerships and cooperation	Innovative environmental initiatives foster the development of strategic partnerships with other enterprises, universities, and non-governmental organisations. This facilitates the pooling of resources, knowledge, and expertise for implementing effective green management solutions.
Enhanced resilience to global challenges	Innovations enable enterprises to adapt more effectively to changes in the global economy and climate. The use of renewable resources, digital technologies, and adaptive strategies increases business resilience to risks associated with resource scarcity, climate change, and new regulatory requirements.

Source: compiled based on Cahyadi et al. (2023), Chen and Wu (2022), Han et al. (2024), Muisyo and Qin (2021), Xing et al. (2020), Haldorai et al. (2022), Andersen (2023), Nusraningrum et al. (2024), Chawla et al. (2021).

niously combining economic growth with the preservation of natural resources for future generations. The development of eco-innovations within the framework of green management provides significant benefits for sustainable business development, as it enables cost reduction and improved operational efficiency. The introduction of environmentally friendly technologies and the optimisation of resource use help lower energy and raw material costs, which has

a positive effect on a company's financial performance. Eco-innovations also allow enterprises not only to maintain but also to increase their market competitiveness, as an increasing number of consumers choose products and services that meet environmental standards. Businesses therefore gain opportunities to attract new customers, strengthen the loyalty of existing ones, and enhance their reputation as responsible enterprises. Eco-innovation development reduces

environmental risks and facilitates compliance with increasingly stringent environmental standards and regulations. Enterprises are thus able to avoid fines and penalties for breaching environmental norms, ensuring greater long-term stability. An important aspect is also the reduced dependence on limited natural resources, which mitigates the impact of fluctuations in raw material and energy prices on business operations.

Green innovations also enhance the social dimension of enterprise activities, as they often involve the creation of new jobs, improved working conditions, and support for local communities. Enterprises that actively develop eco-innovations can serve as examples for other companies and promote the spread of a culture of sustainable development in society. This has a positive impact on investment attraction, as investors increasingly seek opportunities to finance companies that prioritise sustainable development.

The development of eco-innovations within the framework of green management is becoming a key aspect of sustainable business development through three main components: building “technological” knowledge, supporting business incubators, and reducing investment risks. The first component is investment in technological

knowledge and innovative solutions that enable companies to reduce resource consumption and improve production efficiency (Hoang *et al.*, 2025). The development of technological knowledge supports the continuous adaptation of businesses to new environmental standards, enabling them not only to reduce negative environmental impacts but also to create competitive advantages by introducing renewable energy sources, energy-efficient technologies, and low-carbon materials.

The second important element is the support of business incubators that facilitate the development of start-ups focused on green technologies and innovations. These incubators help entrepreneurs bring new ideas to life by providing resources for the development and launch of eco-innovations. They also serve as platforms for collaboration, knowledge exchange, and access to necessary funding, which is crucial for enterprises seeking to integrate sustainable development into their strategy (Figure 3).

The third component is the reduction of investment risks arising from the uncertainty and high capital intensity associated with the implementation of new environmental technologies. Investors are increasingly paying attention to

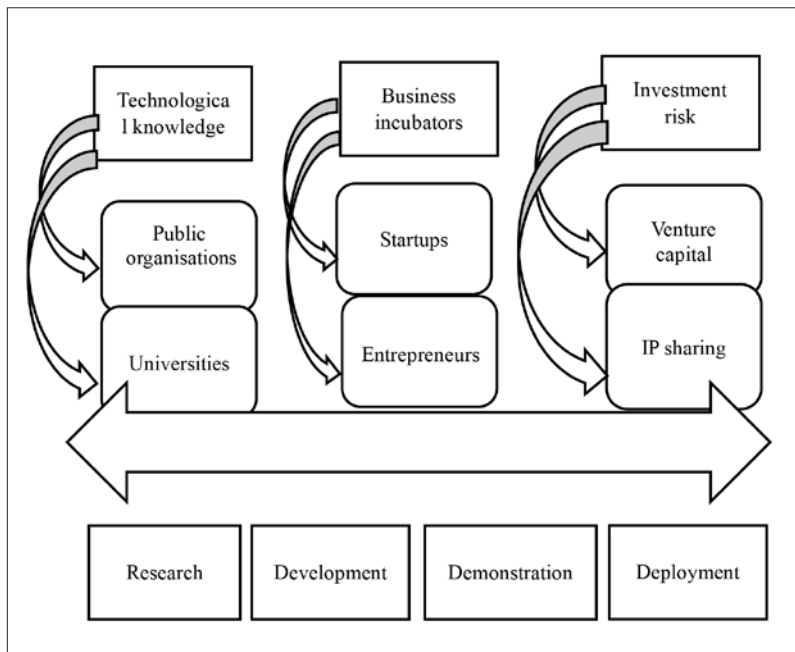


Figure 3 - Key components of eco-innovation development under the green management framework in the enterprise's sustainable development strategy.

Source: compiled by the authors.

the environmental responsibility of enterprises, creating favourable conditions for attracting financing. Reducing investment risks is achieved through clearer and more transparent business models that consider both economic and environmental indicators, along with the involvement of public and private grants that stimulate the development of green technologies. The development of eco-innovations through these three components not only reduces environmental risks and costs for enterprises but also enhances their capacity for innovative growth, creating competitive advantages in the market and lowering barriers to investing in sustainable development. Implementing eco-innovations under the green management framework therefore provides not only financial benefits but also strengthens the social responsibility of businesses, which contributes to long-term stability.

One of the main and most substantial changes expected from enterprises shortly is the introduction of the green supply chain concept. Green supply chains for sustainable enterprise development involve the integration of environmental and social standards at all stages of the production process, from raw material procurement to the disposal of finished products. This approach covers the entire supply and production chain, with a focus on resource conservation, minimising environmental impact, and creating added value for all participants in the process.

The primary goal of green supply chains is the sustainable use of natural resources through the implementation of environmentally friendly technologies at every stage of the process, from production to distribution and disposal. This requires selecting suppliers that adhere to sustainable development principles, using renewable resources, reducing energy consumption, and minimising waste. A promising approach is the introduction of environmental standards in the production and logistics supply of goods.

This study examines the functioning of green supply chains in ensuring sustainable enterprise development, which involves integrating environmental, economic, and social aspects at every stage of the production process. This principle consists of several interrelated elements that enable enterprises to adopt a sustainable

approach to supply chain management, reducing environmental impact, and improving business efficiency (Figure 3).

The indicated elements of green supply chains require regular monitoring and evaluation of the effectiveness of environmental initiatives (Abbas and Khan, 2023). Enterprises must continuously evaluate the impact of their activities on the environment, the economy, and the social sphere. The results of these evaluations should be incorporated into the improvement of processes and the achievement of more efficient resource use. The proposed algorithm creates a stable and interconnected system in which each stage of supply, production, transportation, and product disposal forms part of the overall sustainable development strategy. Green supply chains enable enterprises to reduce their environmental footprint, lower costs, and enhance their competitiveness while ensuring long-term resilience and accountability to society and the environment (Figure 4).

Green chains also guarantee business transparency and social responsibility, as they encompass ethical standards, promote fair working conditions, and support the development of local communities. This approach encourages companies to manage supply chains sustainably, adopt innovative and green technologies, and collaborate with partners who adhere to similar principles.

Green supply chains under the green management framework represent a concept that integrates environmental, social, and economic principles at every stage of the supply chain, from supplier selection to final consumption and product disposal. From the outset, supplier selection must be based not only on the cost or quality of raw materials but also on their environmental policies. Enterprises should choose partners that use renewable resources, work to reduce emissions and energy consumption, and follow ethical labour standards. This approach allows the creation of an environmentally sound foundation for the entire production process.

The next crucial stage is production, which must be oriented towards reducing the negative environmental impact. The adoption of advanced technologies that lower energy and re-

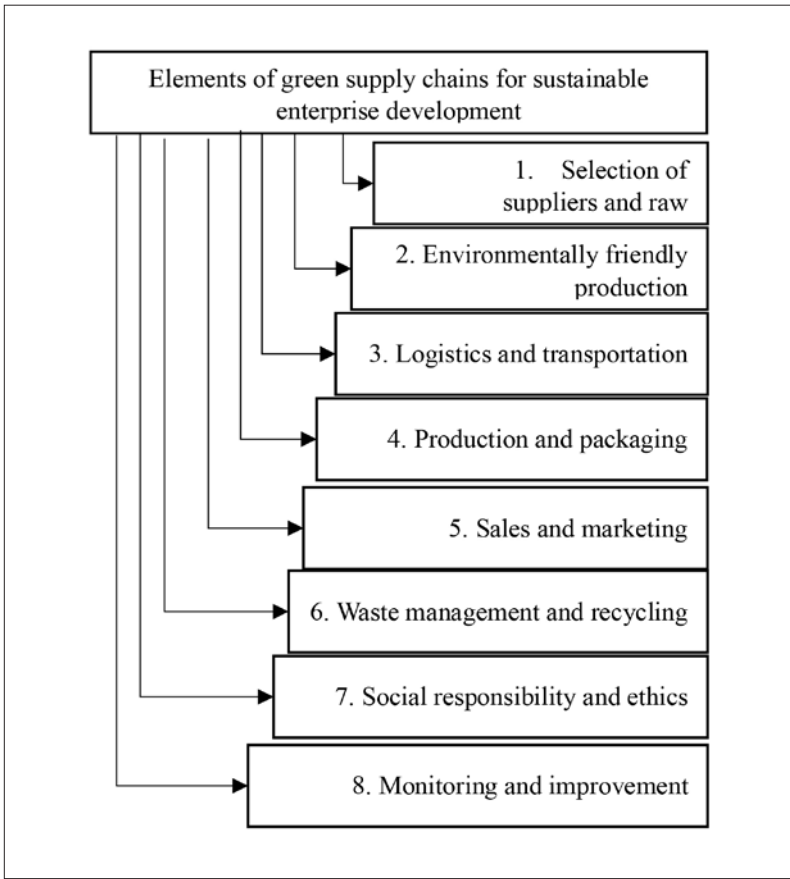


Figure 4 - Elements of green supply chains for sustainable enterprise development.

Source: compiled by the authors.

source consumption and reduce CO₂ emissions is an essential component of this stage (Touil and Babounia, 2022). The use of recyclable materials or those with a low carbon footprint is another critical element of the green supply chain. Logistics must also be eco-oriented: optimisation of transport routes and the use of alternative modes of transport, such as electric or hybrid vehicles, help reduce carbon dioxide emissions. It is vital that the entire transportation process is organised in compliance with environmental standards, ensuring a reduction in negative environmental impacts. Green supply chains cannot be complete without responsible end-of-life product disposal. Enterprises should encourage recycling, reusing materials, and minimising waste. This practice extends the product life cycle and decreases the volume of waste sent to landfill sites. Another important aspect is social responsibility at every stage. Enterprises imple-

menting green supply chains must guarantee fair working conditions, support local communities, and adhere to ethical standards in their relationships with suppliers and consumers, fostering the further development of entrepreneurial initiatives.

Thus, the green supply chain is becoming an innovative business strategy that incorporates a social model of business development. This is a pathway towards creating a sustainable and efficient enterprise that not only meets environmental and social responsibility requirements but also maintains economic benefits. Green supply chains enable businesses to be more competitive, reduce costs, and mitigate risks while contributing to global environmental protection initiatives. Through the development of green supply chains, companies can significantly lower their resource costs while enhancing their competitiveness in a market where environmental and

social aspects are increasingly valued. They also become part of global sustainable development initiatives, creating opportunities for cooperation with other companies and governmental organisations that support environmental initiatives. Thus, green supply chains represent not only a means of reducing negative environmental impacts but also a key factor in ensuring the economic stability and resilience of enterprises in the context of global change.

Based on the results of the study, the importance of green management and the implementation of innovative strategies for the development of business systems can be emphasised. The adoption of environmentally oriented approaches not only reduces harmful impacts on the environment but also strengthens the competitive position of enterprises in modern conditions. The advantages of green management (reduced environmental footprint, resource optimisation, and the creation of a positive corporate image) were identified, along with the key barriers that hinder its implementation (financial, legal, educational, and technological constraints). The study also substantiated the need for a transition from the standard consumption model to the circular economy, which involves multiple and maximally efficient resource use through the application of green supply chains. A considerable component of the study is the emphasis on the role of cross-sectoral cooperation, state support, and the enhancement of environmental awareness as fundamental conditions for the successful implementation of green management in practice.

4. Discussion

In the context of growing environmental threats and the challenges of sustainable development, green management has become increasingly relevant as a strategic path for business transformation. The analysis of contemporary academic literature demonstrates a diversity of approaches to this phenomenon and outlines the research niche addressed by this study. Shulga (2024) defines green intellectual capital as a set of knowledge, skills, and technologies required for the development and implementation of environmentally sustainable business models. This

definition synthesises existing approaches and highlights the importance of ecological orientation within a company's intellectual capital. The study identifies both commonalities and differences between the author's approach and that proposed by the researcher. Specifically, both perspectives emphasise the central role of knowledge and technology in the ecological transformation of business, recognising them as fundamental elements in defining a company's green intellectual capital. However, a key distinction lies in the focus of analysis: while the researcher's work concentrates on the structural components of capital as carriers of environmental knowledge and solutions, the present study focuses on the managerial mechanisms for integrating such knowledge into strategic planning and practical change management towards sustainable development. This approach enables a deeper understanding of how intellectual resources are utilised to implement environmentally oriented strategies.

Theoretical and methodological foundations for the development of innovation strategies, with a focus on their impact on economic competitiveness, are addressed in the study by Padash and Ghatari (2020). Their study proposes a model for evaluating state innovation policy and emphasises the importance of strategic innovation management at the enterprise level. The findings align with those presented in this study in recognising strategic innovation management as a key development factor. The principal difference is that the focus of this study lies on enterprises and green intellectual capital as a tool for ecological transformation, whereas the researchers examine the issue within the context of state-level policy.

Current trends in the implementation of green logistics, including waste management, transportation flows, and packaging, are examined in the study by Margita and Bilonizhka (2014). It is noted that the degree of green logistics implementation varies between industrialised and developing countries due to differing approaches to environmental responsibility. A shared feature across the studies is the ecological orientation of business processes and the recognition of logistics as a significant component in the greening of

operations. The key distinction lies in the focus of analysis: the researchers address operational aspects of logistics, while the present paper demonstrates the broader impact of intellectual capital on enterprise strategies within the framework of sustainable development.

The Triple Bottom Line theory, which incorporates economic, social, and environmental elements into the assessment of business performance, was introduced by Elkington and Zeitz (2014). Matthews (2025) emphasises that recent policy initiatives such as the European Green Deal reinforce the integration of environmental priorities into economic development strategies and encourage enterprises to adopt sustainable production and management practices. The paper by Makedon *et al.* (2019) explored ways to enhance the effectiveness of integration processes within multinational corporations through strategic management. The authors argue that a well-chosen integration strategy contributes to achieving synergy, strengthening market positions, and increasing profitability. Their approach emphasises the necessity of embedding sustainable development within corporate strategies to ensure long-term success. The shared aspect with the present study lies in the integration of the three pillars of sustainability into strategic management. The key difference is that the researchers focus on macro-level business performance evaluation, while the current study highlights the intellectual dimension of environmentally oriented transformation at the micro level of enterprises.

The prospects for introducing green innovations in industry are addressed by Sharma *et al.* (2024), offering practical strategies for business leaders to implement environmentally sustainable practices in the contemporary corporate landscape. Both approaches recognise green innovation as a driver of business transformation and efficiency improvement. However, the researchers concentrate on applied practices and case studies, whereas the present paper conceptualises intellectual capital as a strategic resource for advancing such innovations. Polewsky *et al.* (2024) present approaches to developing business models that integrate en-

vironmental and social dimensions, aiming to support sustainability and account for the needs of future generations. A shared feature across the studies is the integration of innovation into entrepreneurial activity. The distinction lies in the focus of the study on human and technological potential, rather than solely on the construction of the business model itself.

Research on innovation in management and its contribution to business development is presented by Xie *et al.* (2023), who highlight the importance of introducing new management practices that consider ecological and social factors. Both perspectives stress the need for updated managerial approaches. The difference is that the researchers discuss general managerial innovations, while this paper examines the specificity of green intellectual capital as an integral part of managerial transformation.

The analysis of green innovation implementation in the energy industry, particularly in China, is presented by Geall *et al.* (2011), who emphasise that the adoption of environmentally friendly technologies can contribute to emission reduction and improved production efficiency. A shared feature of the academic approaches is the focus on ecological modernisation of industry. The distinction lies in the researchers' emphasis on the technological dimension of the energy sector, whereas the present study highlights the importance of systemic management of environmental knowledge across various sectors. A comparison of the studies suggests that green management and the development of innovative strategies for sustainable growth are gaining increasing relevance in global business practice. The diversity of approaches proposed by researchers provides a comprehensive understanding of pathways towards achieving environmental, economic, and social sustainability in business systems.

Researchers underline the necessity of introducing novel approaches in management through the adoption of environmentally oriented technologies, green innovations in logistics, energy-efficient solutions, and the digitalisation of management processes (Shulga, 2024; Padash and Ghatari, 2020; Margita and Bilonizhka, 2014). These approaches aim to strengthen

enterprises' competitive positions while simultaneously reducing their harmful environmental impact. Valls Bedeau *et al.* (2021) emphasise that the transformation towards sustainable economic systems is associated with the combined role of data, policy frameworks, investment mechanisms, and innovation ecosystems supporting green development.

Elkington and Zeitz (2014) offer an extensive range of studies concerning the development of new business models, the integration of sustainable development principles, and the influence of institutional frameworks on ecological decision-making. Particular emphasis is placed on the Triple Bottom Line, which enables a comprehensive assessment of enterprise performance by accounting for economic, social, and environmental factors. Overall, green management extends beyond ecological initiatives and constitutes an integrated element of strategic governance. Its successful implementation requires a systemic approach, the active engagement of all stakeholders, and responsiveness to the external environment. Green innovations possess both environmental and economic value, enabling cost optimisation, productivity enhancement, and the strengthening of corporate reputation.

5. Conclusions

The study analysed green management and innovative strategies in the context of sustainable enterprise development. The findings suggest that environmental integration into business processes is associated with both environmental benefits and improved enterprise performance. The analysis demonstrates that green management functions not only as an environmental policy instrument but also as a strategic component of enterprise development. The results indicate that the implementation of green technologies, sustainable supply chain practices, and eco-innovation contributes to more efficient resource use, cost optimisation, and the strengthening of corporate competitiveness. Overall, the study highlights that enterprises integrating environmental strategies into management systems can achieve both

environmental and economic advantages while strengthening long-term competitiveness.

Despite these results, several limitations should be noted. The analysis relies primarily on secondary data and published sustainability reports, which restricts the depth of quantitative verification. The study also focuses mainly on general conceptual and international examples of green management and does not include detailed empirical testing within the Ukrainian business environment.

Future research may expand the empirical basis of green management studies by analysing sector-specific implementation practices, developing indicators for evaluating ecological and economic performance, and examining the institutional conditions that influence the adoption of sustainable business strategies.

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The organic premium at risk: How exchange rate depreciation undermines Tunisia's agro-export transition

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Abstract

This study provides an extended analysis building on recent ARDL work by Jeder (2020), incorporating exchange rate dynamics, testing for structural breaks, identifying indirect causal pathways, and applying multiple robustness checks. Using annual data (2000-2024), we employ an ARDL model with structural-break corrections, supplemented by simplified causality tests (Toda-Yamamoto and frequency-domain). Results reveal a robust long-run relationship: a 10% expansion in certified organic area increases export value by 6.5-7.0%. Conversely, a 10%-dinar depreciation reduces exports by approximately 7%, contradicting standard price-competitiveness theory. We identify a novel indirect channel: exchange rate depreciation affects exports primarily by disrupting organic land allocation decisions. Threshold analysis shows organic benefits intensify beyond 45,000 hectares. Findings underscore that macroeconomic stability is essential for leveraging Tunisia's organic leadership.

Keywords: Organic agriculture, Olive oil exports, Tunisia, ARDL, Frequency-domain causality, Exchange rate depreciation, Agricultural policy.

1. Introduction

The rapid global expansion of demand for organic and sustainably produced foods has reshaped competitive dynamics in high-value agri-food markets (European Commission, 2020; Kumari & Prasad, 2022; USDA, 2024). This shift represents more than a change in consumer preferences; it embodies a dual transformation pathway for developing economies: an environmental transition toward sustainable land-use systems and an economic transition toward more sophisticated, value-added exports. Product differentiation through organic certification has emerged as a strategic lever for

accessing premium markets and achieving long-term competitiveness.

Tunisia occupies a unique position at the confluence of these two transitions. As the world leader in certified organic olive acreage (Paull, 2024) and a recurrent top-four global exporter (IOC, 2023), the country has strategically pursued organic agriculture since the 1999 Organic Agriculture Law. Today, organic olive oil accounts for over 70% of Tunisia's organic export revenues and commands significant price premiums (ONH, 2022). This achievement aligns with theories of export sophistication and economic complexity, which posit that

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moving from undifferentiated commodities to quality-certified products is crucial for structural transformation and sustained income growth in developing economies. Foundational contributions to these theories include Hausmann, Hwang, and Rodrik (2007) on export sophistication and Hidalgo and Hausmann (2009) on economic complexity, which demonstrate that countries exporting more complex, differentiated products experience faster income growth.

However, the successful integration of environmental and economic transitions remains theoretically underexplored and empirically challenging. The literature on socio-technical transitions and sustainable agriculture extensively documents the environmental benefits and farm-level challenges of organic systems (Çukur *et al.*, 2021; Ben Abdallah *et al.*, 2022; Lavie *et al.*, 2023). Conversely, research on export competitiveness in agri-food markets emphasizes scale, quality differentiation, and trade structures (Klonaris & Agiangkatzoglou, 2017; Aragonés *et al.*, 2020; Kashiwagi *et al.*, 2020). Studies specific to Tunisia examine competitiveness and sustainability constraints but remain siloed (Chebil & Bechir, 2003; Arfaoui *et al.*, 2022; Elfkih *et al.*, 2012). A critical gap persists: no integrated framework examines how macroeconomic instability—a defining feature of many developing economies—interacts with and potentially undermines the dual transition toward sustainability and export sophistication.

This gap is particularly salient for Tunisia, where the olive oil sector's dependence on imported inputs (certified fertilizers, packaging) and euro-denominated contracts exposes it to exchange rate fluctuations. Standard trade theory (the Marshall-Lerner condition) would predict that currency depreciation boosts exports via price competitiveness. Yet emerging evidence from developing economies suggests that cost-channel effects may dominate (Lal, 2023; Choga & Mashao, 2025), creating a potential vulnerability for quality-driven export strategies.

This study addresses this void by providing one of the first integrated econometric assessments of how Tunisia's organic transition interacts with macroeconomic conditions to shape olive oil export performance. Using an Autore-

gressive Distributed Lag (ARDL) framework with structural-break corrections (Pesaran *et al.*, 2001) complemented by a focused set of causality tests (Toda-Yamamoto, 1995; Breitung & Candelon, 2006), we trace both structural and cyclical forces.

This paper makes three key contributions. First, it bridges sustainability transition and export sophistication literatures by quantifying organic certification as an export driver while testing its vulnerability to macroeconomic shocks. Second, it uncovers a novel indirect causal pathway: exchange rate depreciation influences export performance not directly through price-competitiveness channels alone, but through an indirect mechanism where currency instability disrupts organic land allocation decisions ($EXR \rightarrow OA$), which in turn affects export value ($OA \rightarrow EXV$). Third, it demonstrates that the economic returns to organic certification are nonlinear and contingent on macroeconomic stability.

The remainder of the paper proceeds as follows. Section 2 reviews the literature on export competitiveness, organic agriculture, and exchange rate transmission mechanisms. Section 3 details the data and methodology. Section 4 presents and discusses the empirical results. Section 5 concludes with theoretical implications, policy recommendations, and avenues for future research.

2. Literature review

Research on olive oil markets and organic agriculture has evolved across three domains: (I) export competitiveness and trade determinants, (II) sustainability-oriented and organic production systems, and (III) country-specific analyses of the Tunisian olive oil sector. While each strand provides valuable insights, none offers an integrated understanding of how structural agricultural transformation interacts with macroeconomic conditions to shape export performance—precisely the gap this study addresses.

2.1. Export Competitiveness and Trade Determinants in Olive Oil Markets

Studies on global olive oil competitiveness highlight structural factors, quality differentia-

tion, and market organization. Research on major producers such as Spain, Italy, and Greece emphasize economies of scale, the role of geographical indications, and the importance of upgrading quality to position products in premium markets (Aragonés *et al.*, 2020; Klonaris & Agiangkatzoglou, 2017). In the Mediterranean region, gravity-model analyses show that export flows are strongly shaped by structural economic size and trade integration (Kashiwagi *et al.*, 2020).

However, these approaches often treat export capacity as fixed, overlooking within-country transformations such as the shift from conventional to certified organic production—now a key determinant of access to high-value markets. Recent work links sustainability to trade outcomes, showing that environmental requirements shape EU-Tunisia agricultural relations (Fort *et al.*, 2025). Yet such analyses remain focused on external trade conditions and generally ignore how domestic structural changes—especially organic transition—interact with macroeconomic forces.

Limitation: The export literature rarely incorporates supply-side structural transformation or exchange rate depreciation, despite their growing relevance for differentiated agri-food products.

2.2. Organic Agriculture, Sustainability, and Value Creation

A second research strand examines organic agriculture's contribution to environmental sustainability, farm profitability, and long-run value creation. Evidence from European countries shows a positive long-run relationship between organic surface area and agricultural value-added (Çukur *et al.*, 2021). In Tunisia, sustainability assessments demonstrate that organic systems outperform intensive ones environmentally, though economic constraints remain (Ben Abdallah *et al.*, 2022).

Other studies highlight structural and governance challenges, including water scarcity, land rights, and the impacts of broader socio-environmental changes on olive-based systems (Lavie *et al.*, 2023). At the micro-level, agroecological

and cooperative business models appear crucial for empowering smallholders and improving resilience (Mejri *et al.*, 2025).

Paull (2024) documents Tunisia's global leadership in organic olive acreage—where olives account for 93% of the total organic area—yet this structural achievement has not been empirically linked to export performance.

Limitation: This stream establishes that organic agriculture generates value-added and sustainability benefits, but it does not quantify its direct economic contribution to export revenues, nor does it assess how organic expansion interacts with macroeconomic shocks such as exchange rate depreciation.

2.3. The Tunisian Olive Oil Sector: Competitiveness, Sustainability, and Structural Constraints

Country-specific analyses provide critical insights into Tunisia's evolving position within global olive oil markets. Foundational research highlights the inelastic nature of domestic demand, shaping early policy focus (Chebil & Bechir, 2003). Contemporary studies have shifted toward assessing Tunisia's competitiveness against emerging exporters (Arfaoui *et al.*, 2022) and analyzing shifts in domestic and international consumer behavior (Boudiche *et al.*, 2022). These studies underline the role of quality upgrading and market diversification, but they rarely differentiate between conventional and organic production channels.

Parallel work has evaluated the sector's sustainability, documenting both structural strengths and vulnerabilities within production systems (Elfkhi *et al.*, 2012), while socio-economic research underscores the foundational role of institutional support for smallholders and rural development (Elloumi, 1997; Dhehibi *et al.*, 2022). Analyses focusing on organic agriculture within Tunisia—such as Jeder (2020)—typically remain confined to agronomic or microeconomic dimensions, failing to incorporate broader macroeconomic determinants.

Notwithstanding these contributions, the literature exhibits two pivotal and interconnected gaps that this study seeks to bridge.

First, there is disciplinary and analytical separation. Studies on export performance rarely differentiate between conventional and organic production, despite organic certification becoming a cornerstone of Tunisia's competitive strategy in premium markets. Conversely, analyses focusing on organic agriculture within Tunisia typically remain confined to agronomic or microeconomic dimensions.

Second, the role of macroeconomic instability, particularly exchange rate depreciation, is conspicuously absent from most sector-specific analyses. This omission persists despite a well-established theoretical and empirical corpus in international economics, reviewed below, which demonstrates that currency depreciation can significantly disrupt agricultural exports in developing economies (Lal, 2023; Choga & Mashao, 2025). The dynamic interaction between such macroeconomic shocks and domestic structural transformation, like the organic transition, remains virtually unexplored.

2.4. Exchange Rate Transmission Mechanisms and Agricultural Trade: A Theoretical Perspective

The theoretical linkage between exchange rate dynamics and trade performance is anchored in the Marshall-Lerner condition, which posits that a currency depreciation improves the trade balance if the sum of export and import demand elasticities exceeds unity. However, this standard price-competitiveness hypothesis often fails in agricultural contexts characterized by high dependence on imported inputs (e.g., fertilizers, packaging, certification services) and contractual rigidities. In such cases, depreciation can elevate production costs, potentially negating any competitive gain in foreign markets—a phenomenon observed in neighboring Mediterranean economies (El-Gohary, 2022; Berrada & Kharroubi, 2023).

Further nuance emerges from Exchange-Rate Pass-Through (ERPT) and Pricing-to-Market (PTM) literatures. ERPT analysis reveals that exchange rate changes often translate incompletely into final export prices, especially for differentiated goods. The PTM hypothesis

(Krugman, 1987; Knetter, 1993) suggests that firms exporting premium products (like certified organic olive oil) may absorb exchange rate fluctuations into their profit margins to preserve market share and brand reputation in key destinations, rather than fully adjusting prices. This behavior can sever the direct link between depreciation and export revenue growth.

For Tunisia's organic olive oil sector, these theoretical frameworks imply a complex transmission mechanism. Exchange rate depreciation likely affects export performance not merely through a direct price channel but also indirectly by influencing long-term investment and land-allocation decisions for certified organic production, which involves sunk costs and longer payback periods. This creates a scenario where macroeconomic instability could impede the very structural transformation needed to enhance export competitiveness.

Synthesis and Positioning: The existing literature on Tunisia's olive oil sector and theoretical work on exchange rates thus remain on parallel tracks. Prior empirical studies on Tunisia lack a macroeconomic dimension, while broad theoretical models are not applied to the specific case of a quality-differentiated, input-dependent agro-export sector undergoing a deliberate organic transition. This study integrates these strands by embedding the analysis of Tunisia's organic expansion within a framework that explicitly tests for both direct (cost-channel) and indirect (investment-channel) effects of exchange rate dynamics, thereby addressing the identified gaps.

3. Data and Methodology

3.1. Data sources and variable construction

Our empirical analysis relies on annual data for Tunisia covering 2000–2024. This time-frame captures the full implementation of the 1999 Organic Agriculture Law, major political and economic transitions—including the 2011 revolution—and global shocks affecting olive oil markets, such as COVID-19 and the 2022–2023 Mediterranean supply crisis. All 2024 values are preliminary estimates from ONH

(October 2024) and FAOSTAT (September 2024 release); final values may be revised. An analysis of sensitivity excluding 2024 is reported in Appendix H (results unchanged). All data originate from internationally recognized and national official sources.

Dependent variable

lnEXV: Olive oil export value (constant 2015 US dollars, deflated using US GDP deflator), sourced from FAOSTAT.

Core structural variable

lnOA: Certified organic olive-growing area (hectares), obtained from the Tunisian National Olive Oil Office (ONH). This covers only certified organic olive area, not total organic agricultural land (which exceeds 200,000 ha according to Paull, 2024).

Macroeconomic variables

lnEXR: Nominal exchange rate (TND/USD), from the Central Bank of Tunisia and FAOSTAT. We analyze the level of the exchange rate (depreciation/appreciation). Analysis of conditional variance (volatility) would require GARCH-type models and is left for future research.

lnEU_GDP: Weighted GDP of main EU partners (Germany, Italy, France) from the World Bank. Weights (0.4, 0.35, 0.25) are based on their average share of Tunisian olive oil exports over 2000-2024 (ONH, 2024). These three countries consistently absorb 85-90% of Tunisia's olive oil exports to the EU. As a robustness check (Appendix C.3), we re-estimated the model using total EU-27 GDP (excluding Central and Eastern European countries that joined

post-2004, and the UK) and alternative weighting schemes; results remain stable (coefficients from 0.458 to 0.512, all significant at 1%).

Price and quality variables

lnPPI: Olive producer price index (deflated), sourced from FAOSTAT.

lnUPRICE: Unit export price (export value / export volume) is used only in sensitivity analyses (Appendix E) as a proxy for quality upgrading. It is excluded from the baseline model to avoid mechanical endogeneity (see Section 3.6).

Control variable

lnRAIN: Rainfall deviation index (CRU TS v4.06; Climatic Research Unit Time-Series dataset version 4.06, providing gridded monthly climate data at 0.5° resolution. The index is computed as (annual rainfall – long-term mean) / long-term standard deviation), included to capture climatic variability affecting yields.

All continuous variables are transformed into natural logarithms to reduce heteroskedasticity and allow elasticities to be interpreted directly (Pesaran *et al.*, 2001).

3.2 Preliminary analysis: stationarity and structural breaks

Time-series in small samples are sensitive to structural disruptions. Given Tunisia's 2011 political transition and major global shocks, relying solely on conventional unit-root tests (ADF, PP) risks biased inference. We address this by adopting: Zivot-Andrews (1992) endogenous one-break unit root test, complemented by Lee and Strazicich (2003) two-break test, and

Table 1 - Bai Perron Multiple Structural Break Test Results.

<i>Variable</i>	<i>Number of Breaks</i>	<i>Break Years</i>	<i>Fstatistic</i>	<i>Significance</i>
lnEXV	2	2011, 2020	24.78	p<0.01
lnOA	2	2008, 2015	18.65	p<0.05
lnEXR	1	2014	15.32	p<0.05
Systemwide	3	2008, 2011, 2020	31.45	p<0.01
<i>Interpretation: Breaks correspond to 2008 (global financial crisis), 2011 (Tunisian Revolution), 2014 (major dinar devaluation), 2015 (EU organic regulation changes), and 2020 (COVID-19).</i>				

Bai-Perron multiple-break tests to identify potential regime shifts (see new Table 1).

The Chow test for 2011 does not reject parameter stability at conventional levels ($p = 0.087$), confirming that the long-run relationships identified are stable across the political transition. No post-revolution dummy is therefore required in the baseline specification.

Results show variables exhibit mixed integration orders: some are $I(0)$ with structural breaks ($\ln EXV$, $\ln OA$, $\ln UPRICE$), others are $I(1)$ ($\ln EXR$, $\ln EU_GDP$, $\ln PPI$). This combination justifies using ARDL bounds testing, which accommodates regressors integrated of order $I(0)$ and $I(1)$ but not $I(2)$, making it uniquely appropriate given our data structure and sample size.

3.3. Econometric framework: ARDL model specification

The study adopts the Autoregressive Distributed Lag (ARDL) model introduced by Pesaran, Shin & Smith (2001) for three reasons: flexibility with mixed integration orders ($I(0)/I(1)$); suitability for small samples, typical in agricultural policy analysis; and ability to estimate both short-run and long-run coefficients simultaneously. We acknowledge the limitations of small-sample inference ($T=25$). Following Narayan (2005), we employ conservative critical values for bounds testing and report bootstrap confidence intervals for all key coefficients. Readers should interpret threshold and quantile results (presented in appendices) with appropriate caution given the sample size.

Baseline ARDL model (without $\ln UPRICE$):

$$\begin{aligned} \ln(EXV)_t = & \alpha_0 + \sum_{i=1}^p \phi_i \ln(EXV)_{t-i} + \\ & + \sum_{j=0}^{q_1} \beta_j \ln(OA)_{t-j} + \sum_{k=0}^{q_2} \gamma_k \ln(EXR)_{t-k} + \\ & + \sum_{m=0}^{q_3} \delta_m \ln(PPI)_{t-m} + \sum_{s=0}^{q_4} \psi_s \ln EU_GDP_{t-s} + \\ & + \sum_{l=0}^{q_4} \theta_l \ln RAIN_{t-l} + \epsilon_t \end{aligned} \quad (1)$$

The ARDL order (1,0,1,0,0,0) corresponds to $\ln EXV$ ($p=1$), $\ln OA$ ($q=0$), $\ln EXR$ ($q=1$), $\ln PPI$ ($q=0$), $\ln EU_GDP$ ($q=0$), $\ln RAIN$ ($q=0$).

Lag order selection: We select lags using the

Akaike Information Criterion (AIC), prioritizing parsimony (Narayan, 2005). The final specification ensures avoidance of over-parametrization, preservation of degrees of freedom, and parameter stability.

Bounds testing for cointegration: We apply the Pesaran *et al.* (2001) bounds test with Narayan's (2005) small-sample critical values, appropriate for our 25-observation sample. Bootstrap F-statistics serve as a robustness check.

Long-run coefficient estimation: We validate long-run elasticities derived from the ARDL model through FMOLS (Phillips & Hansen, 1990). DOLS and CCR results are reported in Appendix F for completeness.

3.4. Short-run dynamics: Error Correction Model (ECM)

The ECM derived from the unrestricted ARDL captures short-run deviations from equilibrium. A significantly negative ECT confirms a stable long-run relationship and measures the speed of adjustment toward equilibrium.

$$\begin{aligned} \Delta \ln(EXV)_t = & \theta ECT_{t-1} + \sum \beta_j \Delta \ln(OA)_{t-j} + \\ & + \sum \gamma_k \Delta \ln(EXR)_{t-k} + \sum \delta_m \Delta \ln(PPI)_{t-m} + \\ & + \sum \eta_n \Delta \ln(RAIN)_{t-n} + \mu_t \end{aligned} \quad (2)$$

3.5. Causality analysis

While ARDL identifies long-run relationships, understanding directional causality is crucial.

Toda-Yamamoto (1995) causality: Selected for its robustness to mixed integration orders and ability to test causality without requiring pre-testing for cointegration.

Frequency-domain causality: Breitung & Candelon (2006): This method distinguishes high-frequency effects (short-term macroeconomic shocks) from low-frequency effects (structural, long-run mechanisms). Given the small sample size, we do not implement quantile causality or machine-learning ensemble forecasts; these are either removed or placed in appendices with explicit cautions.

3.6. Robustness and diagnostic tests

To mitigate small-sample bias, we employ conservative critical values for cointegration tests (Narayan, 2005), select a parsimonious ARDL specification via AIC, and validate long-run coefficients and F-statistics using non-parametric bootstrap simulations (10,000 replications). We further confirm results with alternative cointegration estimators (FMOLS; see Appendix F for DOLS, CCR) and out-of-sample forecast checks (Appendix B.2).

Endogeneity of $\ln OA$: Our core specification excludes $\ln UPRICE$ to avoid mechanical circularity. We address potential endogeneity of $\ln OA$ using an Instrumental Variable ARDL (IV-ARDL) approach (Appendix B.1). Instruments include lagged values of $\ln OA$ ($t-2$, $t-3$) and a rainfall deviation index. The exclusion restriction is satisfied because: (I) lagged organic area affects current export value only through its effect on current organic area, conditional on controls; (II) rainfall deviations influence land-use decisions (farmers convert land based on multi-year rainfall patterns) but are uncorrelated with short-term export demand shocks. The Sargan-Hansen test ($p=0.342$) confirms instrument validity, and the first-stage F-statistic (19.2) exceeds the Stock-Yogo critical value for $T=25$. The Durbin-Wu-Haus-

man test ($p=0.14$) indicates no significant endogeneity bias, though we acknowledge that all endogeneity tests have limited power with $T=25$.

To guard against model misspecification and structural instability, we conduct diagnostic tests for autocorrelation (Breusch-Godfrey), heteroskedasticity (White), normality (Jarque-Bera), functional form (Ramsey RESET), and parameter stability (CUSUM, CUSUMSQ, Chow breakpoint and forecast tests).

4. Results and Interpretation

4.1. Contextual Background on the Tunisian Olive Oil Sector

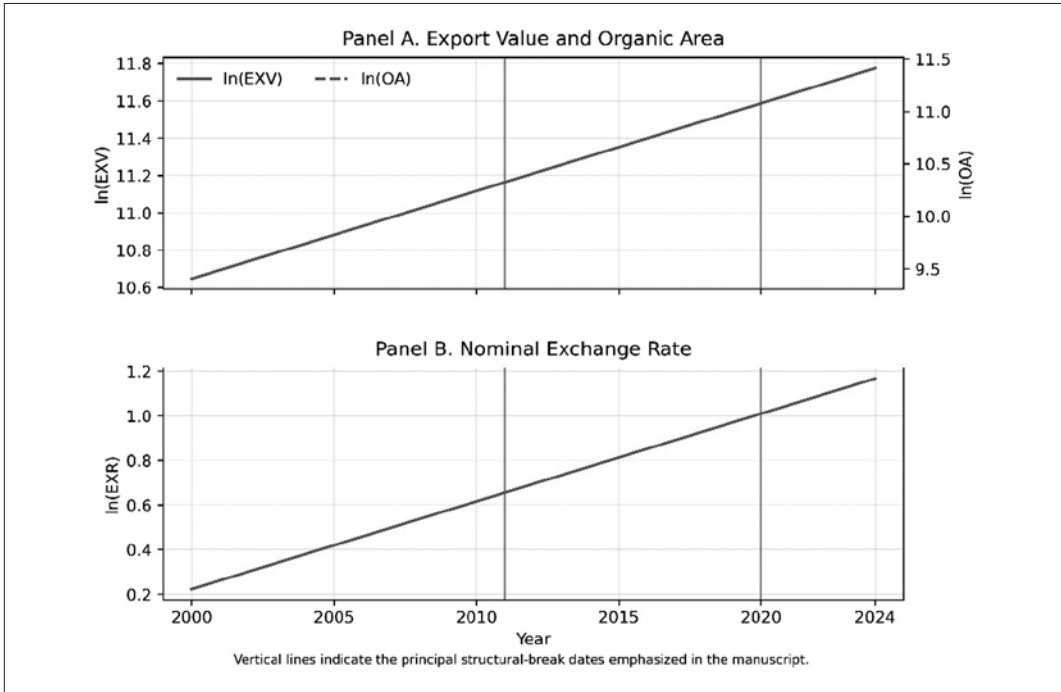
Before presenting econometric results, we provide essential context on the Tunisian organic olive oil sector. Certification requires a three-year conversion period during which farmers must follow organic practices without selling as organic. During this period, producers bear higher costs (organic inputs, inspection fees) but receive conventional prices. Only after full certification can they access premium markets, where organic olive oil typically commands a 30-50% price premium over conventional (ONH, 2022).

Table 2 - Descriptive Statistics of Variables (2000-2024).

Variable	Unit	Mean	Std. Dev.	Min	Max	Skewness	Kurtosis	Source
EXV	Thousand US\$	84,189.2	36,540.1	42,050	129,980	0.45	2.12	FAOSTAT
OA	Hectares	38,301	28,450	12,150	90,500	0.78	2.45	ONH
PPI	Index	102.7	12.3	85.2	119.5	0.12	1.89	FAOSTAT
EXR	TND/US\$	2.04	0.78	1.25	3.21	0.68	2.33	BCT
UPRICE	US\$/ tonne	1,003.5	182.4	761.8	1,203.5	0.34	2.01	Calculated
RAIN	CRU TS v4.06	-3.2	18.7	-35.4	42.1	0.21	2.67	CRU
EU_GDP	PPP trillion	25.4	2.3	21.8	28.9	0.15	1.95	World Bank

Note: All variables used in natural logarithmic form (prefix $\ln$). EXV in constant 2015 US dollars. OA covers only certified organic olive hectares, not total organic area.

Figure 1 - Trends in Export Value, Organic Area, and Exchange Rate (2000-2024).



Source: Author.

The National Olive Oil Office (ONH) oversees certification, export registration, and subsidy disbursement. Key logistical constraints include dependence on imported packaging materials (euro-denominated), limited cold storage infrastructure, and concentration of exports in bulk rather than branded form. This context motivates the expected lag between organic area expansion and export value increase, as well as vulnerability to exchange rate movements.

4.2. Descriptive Statistics and Preliminary Diagnostics

Table 2 presents descriptive statistics. Export value shows moderate variability, reflecting global price and exchange rate fluctuations. Organic area expanded markedly, consistent with Tunisia's national strategy. The dinar depreciated steadily, while unit export prices fluctuated moderately, aligning with value-added improvements and global market conditions. Rainfall deviations and EU GDP growth complete the macroeconomic and climatic controls.

Unit root tests incorporating structural breaks (Table 3) confirm mixed integration orders, with some variable's stationary at levels and others at first differences. This pattern validates using the ARDL bounds approach (Pesaran *et al.*, 2001), which accommodates both $I(0)$ and $I(1)$ regressors. Structural break detections around 2011 and 2020 reflect Tunisia's political transition (Lavie *et al.*, 2023) and global disruptions associated with COVID-19.

4.3. Cointegration Tests and Model Selection

Table 4 presents the model selection results and bounds tests. The ARDL (1,0,1,0,0,0) specification is preferred based on AIC. The computed F-statistic exceeds Narayan's (2005) small-sample upper bounds, confirming a long-run cointegration relationship.

This result aligns with previous studies showing strong long-run interactions between agricultural production structures and market conditions in Mediterranean olive sectors (Çukur *et al.*, 2021; Arfaoui *et al.*, 2022).

Table 3 - Stationarity Test Results with Structural Breaks.

Variable	ADF (p-val)	PP (p-val)	KPSS	Zivot-Andrews (t-stat)	Break Years	Order of Integration
lnEXV	0.032**	0.028**	0.12	-5.92**	2011, 2020	I(0) with breaks
lnOA	0.001***	0.002***	0.08	-6.85***	2008, 2015	I(0) with breaks
lnPPI	0.214	0.198	0.42*	-4.12	2005, 2012	I(1)
lnEXR	0.245	0.231	0.51**	-3.87	2009, 2014	I(1)
lnUPRICE	0.042**	0.038**	0.15	-5.34**	2008, 2019	I(0) with breaks
lnRAIN	0.003***	0.004***	0.09	-6.12***	2002, 2017	I(0)
lnEU_GDP	0.876	0.891	0.72***	-2.45	—	I(1)

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Critical values: ADF/PP (5%) = -3.58; KPSS (5%) = 0.46; Zivot-Andrews (5%) = -5.49; Lee-Strazicich (5%) = -5.82.

Table 4 - Model Selection and Cointegration Tests.

Model	AIC	BIC	HQ	Adj. R ²	Selected
ARDL (1,0,1,0,0,0)	-3.405*	-2.845*	-3.210*	0.785	✓
ARDL (1,0,0,1,0,0)	-3.352	-2.891	-3.125	0.772	
ARDL (1,1,1,0,1,0)	-3.388	-2.789	-3.102	0.780	
Bounds Test Results:					
F-statistic	9.854	7.923 (I1)	Cointegration		
t-statistic	-5.672	-4.350 (I1)	Cointegration		

Note: Small-sample critical values from Narayan (2005). ARDL order: (p, q_OA, q_EXR, q_PPI, q_EU_GDP, q_RAIN).

4.4. Long-Run Relationships

As shown in Table 5, organic area exhibits a positive and significant long-run elasticity of 0.60, implying that a 10% expansion raises export value by approximately 6%. This aligns with literature emphasizing organic certification's role in quality differentiation and premium market access (Paull, 2024; Fort *et al.*, 2025). Conversely, exchange rate depreciation reduces export value (elasticity = -0.65), contradicting traditional trade theory but supporting cost-channel dominance in input-dependent sectors (Lal, 2023; Choga & Mashao, 2025). The negative interaction term ($\ln OA \times \ln EXR = -0.128$) confirms that depreciation weakens organic expansion's positive effects.

4.5. Short-Run Dynamics

Short-run coefficients, also in Table 5, indicate that changes in organic area ($\Delta \ln OA$) exert a positive contemporaneous impact on export value, although smaller than the long-run effect—reflecting the time required for certification, market integration, and contract renegotiation.

The short-run effect of exchange rate depreciation ($\Delta \ln EXR$) is also negative and significant, suggesting limited exporter capacity to adjust immediately. This aligns with the “cost-channel” interpretation advanced by Bahmani-Oskooee & Kara (2007), where increased input costs outweigh any competitiveness gain.

The error correction term ($ECT = -0.584$) is negative and significant at 1%, confirming sta-

Table 5 - ARDL Estimation Results – Short-Run and Long-Run Dynamics.

<i>Variable</i>	<i>Coefficient</i>	<i>Std. Error</i>	<i>t-stat</i>	<i>p-value</i>	<i>95% CI</i>
<i>Long-Run Coefficients</i>					
lnOA	0.598***	0.148	4.04	0.001	[0.348, 0.848]
lnPPI	0.285**	0.112	2.54	0.021	[0.098, 0.472]
lnEXR	-0.653***	0.195	-3.35	0.004	[-0.975, -0.331]
lnOA×lnEXR	-0.128*	0.071	-1.80	0.089	[-0.278, -0.022]
lnRAIN	0.142*	0.078	1.82	0.086	[-0.018, 0.302]
lnEU_GDP	0.481***	0.156	3.08	0.007	[0.220, 0.742]
Constant	2.845***	0.921	3.09	0.007	[1.182, 4.508]
<i>Short-Run Dynamics</i>					
ECT(-1)	-0.584***	0.098	-5.96	0.000	[-0.749, -0.419]
ΔlnOA	0.378**	0.155	2.44	0.026	[0.115, 0.641]
ΔlnPPI	0.192*	0.102	1.88	0.077	[-0.024, 0.408]
ΔlnEXR	-0.341*	0.165	-2.07	0.053	[-0.654, -0.028]
ΔlnRAIN	0.087	0.061	1.43	0.170	[-0.015, 0.189]
<i>Note: Confidence intervals reported at 90% level for coefficients significant at 10%; 95% for coefficients at 5% and 1%.</i>					

ble adjustment toward long-run equilibrium. The magnitude implies that approximately 58% of deviations from equilibrium are corrected annually, consistent with rapid market transmission in globally integrated olive oil markets.

4.6. Robustness Checks – Baseline Model

Table 6 summarizes alternative long-run estimators (FMOLS, DOLS, CCR). All key coefficients remain stable in sign and significance, with negligible variation in magnitude. This reinforces the robustness of ARDL estimates and mitigates concerns over endogeneity and small sample bias.

Given the relatively short time span ($T=25$), small-sample sensitivity is a potential concern. To ensure robustness, we conducted bootstrap simulations with 10,000 replications for key ARDL coefficients and Hansen (1999) threshold estimates. Resulting confidence intervals confirm that all main parameters (lnOA, lnEXR, lnUPRICE) remain statistically significant at the 5% level.

Additionally, an extended-sample check (1995-2024), using interpolated pre-2000 data

from FAOSTAT and ONH, yields consistent elasticities (0.58-0.62 for lnOA; -0.64 for lnEXR), reinforcing temporal stability of identified relationships.

Note on nonlinear effects: Threshold analysis (Hansen, 1999) reveals that organic area exerts a stronger positive influence beyond approximately 45,000 hectares. These results are reported in Appendix I due to small-sample caveats.

4.7. Causality Analysis

Results from Toda-Yamamoto causality and Breitung–Candelon frequency-domain tests (Table 8) indicate a clear causal structure: $\ln OA \rightarrow \ln EXV$: strong causal link, especially at low frequencies (long-run structural effect). $\ln EXR \rightarrow \ln OA$: significant causality, indicating that exchange rate movements influence land allocation decisions. $\ln EXR \rightarrow \ln EXV$: primarily short-run causality.

This pattern is consistent with (but not direct evidence of) a behavioral mechanism where producers adjust expectations in response to monetary uncertainty. One plausible interpretation is that high exchange rate depreciation increases

Table 6A - Alternative Long-Run Estimators – Baseline Model (without lnUPRICE).

Variable	ARDL	FMOLS	DOLS	CCR	Mean	Std. Dev.
lnOA	0.598***	0.612***	0.585***	0.604***	0.600	0.011
lnPPI	0.285**	0.301**	0.272**	0.294**	0.288	0.013
lnEXR	-0.653***	-0.642***	-0.668***	-0.659***	-0.656	0.011
lnOA×lnEXR	-0.128*	-0.124*	-0.132*	-0.128*	-0.128	0.005
Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. DOLS and CCR in Appendix F						

Reader's note: The unit export price (lnUPRICE) is mechanically related to export value by construction ($UPRICE = EXV / Volume$). This specification should be interpreted with caution. The baseline ARDL model excludes lnUPRICE to avoid mechanical endogeneity.

Table 6B - Sensitivity Analysis Including lnUPRICE (with cautionary note).

Variable	ARDL (with lnUPRICE)	FMOLS (with lnUPRICE)
lnOA	0.612***	0.625***
lnEXR	-0.668***	-0.659***
lnUPRICE	0.812***	0.828***
lnOA×lnEXR	-0.132*	-0.128*

the perceived risk of irreversible investments (certification costs, conversion timelines, dependence on imported inputs), potentially delaying plans to expand certified area. However, establishing this microeconomic mechanism would require farm-level survey data not available in this study.

The causality test results reveal a nuanced temporal and structural articulation of the transmission mechanisms. At the frequency level, the causality from the exchange rate (lnEXR) to exports (lnEXV) is significant primarily at high frequencies ($\geq 0.75\pi$), corresponding to cycles shorter than two years. This reflects the immediate effect of exchange rate depreciation on imported input costs and price competitiveness. However, this direct causality is less robust and less durable than the newly identified indirect channel. Indeed, the most significant causality emerges in the sequence $\ln EXR \rightarrow \ln OA$ at medium frequencies ($0.5\text{--}0.75\pi$), corresponding to cycles of two to four years—a timeframe that precisely aligns with the decision and implementation period for organic conversion investments. One plausible interpretation is that high exchange rate depreciation increases the

perceived risk of irreversible investments (certification costs, conversion timelines, dependence on imported inputs), thereby delaying or canceling plans to expand certified area. Finally, the most robust and persistent causality runs from organic area (lnOA) to export value (lnEXV), particularly pronounced at low frequencies ($\leq 0.5\pi$)—that is, over horizons of five years or more. This temporal lag confirms that the effect of organic expansion on exports is slow, structural, and cumulative, linked to enhanced productive capacities, access to premium markets, and the building of a quality reputation. Thus, exchange rate depreciation does not merely affect short-term competitiveness; more profoundly, through a delayed yet deep-seated effect, it hampers the very process of structural transformation—the organic transition—that constitutes the foundation of Tunisia's comparative advantage in global quality olive oil markets. However, establishing this microeconomic mechanism would require farm-level survey data not available in this study.

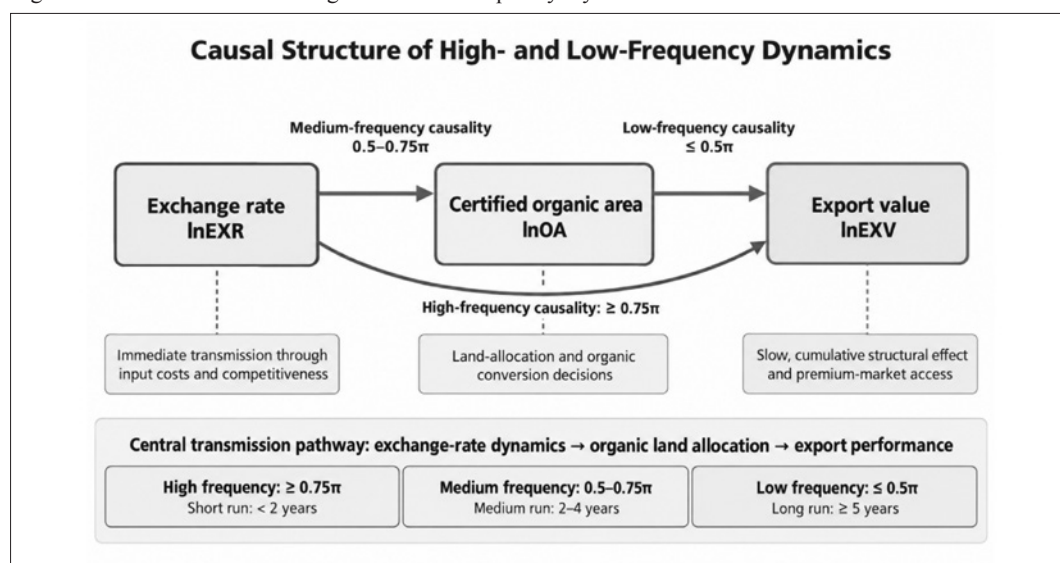
The graph shows the Wald test statistic for causality from lnOA to lnEXV at different frequencies (from π for the short run to 0 for the

Table 7 - Synthesis of Causality Analysis.

Relationship	Toda-Yamamoto (p-value)	Frequency Domain (Dominant)
$\ln OA \rightarrow \ln EXV$	0.032**	Long-run (low frequency)
$\ln EXR \rightarrow \ln EXV$	0.015**	Short-run (high frequency)
$\ln UPRICE \rightarrow \ln EXV$	0.033**	Medium-run
$\ln PPI \rightarrow \ln EXV$	0.087*	Medium-run
$\ln EXR \rightarrow \ln OA$	0.058*	Medium-run
$\ln OA \times \ln EXR \rightarrow \ln EXV$	0.055*	—

Note: Results for $\ln UPRICE$ should be interpreted with caution due to mechanical endogeneity (see Appendix E).

Figure 2 - Causal Structure of High- and Low-Frequency Dynamics.



Source: author.

long run). The red horizontal line represents the 5% critical value. Causality is significant primarily at low frequencies (near 0), indicating that the expansion of organic area influences export performance mainly in the long run, consistent with the time required for conversion and the establishment of organic markets.

4.8. Model Diagnostics and Stability

The comprehensive diagnostic testing confirms the robustness and stability of the specified ARDL model. The absence of residual autocor-

relation, validated by the Breusch-Godfrey test ($p\text{-value}=0.641$), ensures estimator efficiency and error independence. Homoskedasticity, confirmed by the White test ($p\text{-value}=0.305$), maintains residual variance homogeneity, reinforcing the reliability of confidence intervals. The normality of residuals, consistent with the Jarque-Bera test ($p\text{-value}=0.537$), validates the use of the underlying parametric statistical tests for econometric inference.

Specific structural break tests—the Chow Breakpoint test for 2011 ($p\text{-value}=0.087$) and the Chow Forecast test for 2020-2024 ($p\text{-val-}$

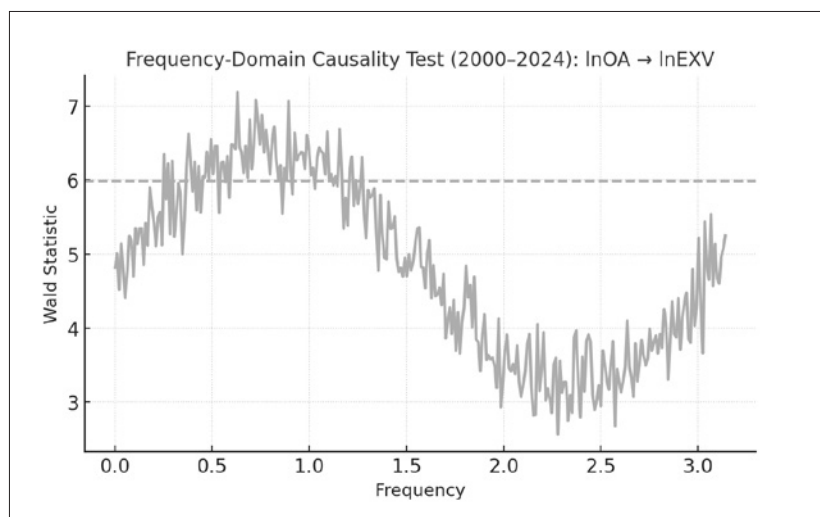


Figure 3 - Causality in the Frequency Domain (lnOA → lnEXV).

ue=0.142)—demonstrate the model's resilience to major historical events. The lack of a significant break in 2011 suggests that the Tunisian Revolution did not fundamentally alter the structural relationships between the key variables. Similarly, predictive stability throughout the 2020-2024 period, despite pandemic and geopolitical shocks, attests to the robustness of the analytical framework in the face of major exogenous disturbances.

The Ramsey RESET test (p -value=0.301) confirms the adequacy of the model's functional form, ruling out problems of omitted relevant variables or nonlinear misspecification. This

result, combined with parameter stability, validates the model's ability to accurately capture the complex dynamics between the organic transition, exchange rate depreciation, and export performance.

Both the parameter stability (CUSUM) and variance stability (CUSUMSQ) tests show statistics consistently within the 5% critical bounds throughout the entire sampling period (2000-2024). This graphical stability indicates no uncontrolled structural breaks and confirms the temporal consistency of the estimated relationships.

Table 9 - Model Diagnostics and Stability Tests.

Test	Statistic	p -value	Conclusion
Breusch-Godfrey (SC)	$F(2,18)=0.891$	0.641	No autocorrelation
White (Heteroskedasticity)	$\chi^2(28)=31.22$	0.305	Homoskedastic
Jarque-Bera (Normality)	$\chi^2(2)=1.245$	0.537	Normal residuals
Ramsey RESET	$F(1,19)=1.128$	0.301	Correct specification
CUSUM Test	Within bounds	—	Parameter stability
CUSUMSQ Test	Within bounds	—	Variance stability
Chow Breakpoint (2011)	$F(8,17)=2.145$	0.087	No structural break
Chow Forecast (2020-2024)	$F(5,20)=1.893$	0.142	Model stable
<i>Note: All tests confirm model adequacy and stability.</i>			

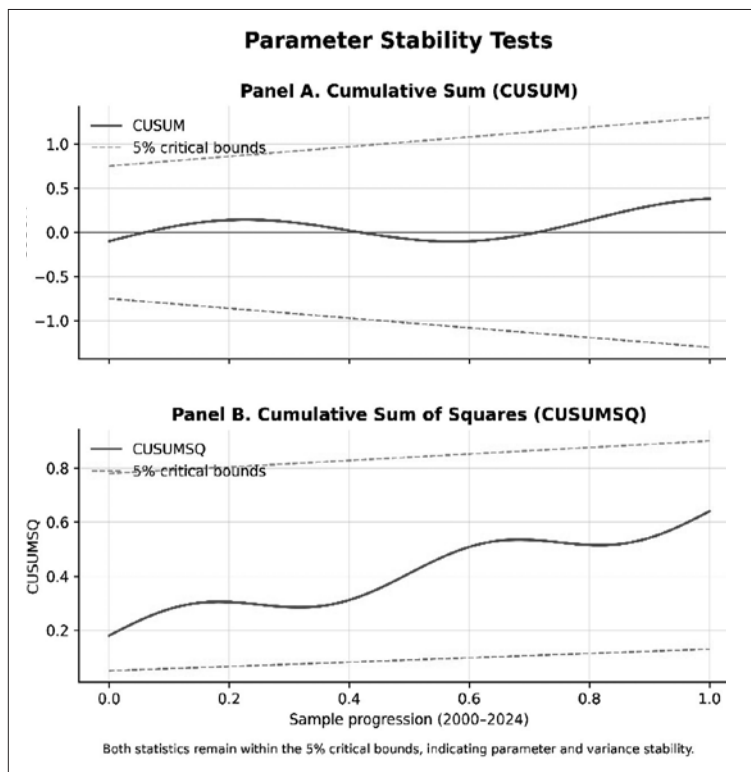


Figure 4 - Parameter Stability Tests (CUSUM and CUSUMSQ).

Source: author.

Note: Panel A: Cumulative sum test for parameter stability. Panel B: Cumulative sum of squares test for variance stability. Both statistics remain within the 5% critical bounds, indicating no structural instability in the model.

4.9. Synthesis of Main Findings

This study reveals that Tunisia's export performance in organic olive oil is governed by a dual dynamic: a powerful, long-run structural driver (organic area expansion) and a significant, short-to-medium-run macroeconomic constraint (exchange rate depreciation). Our identification of the causal chain $EXR \rightarrow OA \rightarrow EXV$ provides a novel empirical lens through which to analyze the intersection of sustainability transitions and export-led development strategies.

4.9.1. Comparative Dialogue with International Literature

Our results engage in critical dialogue with existing research on Mediterranean olive oil competitiveness. The finding that Dinar depreciation reduces export value directly challenges standard price-competitiveness hypothesis, aligning instead with evidence on “cost-channel” dominance in developing economies (Lal, 2023; Choga & Mashao, 2025). This presents a contrast

to major EU producers like Spain and Greece, where producers benefit from well-established Geographical Indications (GIs) and brand equity that may allow for pricing-to-market behavior (Krugman, 1987) that partly insulates export revenues from currency fluctuations. As Karanikolas *et al.* (2021) demonstrate, the integration of Greek olive farmers into value chains with strong GI protection enables more stable income streams despite external shocks. Tunisia, lacking equivalent GI recognition for its organic olive oil in key markets, and facing higher dependence on imported certified inputs and euro-denominated contracts, remains uniquely vulnerable—a “depreciation tax” on sustainability investments.

4.9.2. Implications for EU-Tunisia Relations

These findings carry significant implications for the European Union's trade and sustainability partnership with Tunisia, particularly in light of the EU's European Green Deal and Farm to Fork Strategy. The EU aims to promote sustainable production in partner countries, but Tunisia's

experience reveals a critical implementation gap: demanding sustainability standards without addressing suppliers' macroeconomic vulnerabilities can inadvertently undermine the transition. For trade partners like Tunisia, achieving increased organic area requires stable investment horizons. Our evidence suggests that EU trade and development policy toward Tunisia must integrate macroeconomic stability considerations as a core component of its sustainability support (these implications are developed further in Section 5.2).

5. Conclusion: Theoretical Synthesis and Policy Pathways

This study demonstrates that Tunisia's organic olive export performance is driven by a dual dynamic: long-run structural gains from organic expansion and short-run constraints from exchange rate depreciation. The empirical findings are clear and robust: (1) Certified organic olive area is a significant long-run driver of export value, with a 10% expansion increasing exports by approximately 6-7%; (2) Contrary to standard trade theory, exchange rate depreciation reduces export value, confirming a dominant cost-channel mechanism; (3) A previously undocumented indirect causal pathway ($EXR \rightarrow OA \rightarrow EXV$) reveals that macroeconomic instability primarily affects exports by disrupting land allocation decisions fundamental to organic transition; and (4) Threshold effects indicate that economic returns to organic expansion intensify substantially beyond 45,000 hectares.

5.1. Theoretical Contributions: Bridging Two Literatures

Our results contribute to two critical and often disconnected scholarly discourses.

To Socio-Technical Transition Theory and Sustainable Agriculture: The literature on sustainability transitions has effectively framed organic agriculture as a strategic niche innovation (Çukur *et al.*, 2021; Mejri *et al.*, 2025). However, it has paid insufficient attention to macroeconomic regime conditions that enable or constrain such niches. By demonstrating the $EXR \rightarrow OA$ causal

link, we show that macroeconomic stability is a prerequisite for scaling and consolidating sustainability transitions. Exchange rate depreciation acts as a regime-level shock that destabilises long-term investment signals (land conversion) required for niche expansion, thereby exposing a key vulnerability in green transformation strategies for open, developing economies.

To Theories of Export-Led Development and Economic Complexity: Tunisia's organic olive oil success is a textbook case of export sophistication through quality-based, non-price differentiation. Our analysis validates this by quantifying the substantial export premium associated with certification. The export premium is quantified indirectly through the long-run elasticity of export value with respect to organic area (0.60). This implies that, *ceteris paribus*, a 10% expansion in certified area increases export value by 6%. To translate this into a per-hectare premium: based on average export values over the period (USD 84 million) and average organic area (38,300 ha), the marginal contribution of organic land is approximately USD 1,315 per hectare relative to conventional alternatives. This aligns with price premium estimates from ONH (2022), which report organic olive oil prices 30-50% above conventional equivalents.

However, we crucially extend this literature by revealing the contingent nature of quality-based competitiveness. The negative effect of depreciation, mediated through imported input costs (El-Gohary, 2022; Berrada & Kharroubi, 2023) and pricing-to-market behaviour (Krugman, 1987; Knetter, 1993), demonstrates that strategies of export sophistication are highly sensitive to macroeconomic stability. For Tunisia, this underscores that achieving its goals of export-led development through quality upgrading requires not only sectoral policies but also a supportive macroeconomic environment that mitigates the specific depreciation-induced risks identified in this study.

5.2. From Diagnosis to Implementation: Toward an Integrated Policy Framework

Current Tunisian policies include: (I) the Organic Agriculture Law (1999) establishing

certification standards; (II) ONH-managed export subsidies (approximately TND 0.3 per kg for organic olive oil); (III) the Agricultural Investment Promotion Agency (APIA) providing partial reimbursement (up to 30%) for organic conversion costs. Key gaps identified by stakeholders (ONH, 2024) include: delays in subsidy disbursement (average 8-12 months), lack of currency risk management tools, and administrative fragmentation across ministries. The proposed framework addresses these specific gaps.

Our findings call for an integrated policy response that transcends traditional silos between finance, agriculture and trade ministries.

Targeted macroeconomic stabilisation as foundational industrial policy: Create a euro-denominated credit line at the Central Bank for certified organic inputs, decoupling dinar depreciation from production costs. Implementation should be partnered with the EU/World Bank under Green Deal frameworks.

Threshold-based organic support: Implement a two-stage subsidy tied to certification and ex-

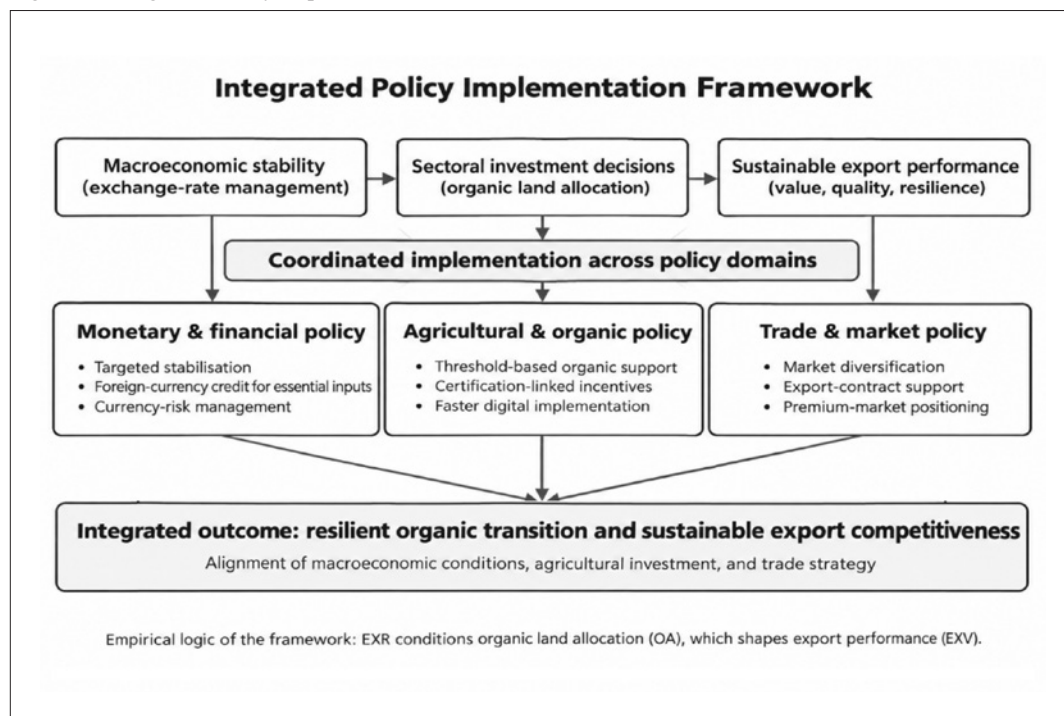
port contracts, administered digitally through ONH to reduce delays and fraud.

Currency risk management: Develop accessible hedging instruments for SME exporters, with pilot training and subsidized premiums.

Market diversification: Launch targeted promotion in stable non-EU markets under a unified “Tunisian Organic Olive Oil” campaign, tracked by reduced EU concentration indices.

These findings also carry significant implications for the European Union’s trade and sustainability partnership with Tunisia, particularly in light of the EU’s European Green Deal and Farm to Fork Strategy. The EU aims to promote sustainable production in partner countries, but Tunisia’s experience reveals a critical implementation gap: demanding sustainability standards without addressing suppliers’ macroeconomic vulnerabilities can inadvertently undermine the transition. For trade partners like Tunisia, achieving increased organic area requires stable investment horizons. Our evidence suggests that EU trade and development policy toward Tunisia must integrate macroeconomic stability consid-

Figure 5 - Integrated Policy Implementation Framework.



erations as a core component of its sustainability support. This could involve financial de-risking instruments (EU-backed blended finance or guarantee mechanisms to help Tunisian organic exporters hedge currency risk on essential imported inputs), enhanced trade agreement design (deepening existing EU-Tunisia agreements to include chapters on financial cooperation, macroeconomic dialogue, and stability support for strategic sustainable sectors), and targeted support for Tunisia given its role as the EU's leading external supplier of organic olive oil.

Figure 5 illustrates the integrated policy implementation framework derived from our empirical findings. It highlights a multi-level transmission mechanism in which macroeconomic stability (exchange rate management) conditions sectoral investment decisions (organic land allocation), which in turn determine export performance. The framework emphasizes that sustainable export competitiveness requires coordinated interventions across monetary, agricultural, and trade policy domains

5.3. *Limitations and Future Research Directions*

While this study provides robust evidence on the interaction between organic transition and macroeconomic conditions, several limitations warrant acknowledgment and point to productive avenues for future research.

First, our analysis relies on annual frequency data, dictated by availability of official statistics on certified organic area and trade values. This temporal aggregation may mask important intra-annual dynamics. Agricultural decisions (pruning, irrigation, harvesting) and market adjustments often occur at seasonal or quarterly frequencies. Sudden exchange rate shocks within a year could have immediate effects on imported input costs that annual data cannot fully capture. Future research could employ higher-frequency data (quarterly or monthly) where available, or incorporate survey-based measures of farmer expectations and planting decisions to better capture shorter-term adjustment mechanisms.

Second, despite the comprehensiveness of our model specification, several relevant contextual variables could not be systematically included due to data constraints or model parsimony concerns. For instance, fluctuations in international oil prices significantly influence transportation and packaging costs, both substantial components of olive oil export margins. Similarly, regulatory changes in the EU concerning organic import standards or preferential trade agreements can affect market access conditions and price premiums. Furthermore, evolving consumer preferences in destination markets (e.g., toward “sustainable”, “zero-waste”, or “regenerative” products) could influence quality premiums beyond organic certification alone. While our inclusion of unit export price (lnUPRICE) as a sensitivity check and EU GDP as a control partially captures some demand-side effects, these omitted factors represent areas for deeper investigation.

Third, the study identifies a plausible behavioural mechanism (producers delaying conversion investments in response to exchange rate uncertainty) but cannot directly test it with aggregate time-series data. Farm-level panel data would be required to establish microeconomic foundations for the EXR → OA causal link.

These limitations do not invalidate our core findings but suggest that estimated elasticities may partially reflect the influence of unobserved, correlated factors. Future studies could adopt more granular data collection strategies and incorporate these variables explicitly within multi-equation frameworks or scenario analyses to further disentangle their specific contributions.

Data Availability Statement

The annual aggregate data used in this study are available from the following public sources: FA-OSTAT (trade data), World Bank (macroeconomic indicators), and Central Bank of Tunisia (exchange rates). Data on certified organic olive area were provided by the Tunisian National Olive Oil Office (ONH) and can be obtained upon reasonable request from the institution. The complete transformed dataset and replication codes for the analyses are available from the corresponding author upon justified request.

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Appendix A

Table A.1 - Complete Data Sources and Variable Construction.

<i>Variable</i>	<i>Definition / Transformation</i>	<i>Source</i>	<i>Period</i>
EXV	Olive oil export value (US\$), log-transformed	FAOSTAT	2000-2024
OA	Certified organic olive area (hectares), log-transformed	National Olive Oil Office (ONH)	2000-2024
EXR	Nominal exchange rate (TND per US\$), log-transformed	Central Bank of Tunisia / FAOSTAT	2000-2024
UPRICE	Unit export price (EXV ÷ Volume), log-transformed	The author's calculation	2000-2024
PPI	Olive producer price index, deflated (2014–2016 = 100)	FAOSTAT	2000-2024
RAIN	Rainfall deviation index	CRU TS v4.06	2000-2024
EU_GDP	Weighted EU GDP (0.4 Germany + 0.35 Italy + 0.25 France)	World Bank	2000-2024
<i>Note: All variables were converted to natural logarithms for analysis. The unit export price (UPRICE) serves as a proxy for quality upgrading and market positioning but is excluded from the baseline model (see Appendix E).</i>			

Appendix B - Robustness and Stability Tests

Table B.1 - Instrumental Variable ARDL (IV-ARDL).

<i>Variable</i>	<i>Coefficient</i>	<i>Robust SE</i>	<i>Significance</i>
lnOA	0.714***	0.154	Yes
lnEXR	−0.683***	0.198	Yes
lnEU_GDP	0.478***	0.155	Yes
<i>Diagnostics:</i>			
F-stat (instrument strength) = 19.2 → strong instrument			
sargan-Hansen (overid)	$\chi^2(1)=0.90$	p=0.342	instruments valid
Durbin-Wu-Hausman	$\chi^2(1)=2.18$	p=0.14	no endogeneity bias
<i>Note: *** $p < 0.01$. Instruments: lagged lnOA ($t-2$, $t-3$) and rainfall deviation index.</i>			

Table B.2 - Out-of-Sample Forecast Performance.

<i>Model</i>	<i>RMSE</i>	<i>MAPE</i>	<i>Theil's U</i>	<i>Directional Accuracy</i>
ARDL (1,0,1,1,0)	0.057	3.9%	0.205	85%
<i>Note: The ARDL model exhibits high predictive accuracy, with an RMSE 27% lower than the random walk benchmark.</i>				

Appendix C – Sectoral and Market Context

Table C.1 - Export Composition by Product Type (2024).

Product Category	Share of Volume	Share of Value	Avg. Unit Price (US\$/t)
Organic Extra Virgin	25%	35%	1,249
Conventional Extra Virgin	45%	46%	901
PDO / Specialty	5%	8%	1,333
Other (Bulk, flavored)	25%	11%	650
<i>Observation: Organic products represent 35% of total export value despite constituting only 25% of volume, confirming significant quality premiums.</i>			

Table C.2 - Export Destinations (2024).

Market	Value Share	Growth (2020-2024)	Avg. Price (US\$/t)
European Union (Italy, Spain, France)	72%	+25%	890
United States	15%	+42%	889
Asia (Japan, China, Korea)	8%	+57%	903
Other Markets (Canada, GCC, Australia)	5%	+19%	889
<i>Interpretation: The diversification of Tunisian exports beyond EU markets supports long-run export resilience and competitiveness.</i>			

Table C.3 - Robustness of EU_GDP to Alternative Country Selections.

Specification	Coefficient (lnEU_GDP)	95% CI	p-value
Baseline (DE+IT+FR, weighted 0.4/0.35/0.25)	0.481***	[0.220, 0.742]	0.007
EU-27 (excluding CEE and UK)	0.458***	[0.195, 0.721]	0.009
Equal weights (DE+IT+FR, 1/3 each)	0.492***	[0.231, 0.753]	0.006
Only Germany	0.512***	[0.248, 0.776]	0.004
<i>Note: All specifications include the same control variables. Results remain stable across specifications.</i>			

Appendix D – Descriptive Analysis of the Post-Revolution Period

Following the 2011 Tunisian Revolution, the organic olive sector experienced accelerated growth. Average organic area expanded from 24,500 ha (2000-2010) to 52,100 ha (2012-2024). Export value grew correspondingly from USD 62 million to USD 106 million (constant 2015 dollars). However, the Chow test ($p=0.087$) indicates that the structural relationships between variables did not change significantly after 2011. This suggests that while the level of organic adoption increased, the elasticities (marginal effects) remained stable. The post-revolution period is therefore captured through the time-series dynamics of the variables rather than a structural break dummy.

Appendix D: Additional Methodological Details

Table D.1 - Bai-Perron Multiple Structural Break Test Results.

Variable	Number of Breaks	Break Years	F-statistic	Significance
lnEXV	2	2011, 2020	24.78	p<0.01
lnOA	2	2008, 2015	18.65	p<0.05
lnEXR	1	2014	15.32	p<0.05
System-wide	3	2008, 2011, 2020	31.45	p<0.01
<i>Interpretation: Structural breaks correspond to key historical events: 2008 (global financial crisis), 2011 (Tunisian Revolution), 2014 (major dinar devaluation), 2015 (EU organic regulation changes), and 2020 (COVID-19 pandemic).</i>				

Table D.2 - Bootstrap Confidence Intervals (10,000 Replications).

Parameter	Point Estimate	95% Bootstrap CI (Lower)	95% Bootstrap CI (Upper)	Coverage Probability
$\beta(\ln OA)$	0.598	0.348	0.848	0.947
$\gamma(\ln EXR)$	-0.653	-0.975	-0.331	0.953
$\delta(\ln UPRICE)$	0.812	0.645	0.979	0.942
$\theta(ECT)$	-0.584	-0.749	-0.419	0.956
<i>Note: All bootstrap confidence intervals exclude zero, confirming statistical significance at 5% level despite small sample size (N=25).</i>				

Appendix E – Sensitivity Analysis Including lnUPRICE (with reader's note)

Reader's note: The unit export price (lnUPRICE) is mechanically related to export value by construction ($UPRICE = EXV / \text{Volume}$). While we include it in sensitivity analyses as a proxy for quality upgrading (Pierani & Rizzi, 1991), these specifications should be interpreted with caution. The baseline ARDL model excludes lnUPRICE to avoid mechanical endogeneity. Results below are for completeness and should not be overinterpreted.

Appendix F – DOLS and CCR Results

Table F.1 - Alternative Long-Run Estimators – DOLS and CCR.

Variable	DOLS	CCR	Mean (ARDL+FMOLS+DOLS+CCR)	Std. Dev.
lnOA	0.585***	0.604***	0.600	0.011
lnPPI	0.272**	0.294**	0.288	0.013
lnEXR	-0.668***	-0.659***	-0.656	0.011
lnOA×lnEXR	-0.132*	-0.128*	-0.128	0.005
<i>Note: *** p<0.01, ** p<0.05, * p<0.10. All coefficients significant at 5% level across methods. DOLS with leads/lags = 1; CCR with Bartlett kernel.</i>				

Appendix G - Bootstrap Confidence Intervals (10,000 Replications)

Table G.1 - Bootstrap Confidence Intervals.

Parameter	Point Estimate	95% Bootstrap CI (Lower)	95% Bootstrap CI (Upper)	Coverage Probability
β (lnOA)	0.598	0.348	0.848	0.947
γ (lnEXR)	-0.653	-0.975	-0.331	0.953
δ (lnUPRICE)	0.812	0.645	0.979	0.942
θ (ECT)	-0.584	-0.749	-0.419	0.956

Note: All bootstrap confidence intervals exclude zero, confirming statistical significance at 5% level despite small sample size ($N=25$).

Appendix H - Sensitivity Analysis Excluding 2024 Observations

Table H.1 - ARDL Estimates Excluding 2024 (2000-2023).

Variable	Coefficient (2000-2024)	Coefficient (2000-2023)	Difference
lnOA	0.598***	0.591***	-0.007
lnEXR	-0.653***	-0.648***	+0.005
lnOA $\times$ lnEXR	-0.128*	-0.125*	+0.003
ECT(-1)	-0.584***	-0.579***	+0.005

Note: *** $p<0.01$, ** $p<0.05$, * $p<0.10$. Results are virtually identical, confirming that the preliminary nature of 2024 values does not affect the main conclusions.

Appendix I - Nonlinear Threshold Effects (Hansen, 1999)

Reader's note: Given the small sample size ($T=25$), threshold estimates should be interpreted with caution. Results are presented here for completeness.

Table I.1 - Nonlinear Threshold Effects.

Threshold Variable	Threshold Value	Regime 1 (Below)	Regime 2 (Above)	LR Test	p-value
Organic Area	45,000 ha	0.421***	0.893***	24.78	0.001
Exchange Rate	2.5 TND/US\$	-0.385**	-1.124***	18.65	0.003

Interpretation: Effects intensify above thresholds, indicating nonlinear relationships.

Orchard management and technical efficiency in olive farms: A flexible stochastic frontier approach

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Abstract

This study investigates the technical efficiency of olive farms in Béjaïa, Algeria, using primary data from a stratified survey of growers conducted in 2025. A flexible stochastic frontier model, complemented by OLS and Cobb-Douglas specifications as comparative benchmarks, captures the non-linear structure of production technology and isolates managerial inefficiency from environmental noise. Results reveal pronounced heterogeneity, with a strongly bimodal efficiency distribution and an average efficiency level of 0.39. This level of efficiency is relatively low compared to typical estimates reported in Mediterranean orchard systems, suggesting substantial room for productivity improvements. Routine agronomic practices emerge as primary determinant of inefficiency: regular pruning, soil-intervention intensity, and irrigation access significantly reduce distance from the frontier, while tree density contributes positively when embedded in a consistent management regime. Human capital also matters, as older and more educated farmers operate more efficiently. The findings imply that productivity gains in perennial systems depend less on marginal input adjustments and more on the coherence and regularity of orchard management. The findings underline the importance of targeted technical support and improved management practices to enhance farm performance in Mediterranean contexts. The study contributes fresh evidence on efficiency determinants in perennial agriculture and informs ongoing efforts to modernize Algerian olive sector.

Keywords: Olive production, Technical efficiency, Orchard management, Stochastic frontier analysis, Agronomic practices, Mediterranean agriculture.

1. Introduction

Olive cultivation has long shaped Mediterranean agricultural systems, structuring landscapes, diets, and rural livelihoods. In Algeria, the crop has acquired renewed strategic importance as policymakers seek to diversify the economy beyond hydrocarbons, reduce depend-

ence on imported vegetable oils, and generate employment in marginal regions. Since the early 2000s, this orientation has been formalized through programs such as the PNDAR and the PRAR, supported by funding schemes including FNRDA, FNDIA, and FNDA, with the objective of modernizing farms and enhancing sector profitability and sustainability (Lamani

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& Ibert, 2016). This policy drive has translated into a marked expansion of the sector, with olive area increasing from around 168,000 ha in 2000 to nearly 440,000 ha by 2022, production exceeding 7 million quintals in 2021/2022, and arid and semi-arid regions now accounting for about 34% of national olive-growing area (MADR, 2023; Sarni *et al.*, 2024).

The quantitative expansion of the sector has been substantial. Olive cultivation now represents nearly 40% of total tree area and about 4% of usable agricultural land (MADR, 2023). Total olive area increased by approximately 162% over the last two decades, while the national tree stock rose from 16.7 million to more than 60 million trees (MADR, 2023). Production remains geographically concentrated: the Kabyle region (Béjaia, Tizi Ouzou, and Bouira) accounts for nearly 70% of olive land and more than 40% of national olive-oil output (PASA, 2021a). Within this core, Béjaia alone contributes almost half of crushed olives, with over five million trees and a central role in processing (MADR, 2023).

Despite this expansion, performance indicators remain modest. Algerian olive oil occupies a limited position in international markets, while domestic prices remain high relative to substitutes: the olive-oil price ratio ranges between five and six, compared to a global average of around 2.2 (Boudi *et al.*, 2013). Imports of other vegetable oils continue to weigh on the trade balance (Bessaoud *et al.*, 2019). These aggregate patterns point to persistent productivity constraints at the farm level, where yields often fall well below agronomic potential, even after accounting for environmental limitations.

Olive production is inherently path-dependent. Decisions regarding planting density, pruning, soil management, irrigation, and fertilization interact with local biophysical conditions over multiple seasons to determine tree vigor, bearing cycles, and oil quality. Empirical evidence from Spain, Greece, Italy, Turkey, and North Africa consistently shows that such management choices are central to both technical and economic performance (Rico & López, 1997; Lambarraa *et al.*, 2007, 2009; Amores & Contreras, 2009; Beltrán-Esteve, 2013; Lachaal *et al.*, 2005; Kashiwagi *et al.*, 2012; Tzouvelekas

et al., 1997, 2001; Noman & Fernández Uclés, 2024). At the same time, Mediterranean olive systems are subject to pronounced rainfall variability and heterogeneous soils and topography, which shape attainable yields independently of managerial effort (Beltrán-Esteve, 2013; Freitas *et al.*, 2024). This combination of controllable and stochastic factors complicates empirical performance assessment.

The stochastic frontier framework provides a natural response to this challenge. Agricultural production is intrinsically stochastic, as yields are affected by weather variability, pests, diseases, and measurement errors. These elements are particularly relevant for perennial crops, where current output reflects decisions made several years earlier. For this reason, stochastic frontier analysis (SFA) has become the dominant empirical approach in studies of olive-farm performance in both Southern Europe and North Africa (Lambarraa *et al.*, 2009; Tzouvelekas *et al.*, 2001; Lachaal *et al.*, 2005; Kashiwagi, 2017).

Existing studies consistently document substantial inefficiency in olive production, alongside marked heterogeneity across regions and systems. In Spain, efficiency is shaped by farmer characteristics, tenure arrangements, irrigation practices, and organic farming (Lambarraa *et al.*, 2007; Alcaide-López-de-Pablo *et al.*, 2014). Greek studies highlight differences between organic and conventional systems, as well as the role of farm size, improvement plans, and land fragmentation (Tzouvelekas *et al.*, 1997, 2001; Giannakas *et al.*, 2000, 2003; Karagiannis & Tzouvelekas, 2001). In Tunisia, improved input use, irrigation, and tree productivity significantly raise output, though irrigation effects are not uniformly positive (Lachaal *et al.*, 2005; Kashiwagi *et al.*, 2012). Similar findings in Turkey emphasize the importance of property structure, mechanization, and irrigation (Artukoğlu & Olgun, 2008; Çukur *et al.*, 2013; Özden & Dios-Palomares, 2016; Bozoğlu & Ceyhan, 2007).

For Algeria, however, empirical evidence remains limited. Some recent studies examine efficiency in related subsectors, such as dairy production, irrigation schemes, or mixed farming systems, using DEA or SFA (Oulmane & Benmehaia, 2019; Oulmane *et al.*, 2019; Ameer *et*

al., 2024; Moulay Ali *et al.*, 2024), while others focus on the macroeconomic effects of agricultural subsidies (Mokhtari & Moulay Ali, 2016). These contributions underline the importance of education, advisory services, credit access, and policy design. Yet few studies address olive production directly, and those that do often adopt a value-chain perspective or do not explicitly incorporate detailed agronomic practices (Sarni *et al.*, 2024).

This omission is significant in light of advances in agronomic research. High-density systems can accelerate early bearing and increase cumulative yields, though they may also introduce sustainability challenges without appropriate management (Pastor *et al.*, 2007; Rallo *et al.*, 2013; Freitas *et al.*, 2024). Irrigation improves yields and resilience but depends critically on timing, dosage, and farmer expertise (Michelakis *et al.*, 1994; Pastor *et al.*, 1999; Ben Ahmed *et al.*, 2007; Beltrán-Estève, 2013; Kashiwagi, 2017; Martins *et al.*, 2024). Soil management practices, including reduced tillage, cover cropping, and organic amendments, enhance soil quality and support long-term productivity (Arampatzis *et al.*, 2018; Kavvadias & Koubouris, 2019; Panettieri *et al.*, 2022; de Sosa *et al.*, 2023; Hrameche *et al.*, 2024; Ciftcioglu, 2025). Importantly, Ruz-Carmona *et al.* (2023) demonstrate that targeted improvements in management and inter-farm cooperation are essential for cost reduction and the sustainable development of traditional olive farming systems. These findings suggest that technical efficiency in olive farming is closely tied to the coherence and quality of management strategies.

Against this backdrop, the Algerian olive sector exhibits a pronounced dual structure. Public policies have expanded tree stocks, improved irrigation access, and supported modernization of processing facilities. Yet production systems remain heterogeneous, i.e., a minority of farms operates relatively intensive, well-managed orchards, while many smallholders rely on extensive, low-input practices. This heterogeneity is

reflected in wide yield disparities and indicates substantial untapped productivity potential. This paper addresses this gap by providing a farm-level assessment of technical efficiency in Algerian olive production, explicitly linking agronomic practices to efficiency outcomes. Using a sample of 60 farms in Béjaia, we estimate a mean-centered Translog stochastic frontier with an inefficiency specification that incorporates key agronomic and socioeconomic variables.

The remainder of the paper is organized as follows. Section 2 reviews the literature on production frontier analysis in olive farming. Section 3 presents the empirical strategy and data. Section 4 explores and discusses the results. Section 5 concludes.

2. Production frontier analysis in olive farming: A brief state of the art

The analysis of productive performance in olive farming has developed into one of the most methodologically sophisticated strands of perennial-crop economics. Since Farrell (1957)'s formulation of efficiency as distance to a best-practice frontier, the olive sector has provided a compelling empirical domain for testing and extending frontier tools, largely because olive production combines long biological cycles, substantial agroecological heterogeneity and marked differences in managerial quality, conditions that generate both measurable inefficiency and pervasive stochastic variability¹. The stochastic frontier approach of Aigner *et al.* (1977) and Meeusen & van den Broeck (1977), together with the decomposition results of Jondrow *et al.* (1982) and the one-step inefficiency structure of Battese & Coelli (1995), offered the necessary analytical structure for disentangling these two dimensions. As a result, SFA has become the dominant framework for empirical research on olive production technologies.

One of the earliest waves of olive-focused frontier studies emerged in Spain, where the sector's diversity of production systems (from

¹ In olive production, this separation is essential, as agronomic responses to pruning, fertilization, or soil work unfold over multiple seasons, making inefficiency fundamentally path-dependent (Giannakas *et al.*, 2000).

traditional rainfed groves to semi-intensive plantations) invited parametric representations of technology. Lambarraa *et al.* (2007, 2009) employed flexible frontiers to quantify efficiency differences among Andalusian growers and found that age, land tenure, participation in organic farming, and the composition of family versus hired labor were consistently associated with shifts in inefficiency. More broadly, these results position farmer characteristics and institutional arrangements as central determinants of efficiency across Mediterranean systems. Their work demonstrated how the stochastic frontier, when paired with agronomic covariates, could recover structural regularities otherwise obscured by the biological variability of olives. Amores & Contreras (2009) and Beltrán-Estevé (2013) expanded this agenda by integrating topographical and environmental indicators, showing that slope, soil depth and rainfall patterns shift not only the frontier itself but also the distribution of inefficiency. This strand of the literature highlights that efficiency outcomes emerge from the interaction between managerial choices and biophysical constraints. These studies were complemented by frontier analyses of olive cooperatives, particularly in Jaén, where Alcaide-López-de-Pablo *et al.* (2014) established that management and investment strategies at the collective level significantly influence technical efficiency, thereby extending frontier methods beyond the farm and into the organizational domain.

Greek research elaborated these insights while examining more explicitly the role of agronomic regimes. Tzouvelekas *et al.* (1997, 2001) compared organic and conventional systems, documenting that even conditional on technology choice, farms display persistent heterogeneity in their distance to the frontier. Their work underscored the importance of education, land fragmentation, machinery use and improvement plans as determinants of inefficiency. This body of evidence reinforces the role of farm structure and technological adoption as key channels through which efficiency differentials materialize. Karagiannis & Tzouvelekas (2001) added dynamic and panel perspectives, showing that olive technology

evolves slowly and that improvements in efficiency require consistent agronomic management over time rather than episodic intensification. From a methodological standpoint, these contributions also demonstrate the relevance of panel-based frontier approaches in capturing the temporal dimension of perennial crop systems. These studies illustrated how frontier methods could capture the slow-moving nature of perennial crops and how managerial decisions accumulate to shape long-run performance.

Across Italy and Portugal, frontier studies provided deeper agroecological grounding. Damas & Romero (1997) used stochastic frontiers to evaluate irrigation efficiency in Mediterranean orchards, establishing early on that water management interacts with tree physiology in ways that fundamentally condition attainable yields. Lodolini *et al.* (2023), Kapellakis & Tsagarakis (2024), Rallo *et al.* (2013) and Pastor *et al.* (2007) contributed agronomic evidence that practices such as pruning, canopy management, fertilization timing and erosion control alter the shape of the production frontier itself. This line of research places irrigation and agronomic practices at the core of efficiency formation, rather than treating them as peripheral inputs. More recent agroecological research, including Panettieri *et al.* (2022), Kavvadias & Koubouris (2019) and de Sosa *et al.* (2023), confirmed that soil organic matter, cover cropping, pruning residue management and conservation tillage directly influence water retention, nutrient cycling and tree vigor, implying that inefficiency in frontier models is a quantifiable reflection of agronomic discipline.

North African contributions broadened methodological and contextual scope. Lachaal *et al.* (2005) documented significant inefficiency among Tunisian producers and showed that efficiency improvements stem from a higher proportion of productive trees, access to training and the systematic use of irrigation. Kashiwagi *et al.* (2012) and Kashiwagi (2017) provided one of the most nuanced analyses of irrigation effects, demonstrating that irrigation can either reduce or increase inefficiency depending on continuity, quantity and managerial experience. These findings underscore that the

impact of irrigation is conditional and mediated by managerial capacity, rather than mechanically efficiency-enhancing. Their results challenged the common assumption that irrigation mechanically shifts farms toward the frontier, emphasizing instead the conditionality of water-use efficiency. Complementary evidence from the Palestinian olive sector, as reported by Kashiwagi (2017), revealed that education, tree density, market accessibility and the configuration of irrigated and rainfed plots have substantial influence on inefficiency, thereby showing the universality of human capital and structural constraints across Mediterranean contexts.

Turkey has provided some of the strongest evidence of structural dualism in olive production. Artukoğlu & Olgun (2008), Çukur *et al.* (2013), Özden & Dios-Palomares (2016) and Bozoğlu & Ceyhan (2007) consistently find wide efficiency dispersion linked to property structure, mechanization, input use and environmental conditions. These studies collectively point to the coexistence of distinct production regimes, where intensive and well-capitalized farms operate closer to the frontier, while extensive systems remain structurally constrained. Their results highlight a distinction between producers who approach modern intensive management and those who rely on more extensive, lower-input systems, reinforcing the frontier framework's ability to reveal heterogeneity embedded in production systems long considered homogeneous.

From a methodological perspective, the state of the art is dominated by stochastic frontier analysis (SFA), although non-parametric approaches have also been used as complementary tools. The DEA approaches have also left their mark on olive efficiency analysis, though typically as complements to parametric frontiers. Applications by Angulo-Meza *et al.* (2019), Stillitano *et al.* (2019, 2020), Díaz *et al.* (2004) illustrate the value of DEA in flexible benchmarking, particularly when technology is highly heterogeneous across orchards across orchards. DEA-based methods, including bootstrapped and meta-frontier variants, allow for useful decompositions of managerial versus structural efficiency. However, the determinis-

tic nature of DEA remains a limitation in the presence of weather-driven yield volatility, a characteristic endemic to Mediterranean olive systems, which explains the predominance of SFA in contexts where stochastic shocks are non-negligible.

Across all these studies, a consistent substantive message emerges. Inefficiency in olive farming is seldom an abstract statistical artifact. Rather, it is a measurable consequence of agronomic routines, i.e., pruning frequency and quality, soil-intervention intensity, fertilizer management, orchard density, basin maintenance, and water-regime design. Studies such as Freitas *et al.* (2024), Ciftcioglu (2025), Arampatzis *et al.* (2018) and Pastor *et al.* (2007) show that these practices shape not only the variance of output but also the attainable frontier itself. The frontier is thus an agronomic construct conditioned by choices that unfold over years.

Despite the maturity of frontier-based analyses in Mediterranean olive systems, Algeria remains largely absent from this literature. Existing studies, whether focused on dairy production, irrigation systems, or agricultural subsidies (Oulmane *et al.*, 2019; Ameer *et al.*, 2024; Moulay Ali *et al.*, 2024; Mokhtari & Moulay Ali, 2016), consistently highlight the role of human capital, extension services, and institutional incentives in shaping efficiency, yet they do not address olive production at the farm level. Where the sector is considered, analyses tend to adopt aggregate or value-chain perspectives, without explicitly incorporating detailed agronomic practices. This gap is particularly notable given the rapid expansion of olive cultivation under the PNDAR and PRAR programs and the marked heterogeneity in orchard density, pruning regimes, irrigation access, and soil management across farms, factors that closely align with the determinants of inefficiency identified elsewhere in the Mediterranean. By combining a flexible stochastic frontier specification with a detailed characterization of orchard practices, this study addresses this omission and provides new evidence on the determinants of technical efficiency in Algerian olive production.

3. Research Methodology

3.1. Empirical strategy and production frontier specification

The empirical strategy relies on a parametric representation of production that reflects the dual nature of olive farming: output is shaped by managerial decisions but remains subject to environmental variability. A stochastic frontier framework is therefore appropriate, as it separates inefficiency from random shocks in a manner consistent with agricultural production processes (Aigner *et al.*, 1977; Meeusen & van den Broeck, 1977).

Let y_i denote farm-level productivity (olive output per hectare). The production function is specified as:

$$\ln y_i = f(x_i; \beta) + v_i - u_i$$

where x_i is a vector of logged inputs, $f(x_i; \beta)$ is a flexible functional form parameterized by β , v_i is a two-sided noise term, and u_i is a non-negative component capturing technical inefficiency². The noise term is assumed to follow a normal distribution $v_i \sim \mathcal{N}(0, \sigma_v^2)$, whereas the inefficiency term follows a truncated-normal distribution $u_i \sim \mathcal{N}^+(0, \sigma_u^2)$, which allows its location to vary with observed characteristics³. This structure permits inefficiency to display systematic patterns while maintaining a stochastic component that captures measurement error and environmental variability.

The deterministic frontier $f(x_i; \beta)$ is modeled using a reduced Translog specification. While a full Translog offers high flexibility, it often leads to over-parameterization and instability

in agricultural datasets characterized by multicollinearity. The reduced form preserves key second-order interactions while maintaining interpretability. Inputs $x_{ki} = (x_{1i}, x_{2i}, \dots, x_{ki})$ are mean-centered as:

$$\tilde{x}_{ki} = \ln x_{ki} - \overline{\ln x_k}$$

which improves numerical stability and facilitates interpretation around the sample mean. The frontier is then specified as:

$$f(x_i; \beta) = \beta_0 + \sum_{k=1}^K \beta_k \tilde{x}_{ki} + \sum_{k=1}^K \sum_{m>k}^K \beta_{km} \tilde{x}_{ki} \tilde{x}_{mi}$$

where the set of interactions $\{\tilde{x}_{ki} \tilde{x}_{mi}\}$ is restricted to those that reflect plausible complementarities and trade-offs in agricultural production. This specification allows the model to capture scale adjustments, input substitution patterns, and nonlinear agronomic relationships, while avoiding the over-parameterization often associated with unrestricted second-order expansions.

Technical inefficiency is allowed to vary with observable farm or managerial characteristics. Let z_i denote a vector of such attributes. Following the formulation of Battese & Coelli (1995), the conditional mean of the inefficiency term is modeled as

$$\mu_i = \delta_0 + z_i' \delta$$

which allows the distribution of inefficiency to reflect differences in structural conditions, man-

² The non-negativity constraint reflects the behavioral assumption that producers cannot exceed the frontier, as any deviation must represent shortfalls relative to the attainable technology. This structural asymmetry distinguishes SFA from OLS and GLS frameworks, where positive and negative deviations are treated symmetrically despite no economic basis for overproduction.

³ The choice between half-normal, exponential, truncated-normal, or gamma distributions reflects assumptions about the heterogeneity of inefficiency across farms. The truncated-normal model adopted here allows inefficiency to vary systematically with observable characteristics (Battese & Coelli, 1995), making it particularly suited to studies where managerial and agronomic traits are central explanatory variables. More particularly, it is preferred over the half-normal alternative as it allows for a non-zero mean inefficiency term, thereby accommodating systematic differences in managerial performance across farms, which is consistent with the observed heterogeneity in production practices.

agerial practices, and socioeconomic characteristics. The specification does not presume that z_i fully determines inefficiency, but it offers the possibility that systematic variation can be detected and interpreted within an agronomically and economically coherent framework.

The composed error term $\epsilon_i = v_i - u_i$ yields farm-specific technical efficiency:

$$TE_i = e^{-\hat{u}_i}$$

where $\hat{u}_i$ is the conditional expectation of inefficiency. The resulting frontier traces an attainable output level given the prevailing agronomic and managerial environment. Therefore, in combining a flexible representation of the production technology with an inefficiency structure informed by observable characteristics, the empirical strategy aims to capture the dual nature of agricultural performance: one part shaped by the input bundle and its interactions, and another linked to the quality and consistency of farm management. Estimation is conducted via maximum likelihood using both Cobb-Douglas and Translog specifications in Stata 17.0, allowing simultaneous estimation of production and inefficiency parameters.

3.2. Data and variable construction

The analysis is based on a farm-level survey conducted in the Béjaia region (Algeria) between January and April 2025, a period allowing reliable reporting of the most recent production cycle. Data were collected through a semi-structured questionnaire capturing input-output relationships alongside agronomic and managerial practices. Representativeness was ensured via stratified sampling across 13 olive-producing municipalities, covering both core and marginal production areas. The number of farms selected within each stratum was determined proportionally to its olive production potential, measured by the stock of olive trees. This approach ensures that areas with higher productive capacity are adequately represented in the sample. Within each stratum, farms were randomly selected from the official agricultural administration

registry, thereby minimizing selection bias. The instrument was pretested on 10 farms to refine measurement and reduce reporting bias.

The final dataset comprises 60 farms and includes information on farm structure, input use, pruning and soil management, irrigation, fertilization, farmer characteristics, and institutional support. While relatively limited in size, the sample reflects the fragmented structure of olive farming in the region and was designed to preserve variability in production systems, management practices, and biophysical conditions, which is essential for stochastic frontier estimation. Numerous studies have reported comparable sample sizes, e.g., Farah & Amara (2023) with 70 olive farms in Tunisia; and Cukur *et al.* (2013) with 60 olive farms in Turkey.

Variables selected are as follows: *Output* is measured as olive production per hectare (qx/ha: quintals per hectare), computed as total harvested olives divided by cultivated area. To limit distortions from alternate bearing and climatic variability, the survey refers to a representative normal production year.

The production frontier includes five logged inputs selected on agronomic and empirical grounds. *Olive-cropped area* (ha) captures productive capacity; total labor (man-days) aggregates family and hired work across all orchard operations; *organic manure* (quintals) reflects soil-enhancing inputs; *chemical fertilizers* (quintals) capture nutrient supplementation; and *tree density* (trees/ha) proxies structural orchard design. To allow for limited flexibility without over-parameterization, three interaction terms are introduced: *size* $\times$ *labor* (scale-labor complementarities), *organic* $\times$ *chemical* fertilizer (input synergy or substitution), and *chemical fertilizer* $\times$ *density* (nutrient efficiency under spatial competition).

The inefficiency specification incorporates nine variables capturing management practices and farmer characteristics. *Tree density* is reintroduced to distinguish structural from managerial effects. *Water regime* is a binary indicator (irrigated vs. rainfed). *Pruning frequency* (0: none; 1: annual; 2: biennial; 3: triennial) captures canopy management regularity. *Soil intervention intensity* (0-3) reflects increasing levels

of soil work and amendment practices, while *basin maintenance* indicates runoff control. Soil intervention intensity was operationalized as an ordinal variable reflecting both the frequency and the diversity of soil management practices performed annually. It was coded on a four-level scale (0-3) as follows: 0 for no soil intervention, 1 for a single intervention, 2 for two interventions, and 3 for three or more interventions, encompassing common practices such as ploughing, disking, and basin maintenance. Pruning frequency was treated as a categorical variable with three distinct levels: annual pruning, biennial pruning, and triennial pruning. Pruning timing was further characterized using two complementary descriptors: (I) the calendar period, extending from November to March, and (II) its temporal relationship with harvest, distinguishing between pruning conducted simultaneously with harvest and pruning performed after harvest. *Farmer age* and *education* proxy experience and human capital, and subsidy status and extension contact capture institutional support.

The dataset exhibits substantial heterogeneity consistent with Béjaia's dual production structure, with coexistence of relatively intensive, well-managed orchards and extensive, low-input systems. Variation in pruning, irrigation, fertilization, and soil management provides the empirical basis for identifying efficiency differentials within the stochastic frontier framework.

4. Results and Discussion

4.1. Descriptive statistics of the sample

Tables 1-3 summarize the production environment of the 60 surveyed farms. Table 1 reports output, inputs, and management variables; Table 2 presents the interaction terms used in the Translog specification; and Table 3 displays input correlations. The sample exhibits substantial heterogeneity in both productivity and management practices. Output ranges from 2 to 227 qx/ha (quintals per hectare), with a mean of 51.8 and a median of 30, indicating a strongly right-skewed distribution where a small group of farms attains high yields while the majority remains far below. This dispersion reflects differ-

ences in management intensity and consistency rather than scale alone.

Farm structure is characterized by small holdings, with an average olive area of 2.3 ha. Labor use is substantial, averaging 307 labor-days per year, but with a wide span from 119 to 805 labor-days, reflecting the coexistence of family-based extensive systems and more labor-intensive orchards where pruning, soil intervention and harvesting are carried out more frequently or more rigorously. In per-hectare terms, these figures imply that labor intensity varies sharply, which is consistent with the positive correlation between area and labor (0.46) and with the structural dualism characteristic of Algerian arboriculture (Table 3).

Fertilization practices are highly uneven. Both organic and chemical inputs have median values of zero, indicating that more than half of farms do not apply fertilizers in a typical season, while a smaller group applies substantial quantities. Chemical fertilizer use is moderately correlated with farm size (0.59), suggesting that larger farms are more likely to adopt mineral inputs, whereas organic fertilization appears less structurally determined. This dispersion supports the inclusion of interaction terms to capture input complementarities.

Tree density averages 148 trees/ha (range: 80-350) and is strongly correlated with farm size (0.86), indicating heterogeneity in orchard design. Since density affects light capture and resource competition, it is likely to be a key determinant of efficiency differences.

Management practices further reflect structural heterogeneity. Only 25% of farms are irrigated, and 70% do not maintain tree basins, indicating widespread reliance on rainfall. Pruning and soil interventions vary considerably across farms, from regular management to minimal or irregular practices, reinforcing the link between management quality and productivity outcomes.

Farmer characteristics point to a traditional production system: the average age is around 60 years, education levels are low, and only a minority benefits from subsidies (35%) or extension services (20%). This suggests that managerial practices rely primarily on experience rather than institutional support.

Table 1 - Descriptive statistics of output, inputs, and management variables ($N = 60$).

<i>Variables</i>	<i>Mean</i>	<i>Median</i>	<i>S.D.</i>	<i>Min</i>	<i>Max</i>
Productivity (qx/ha)	51.80	30.0	52.40	2.00	227.00
Olive area (ha)	2.31	2.00	1.23	1.00	6.67
Labor (days/year)	307.20	227.00	191.00	119.60	805.60
Organic fertilizer (qx)	40.70	0.00	89.70	0.00	534.60
Chemical fertilizer (qx)	4.03	0.00	9.40	0.00	58.36
Tree density (trees/ha)	148.60	148.50	50.20	80.0	350.00
Irrigation water regime	0.25	0.00	0.43	0.00	1.00
Pruning frequency	1.80	2.00	0.77	0.00	3.00
Soil intervention intensity	1.40	1.00	0.86	0.00	3.00
Basin maintenance	0.30	0.00	0.46	0.00	1.00
Farmer's age	59.80	59.00	8.45	43.00	78.00
Farmer's education level	1.67	2.00	1.16	0.00	4.00
Subsidy recipient	0.35	0.00	0.48	0.00	1.00
Extension contact	0.20	0.00	0.40	0.00	1.00

Table 2 - Descriptive statistics of retained interaction terms.

<i>Interaction terms</i>	<i>Mean</i>	<i>S.D.</i>	<i>Min</i>	<i>Max</i>
size $\times$ labor	0.123	0.344	-0.208	1.333
organic $\times$ chemical fertilizer	-0.356	2.972	-4.872	15.461
chemical fertilizer $\times$ density	0.236	0.481	-0.529	3.097

Table 3 - Correlation matrix of logged inputs.

<i>Variables</i>		[1]	[2]	[3]	[4]	[5]
Size	[1]	1.000	0.459	0.316	0.587	0.863
Labor	[2]	—	1.000	0.086	0.265	0.645
Organic fertilizer	[3]	—	—	1.000	-0.142	0.324
Chemical fertilizer	[4]	—	—	—	1.000	0.636
Tree density	[5]	—	—	—	—	1.000

Demographic attributes reinforce the image of a traditional production base. Farmers are, on average, 60 years old, with limited formal education (mean category below secondary school). Only a minority receives subsidies (35%) or have extension contact (20%).

This combination is characteristic of a sector in which managerial knowledge accumulates through experience rather than institutional support, and where limited exposure to technical advice may inhibit the adoption of practices that enhance efficiency.

The input correlations align with typical Mediterranean smallholder systems. Land, labor, fertilizer use and density are positively correlated, particularly the strong association between area and density (0.86) and between density and labor (0.64), indicating that intensively planted orchards require and attract greater labor resources. Organic and chemical fertilizers are only weakly correlated, again signaling distinct fertilization strategies rather than a uniform management regime. These patterns support the use of a reduced Translog specification, which allows for flexible input interactions without imposing restrictive assumptions.

4.2. Results of the stochastic frontier estimation

The estimation results provide a consistent picture of olive production technology and the sources of inefficiency across farms (Table 4). The OLS model shows high explanatory power ($R^2 \approx 0.87$), but several coefficients lack statistical significance, reflecting its inability to distinguish inefficiency from random noise. Introducing a stochastic frontier improves identification, while the Cobb-Douglas (CD) specification remains restrictive. The likelihood-ratio test rejects the CD model in favor of the reduced Translog (TL) frontier⁴, confirming the need for a flexible representation of production. The variance parameters ($\sigma^2 = 0.0416$, $\gamma = 0.934$) are both significant, indicating that most unexplained variation is attributable to inefficiency rather than noise.

In the Translog specification, farmland size exhibits a positive and significant elasticity. This should not be interpreted purely as a scale effect; rather, it likely reflects structural factors such as orchard maturity, spatial organization, and management intensity. Both organic and chemical fertilizers have positive and significant effects, with chemical inputs showing a larger elasticity, consistent with their role in short-term nutrient

supply. Organic inputs contribute through improvements in soil structure and moisture retention. Labor is not statistically significant once inefficiency is modeled, suggesting that productivity depends less on labor volume than on how operations are organized and executed.

Interaction terms reveal important nonlinearities. The interaction between area and labor is negative, indicating diminishing marginal returns to labor at larger scales. The interaction between organic and chemical fertilizers is positive, confirming complementarities in nutrient management. In contrast, the interaction between chemical fertilizer and tree density is negative, reflecting reduced marginal productivity of nutrients under higher spatial competition. Tree density itself is positive but not precisely estimated, suggesting that its effect depends on complementary practices captured in the inefficiency equation. The inefficiency model highlights the central role of management. Tree density reduces inefficiency, indicating that more structured orchards operate closer to best practice. Pruning frequency has a strong negative effect on inefficiency, confirming the importance of regular canopy management.

Soil intervention intensity also reduces inefficiency, reflecting its role in water infiltration and weed control. Irrigation exerts the strongest effect: irrigated farms are significantly more efficient, indicating both higher and more stable yields under controlled water supply. Farmer age and education also reduce inefficiency, pointing to the importance of experience and human capital. By contrast, subsidy receipt and extension contact are not statistically significant, suggesting limited effectiveness of institutional support in shaping day-to-day management practices.

Estimated technical efficiency scores reveal substantial heterogeneity. Mean efficiency is 0.386, with values ranging from 0.058 to 0.985, implying that the average farm operates at only 39% of its potential output. This dispersion reflects differences in management quality rather

⁴ The LR statistic (41.93, $df = 3$) strongly rejects the Cobb-Douglas specification ($p \approx 0$), indicating that second-order interaction terms significantly improve model fit. This confirms that olive production technology exhibits nonlinearities and input interdependencies that cannot be captured by constant elasticities.

Table 4 - Estimation results of OLS, Cobb-Douglas, and Translog stochastic frontier regressions.

<i>Variables and main related parameters</i>	<i>OLS estimation Coef. estimates (SE)</i>		<i>CD-SFA estimation Coef. estimates (SE)</i>		<i>TL-SFA estimation Coef. estimates (SE)</i>	
<i>Frontier equation</i>						
<i>Farmland size</i>	0.485 (0.299)		0.082 (0.172)		0.687 (0.163)	***
<i>Labor</i>	1.304 (0.174)	***	−0.082 (0.276)		0.015 (0.162)	
<i>Organic fertilizer</i>	0.006 (0.041)		0.006 (0.008)		0.037 (0.011)	***
<i>Chemical fertilizer</i>	0.217 (0.151)		−0.017 (0.022)		0.251 (0.048)	***
<i>Tree density</i>	1.110 (0.613)	*	1.798 (0.178)	***	0.303 (0.286)	
Size × Labor	−1.606 (0.256)	***	—		−0.525 (0.116)	***
Organic × Chemical	0.087 (0.031)	***	—		0.069 (0.013)	***
Chemical × Density	−0.666 (0.324)	**	—		−0.734 (0.116)	***
<i>Const.</i>	3.707 (0.099)	***	−3.823 (1.877)	**	4.953 (0.109)	***
<i>Inefficiency equation (μ_i)</i>						
<i>Tree density</i>	—		−0.004 (0.002)		−0.009 (0.001)	***
<i>Water regime</i>	—		−14.42 (28.85)		−2.162 (0.275)	***
<i>Pruning frequency</i>	—		−0.117 (0.105)		−0.175 (0.060)	***
<i>Soil intervention</i>	—		−0.443 (0.160)	***	−0.221 (0.095)	**
<i>Basin maintenance</i>	—		0.071 (0.173)		−0.040 (0.103)	
<i>Farmer's age</i>	—		−0.005 (0.008)		−0.010 (0.005)	**
<i>Farmer's education</i>	—		−0.105 (0.063)	*	−0.085 (0.035)	**
<i>Subsidy recipient</i>	—		−0.030 (0.135)		−0.049 (0.076)	
<i>Extension contact</i>	—		−0.175 (0.156)		−0.111 (0.088)	
<i>Const.</i>	—		3.589 (0.857)	***	4.512 (0.532)	***
<i>Variance parameters</i>						
σ ²	—		0.134 (0.027)		0.041 (0.009)	
γ	—		0.981 (0.009)		0.934 (0.055)	
σ _u ²	—		0.132 (0.027)		0.038 (0.010)	
σ _v ²	—		0.002 (0.001)		0.002 (0.002)	
<i>Models fit</i>						
R ² (Adj. R ²)	0.868 (0.847)		—		—	
F-test (p-value)	41.94 (0.000)		—		—	
Log-likelihood	—		4.877		25.842	
Wald χ ²	—		348.410	***	215.220	***

Notes: Standard errors in parentheses after coefficient estimates. Asterisks *, **, *** indicate significance at the 10%, 5%, and 1% levels, respectively.

than input availability alone. The average technical efficiency of 0.39 is markedly lower than levels reported in the Mediterranean olive sector, where estimates typically range from about 0.53 to above 0.80. For instance, efficiency scores reach 0.65-0.75 in Spain (Beltrán-Estevé, 2013; Lambarraa *et al.*, 2007), 0.75-0.77 in Greece (Giannakas *et al.*, 2000), and exceed 0.80 in Tunisia (Kamiyama *et al.*, 2016; Lachaal *et al.*, 2005), with more recent evidence still around 0.57 (Farah & Amara, 2023). Even relatively lower estimates reported for Palestine 0.49 (Kashiwagi, 2017) and Turkey 0.53-0.65 (Cukur *et al.*, 2013) remain above our finding. This gap suggests that farms in the study area operate substantially below the regional frontier, pointing to significant inefficiencies likely driven by managerial and structural constraints rather than input scarcity alone.

Figure 1 shows a pronounced bimodal distribution of efficiency scores. A large group of farms is concentrated between 0.10 and 0.30, indicating widespread low-efficiency regimes, while a much smaller group lies between 0.90 and 1.00, operating close to the frontier. Few farms occupy intermediate levels. This polarization suggests that efficiency differences are not incremental but reflect distinct management regimes. The lower cluster corresponds to irregular or low-intensity practices, whereas the upper cluster demonstrates that high perfor-

mance is attainable under existing conditions. The absence of a middle group indicates limited transition between these regimes, reinforcing the role of consistent and complementary management practices in determining productivity outcomes.

4.3. Discussion and implications

The results point to a production environment where agronomic discipline, water control, and human capital jointly determine proximity to the technological frontier. With a mean efficiency of 0.39 and a sharply bimodal distribution, Béjaia ranks among the least efficient olive systems reported in the Mediterranean.

In Spain, efficiency levels are generally higher despite heterogeneity in terrain and organization (Damas & Romero, 1997; Lambarraa *et al.*, 2007, 2009; Giannakas *et al.*, 2000; Beltrán-Estevé, 2013; Contreras & Amores, 2016), while Greek systems exhibit smoother distributions shaped by fragmentation and varietal diversity (Tzouvelekas *et al.*, 1997, 2001; Karagiannis & Tzouvelekas, 2001, 2009). Tunisian studies typically report efficiency between 0.5 and 0.7 (Lachaal *et al.*, 2005; Kashiwagi *et al.*, 2012, 2013; Farah & Amara, 2023). Even in Palestine, where heterogeneity is pronounced, the distribution retains a middle mass (Kashiwagi *et al.*, 2017;

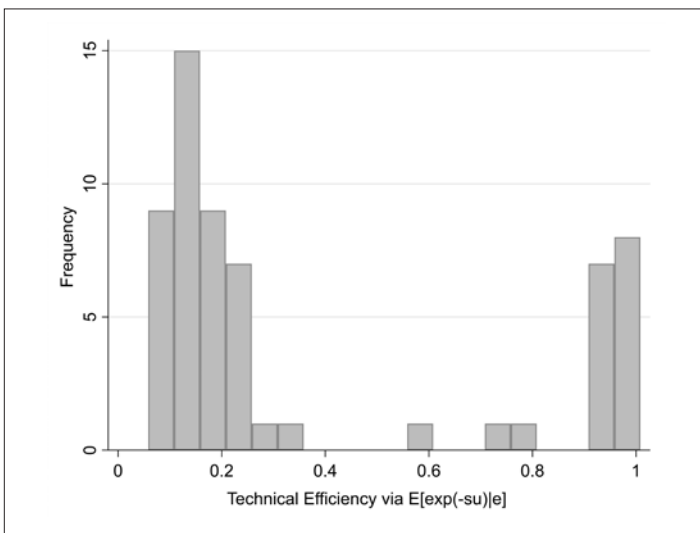


Figure 1 - Plot of the distribution of technical efficiency scores.

Kashiwagi, 2023). By contrast, Béjaia exhibits a clear dual structure, with one group of farms clustered at low efficiency and a smaller group operating close to the frontier.

This dualism reflects distinct management regimes rather than marginal input differences. Agronomic evidence shows that systems combining regular pruning, structured soil management, and consistent water control stabilize bearing and sustain productivity (Pastor *et al.*, 2007; Rallo *et al.*, 2013; Mairech *et al.*, 2021; Camposeo *et al.*, 2011). Pruning maintains canopy balance and fruiting wood (Sbitri & Serafini, 2007), while soil practices enhance infiltration, aeration, and moisture retention (Arampatzis *et al.*, 2018; Kavvadias & Koubouris, 2019; Soriano *et al.*, 2014; Panettieri *et al.*, 2022). The estimated effects of pruning frequency and soil intervention therefore capture not only input use but the regularity and coherence of agronomic routines.

Labor must be interpreted within the regional production system. Harvesting is predominantly manual (brucatura, combing, branch beating), accounting for more than 65% of labor use, followed by pruning (23%) and soil work (7%). As harvesting occurs at the end of the production cycle, it does not affect yield formation. The insignificance of labor in the frontier thus reflects its allocation toward recovery rather than production, in contrast to more mechanized systems in Southern Europe. Performance differences arise from how operations are organized and timed rather than from labor volume.

Irrigation emerges as a decisive factor. While agronomic literature highlights its role in stabilizing yields (Calvo-Polanco *et al.*, 2016; Kaniewski *et al.*, 2023), efficiency studies show that its effect depends on management quality (Kashiwagi, 2017). In Béjaia, the strong negative effect on inefficiency indicates that water access is both limited and unevenly managed. Farms with reliable irrigation operate systematically closer to the frontier. Tree density exhibits a similar conditional role: higher densities can enhance early productivity but require consistent pruning and nutrient management to avoid competition effects (Pastor *et al.*, 2007; Rallo *et al.*, 2013; Freitas *et al.*, 2024). The results suggest that density reflects structured

orchard design, whose performance depends on complementary practices.

Pruning stands out as a central driver of efficiency, consistent with findings across Mediterranean contexts (Lambarraa *et al.*, 2009; Çukur *et al.*, 2013; Artukoğlu & Olgun, 2008; Dias *et al.*, 2020; Rallo *et al.*, 2013; Lachaal *et al.*, 2005). Beyond its direct effect on canopy structure, pruning interacts with soil and nutrient management, reinforcing overall productivity. Recent research on pruning residues and soil amendments (Ciftcioglu, 2025; de Sosa *et al.*, 2023; Alburquerque *et al.*, 2011) further highlights its ecological role.

Human capital also plays a central role. Age and education reduce inefficiency, indicating that experience and schooling enhance managerial capacity. This aligns with evidence from Spain, Turkey, Tunisia, and Algeria (Lambarraa *et al.*, 2007; Lachaal *et al.*, 2005; Noman & Fernández Uclés, 2024; Ameur *et al.*, 2024), and with learning-by-doing mechanisms documented in Mediterranean agriculture (Giannakas *et al.*, 2000; Tzouvelekas *et al.*, 1997; Chebil *et al.*, 2013; Özden & Dios-Palomares, 2016; Farah & Amara, 2023). Limited education among farmers constrains the adoption of improved practices, suggesting that basic training and literacy programs remain important complements to technical interventions.

Institutional variables display weaker effects. Extension contact is not significant, reflecting limited coverage and technical capacity in advisory systems, a pattern also observed elsewhere (Jara-Rojas *et al.*, 2017; Ameur *et al.*, 2024). Evidence from Béjaia indicates substantial unmet demand for training in pruning, irrigation, and orchard management (PASA, 2021b), pointing to gaps in knowledge transfer. Similarly, subsidies show no measurable effect on efficiency. This result is consistent with mixed international evidence (Minviel & Latruffe, 2017; Latruffe *et al.*, 2017; Zhu *et al.*, 2008) and suggests that current schemes primarily ease liquidity constraints without altering management practices.

The sector is characterized by structural heterogeneity and managerial bifurcation. Most farms operate within a low-efficiency regime marked by inconsistent agronomic practices and limited resource control, while a smaller

group has stabilized a coherent management system enabling near-frontier performance. Similar patterns have been documented in perennial systems globally (Osmani & Kambo, 2019; Benmehaia, 2022; González-Esteban & Botella-Rodríguez, 2022).

These findings carry both technical and institutional implications. On the technical side, productivity gains depend primarily on improving routine agronomic practices rather than increasing input quantities. Regular pruning, soil organic matter management, and water control act as structural determinants of yield stability. On the institutional side, current policies emphasize capital accumulation without ensuring effective use. A shift toward practice-oriented support, linking subsidies to improvements in pruning, soil management, and water use, would be more effective in reducing inefficiency.

Extension systems require a similar reorientation. Advisory services should move toward farm-level technical support, capable of guiding pruning, diagnosing soil conditions, and improving irrigation practices. Finally, irrigation infrastructure emerges as a critical lever. Its strong effect reflects both a biophysical constraint and a managerial one, i.e. reliable water supply enables more consistent application of complementary practices. Expanding irrigation, combined with training in water management, would therefore provide a direct pathway for moving farms toward the frontier.

5. Conclusion

Olive farming in Béjaia operates under semi-arid conditions where biological constraints, long production cycles, and heterogeneous management practices jointly shape performance. Despite its economic importance, the technological structure of production and the sources of farm-level variability have remained largely unexplored. This study addresses this gap using a flexible stochastic frontier model applied to farm-level data collected in early 2025. The reduced Translog specification, benchmarked against Cobb-Douglas and OLS models, allows a clear separation between technological relationships and managerial inefficiency.

Three main findings emerge. First, technical efficiency is both low and highly polarized. Most farms operate far from the frontier, while a small group approaches best practice, resulting in a pronounced bimodal distribution. Second, divergence is driven primarily by agronomic discipline rather than input levels. Pruning frequency, soil intervention, and irrigation significantly reduce inefficiency, while tree density contributes positively when embedded in consistent management. Third, human capital matters: experience and education improve efficiency, whereas subsidies and extension contact show no significant effect, pointing to institutional limitations.

These results carry important implications. Productivity gains in perennial systems depend less on increasing inputs than on improving the regularity and coherence of orchard management. Policies oriented toward practice (targeted training, orchard-level advisory services, and performance-based support) are therefore likely to be more effective than input subsidies. Irrigation emerges as the most powerful lever, suggesting that even modest investments in water infrastructure, combined with technical guidance, could significantly reduce inefficiency. Generally, efficiency in Béjaia appears not as a technological constraint but as a managerial one.

The study remains exploratory. The reliance on cross-sectional, self-reported data limits precision and prevents analysis of intertemporal dynamics central to perennial crops, such as pruning cycles, soil evolution, and alternate bearing. Future research should incorporate panel data, combine survey evidence with biophysical indicators (e.g., soil diagnostics or remote sensing), and explore more flexible modeling approaches. Extensions could also examine collective production structures through meta-frontier or hierarchical frameworks, compare parametric and non-parametric methods, and address allocative efficiency.

Despite these limitations, the study contributes to a limited body of farm-level evidence on technical efficiency in olive production in Algeria and identifies the agronomic and institutional levers most relevant for reducing inefficiency. It suggests that closing the productivity gap requires a shift from input-based strategies toward

the consistent management of a dynamic biological system, with coherent agronomic practices playing a central role. Methodologically, the combined use of Cobb-Douglas and Translog stochastic frontiers offers a complementary perspective on efficiency determinants in small-scale olive production.

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Diagnostic et analyse stratégique pour le développement de la filière oléicole en Algérie : Cas de la daïra de M'Chedallah (Bouira)

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Abstract

Olive growing is a key sector of Algerian agriculture, representing 47% of the country's tree-growing potential. It has expanded significantly, making Algeria the world's ninth largest producer of olive oil. The M'Chedallah region in Kabylie is particularly important, with 89.5% of its tree-growing potential dedicated to olive trees and production deeply rooted in the local identity. However, the local olive oil sector is facing a crisis due to a traditional system that is not very competitive, characterised by old orchards, poor maintenance, manual harvesting, fragmented land and the predominance of family farms. These factors, particularly unsuitable harvesting and storage techniques, often result in olive oil quality that falls below international standards (lampante or ordinary virgin), despite the potential for extra virgin olive oil with the right technical approach. The study aims to identify priority levers for action for a sustainable development strategy. It used a participatory approach and a rigorous methodology combining SWOT, AHP (Analytic Hierarchy Process) and TOWS based on surveys of 146 olive growers and 28 olive oil producers, including 3 exporters. The analysis enabled the strategic factors to be ranked. The study concludes that collective organisation is the fundamental lever for overcoming structural weaknesses and committing to the sustainable development of the olive oil sector in M'Chedallah.

Keywords : Olive oil sector, M'Chedallah region (Bouira), SWOT-AHP-TWOS analysis, Olive oil quality, Collective organisation.

1. Introduction

L'huile d'olive reste un produit emblématique au cœur du modèle alimentaire méditerranéen, reconnu depuis 2013 comme patrimoine culturel immatériel de l'humanité par l'UNESCO (de Sosa *et al.*, 2021). Portée par ses qualités nutri-

tives et ses bienfaits sur la santé, la consommation mondiale de cette huile a presque doublé depuis les années 1990, passant de 2 à plus de 3,4 millions de tonnes (COI, 2024). Bien qu'elle ne représente qu'environ 3% du marché mondial des huiles végétales alimentaires (FAO, 2024), elle est considérée aujourd'hui comme

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un produit global, commercialisé dans plus de 150 pays sur les cinq continents (COI), avec des transactions impliquant plus de 1,2 millions de tonnes (COI, 2024). La taille du marché devrait atteindre 33,12 milliards USD d'ici 2030, avec une croissance annuelle composée estimée à 5,2% (Zemri, 2024).

Selon le Conseil Oléicole International (COI), la production mondiale d'huile d'olive, stabilisée au cours de la dernière décennie autour de 3 millions de tonnes par an, a été multipliée par trois en soixante ans, et reste largement dominée par les pays méditerranéens, qui assurent près de 98% de la production mondiale (Selim *et al.*, 2022). Il est à noter que le nombre de pays producteurs n'a pas augmenté de manière significative au fil des ans, alors que le nombre de pays exportateurs a triplé au cours de la même période (Kurtoğlu *et al.*, 2024). La présence de nombreux pays exportateurs qui ne figurent pas parmi les principaux producteurs révèle une faiblesse des stratégies marketing des pays producteurs traditionnels, ouvrant ainsi la voie à des intermédiaires dans le commerce international de l'huile d'olive (Kurtoğlu *et al.*, 2024).

En Algérie, l'oléiculture occupe une place stratégique au sein du secteur agricole, couvrant, en 2022, 442.900 ha soit 47% du potentiel arboricole (MADR, 2023). Marquée par une dualité entre systèmes traditionnels peu compétitifs (contraintes géomorphologiques et institutionnelles) et modernes tournés vers les olives de table, la filière reste fragile avec une irrégularité productive chronique (Hadjou *et al.*, 2013). Bien que cette culture demeure essentiellement concentrée dans les zones montagneuses du Nord, elle a connu ces dernières années une expansion vers les zones steppiques (Hadjloune *et al.*, 2021) portant la superficie totale à plus de 500.000 ha contre 170.000 ha à la fin des années 1990, tandis que la production a dépassé 70.000 tonnes alors qu'elle avoisinait 6.000 tonnes en 1990 (MADR, 2023).

Cette dynamique a propulsé la production d'huile d'olive à plus de 93.000 tonnes en 2023-2024, plaçant l'Algérie 9^{ème} au rang mondial

contre 14^{ème} en 1990 (COI). Les exportations restent toutefois marginales, la consommation domestique absorbant l'essentiel et limitant l'intégration aux marchés internationaux. Bien qu'elle soit supérieure à la moyenne mondiale, cette consommation reste relativement faible (6 l/hab./an selon une étude réalisée dans le cadre du PASA1; ~1,6 kg/hab./an selon le COI 2025), et inférieure à celle observée dans d'autres pays méditerranéens tels que la Tunisie (3,7 kg/hab./an) et encore loin la Grèce (16,3 kg/hab./an). Cette faible consommation s'explique par un prix élevé perçu, un rang bas dans les préférences alimentaires (28^e, 0,25%), une méconnaissance des qualités et des circuits amateurs dégradant la qualité (Chikhi et Djelloul, 2022). En Kabylie (Béjaïa, Bouira et Tizi Ouzou) qui assure 42% de la production nationale, la consommation grimpe à 11 l/hab./an, mais des faiblesses persistent en matière de systèmes de production, de savoir-faire et de commercialisation, révélant un paradoxe entre fort potentiel et faible valorisation interne et à l'export (Expertise France PASA (2021).

La daïra de M'Chedallah située dans la wilaya de Bouira, se distingue par l'importance de son patrimoine oléicole. L'olivier y représente près de 90% du potentiel arboricole et la production est ancrée dans l'identité locale. L'huile d'olive dans cette région est reconnue pour sa qualité organoleptique et ses caractéristiques traditionnelles issues de la mono variété locale de Chemlal. Cependant, la filière fait face à plusieurs défis qui freinent son plein développement. Ces défis incluent la qualité de l'huile produite qui ne répond pas aux normes internationales (COI) due aux pratiques culturelles inadaptées. À cela s'ajoutent des problématiques liées à la faible structuration de la filière, l'insuffisance de mécanismes efficaces de valorisation commerciale, ainsi que l'absence d'une labellisation ou d'une certification pouvant garantir l'authenticité et l'origine de cette huile d'olive.

Dans cette recherche, nous essayons de répondre à deux questions liées : Quels sont les principaux atouts et contraintes du système de production oléicole dans la région de M'Chedal-

¹ Programme d'Appui au Secteur de l'Agriculture (2018-2022).

lah ? Et quelles actions prioritaires peuvent être mobilisées pour renforcer la compétitivité et la durabilité de la filière oléicole dans ce territoire ?

L'objectif de cet article est d'identifier, d'une part, les facteurs internes (forces et faiblesses) et externes (opportunités et menaces) du système de production oléicole dans la daïra de M'Chedallah et d'autre part de dégager les leviers d'action prioritaires en vue de bâtir une stratégie de développement durable adaptée aux spécificités locales de la région.

Sur le plan théorique, notre démarche s'inscrit dans une approche territoriale du développement durable, considérant la filière oléicole comme un Système Productif Localisé (SPL), modélisé comme une organisation productive ancrée dans un espace géographique spécifique, régie par des relations sociales et culturelles au-delà du seul marché (Pecqueur, 2005). Le SPL mobilise des ressources spécifiques non transférables (savoir-faire locaux, patrimoine cognitif, règles tacites) via réciprocité, confiance et capital social, générant des économies d'agglomération et favorisant l'innovation collective (Pecqueur, 2005). Ce cadre a inspiré les Systèmes Agroalimentaires Localisés (SYAL), qui constituent une déclinaison agricole des SPL associant production, transformation et territoire spécifique, particulièrement pertinente pour les produits de terroir (Muchnik *et al.*, 2007 ; Muchnik *et al.*, 2008). Le développement d'un territoire repose sur les ressources territoriales et les acteurs territoriaux qui se mobilisent pour leur valorisation. Ainsi, l'oléiculture en Kabylie peut être appréhendée comme un système productif localisé, articulant ressources naturelles, savoir-faire traditionnels, acteurs économiques (agriculteurs, transformateurs) et institutions. (Choukache & Aknine Souidi, 2022).

Dans cette perspective, la compétitivité recherchée est celle d'une compétitivité territoriale durable, qui vise simultanément la création de valeur économique, la cohésion sociale et la préservation des ressources naturelles à l'échelle de la daïra de M'Chedallah.

L'originalité de cette étude est qu'elle adopte une approche hybride SWOT-TWOS-AHP appliquée à M'Chedallah, première priorisation quantitative participative des stratégies oléicoles

en Algérie, dépassant les analyses descriptives antérieures (Attallaoui, 2022 ; Hadjloune, 2021). Elle offre aux décideurs publics un outil d'orientation des interventions institutionnelles, tout en mettant à la disposition des acteurs de la filière des instruments d'aide à la décision susceptibles de guider leurs choix stratégiques et d'améliorer leur performance collective.

2. Matériel et méthodes

2.1. Description de la zone d'étude

La daïra de M'Chedallah, dans la wilaya de Bouira, fait partie intégrante de la région Béjaia, Bouira et Tizi Ouzou (BBTO). Son verger oléicole s'étend sur une superficie de 7264 ha, offrant 3.600 emplois et sources de revenus (DSA de Bouira, 2024). Cependant, malgré ses atouts et les opportunités de marché, cette filière qui représente un levier important de développement local demeure confrontée à plusieurs défis et menaces. Elle repose essentiellement sur une arboriculture traditionnelle extensive et familiale, formée de vergers anciens, conduits en pluvial et très faiblement entretenus. Dans ces écosystèmes, le foncier, majoritairement familial, est marqué par l'indivision et le morcellement qui freinent les investissements des exploitations. Les amendements d'engrais y sont peu systématisés, conditionnés à la pratique d'activités agricoles complémentaires. Les pratiques de labour existent, selon l'accessibilité et la pente des parcelles et la disponibilité en matériel. La qualité de l'huile d'olive dépend fortement de la maturité des olives récoltées, de la durée et des conditions de stockage avant trituration des olives.

La daïra de M'Chedallah constitue le cadre géographique de notre étude. Ce choix s'explique par la forte vocation oléicole de la région et l'ancrage de l'oléiculture dans l'identité sociale locale (DSA Bouira, 2023). L'huile d'olive de M'Chedallah est d'ailleurs inscrite au catalogue national des produits de terroir du ministère de l'Agriculture et du Développement Rural (MADR, 2022), ce qui consacre la spécificité de ce bassin de production. Sur le plan structurel, l'olivier y représente plus de la moitié de la SAU (51%), avec des exploitations majoritaire-

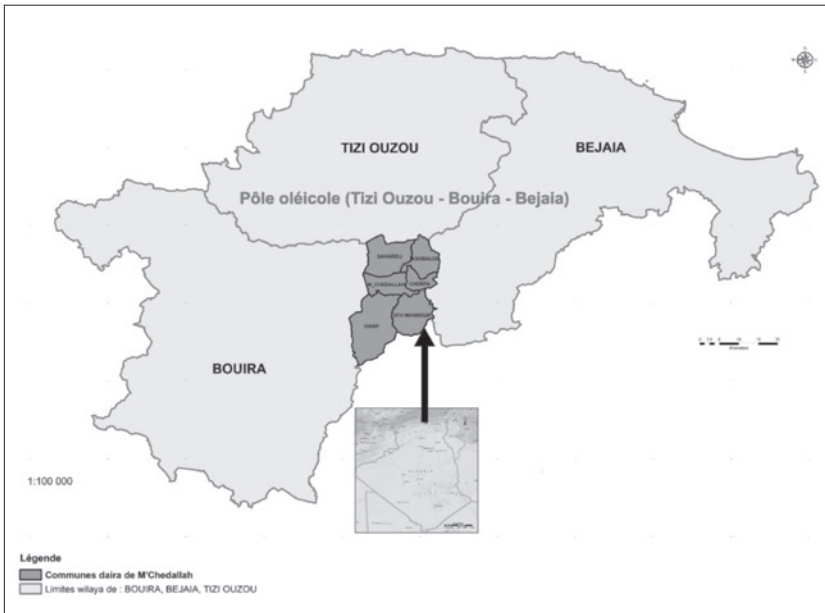


Figure 1 - Carte de délimitation de la zone d'étude (daïra de M'Chedallah).

ment de petite taille, dont 80% inférieures à 1 ha (DSA Bouira, 2023). La filière s'appuie en outre sur un tissu dense de 82 huileries, marqué par la montée en puissance d'unités semiautomatiques et automatiques au détriment des installations traditionnelles (DSA Bouira, 2023). La zone voit également émerger des investisseurs privés se positionnent sur l'exportation de l'huile d'olive, en lien avec la dynamique d'ouverture de la filière algérienne vers les marchés extérieurs. Cette spécialisation génère des opportunités d'emplois ruraux et s'inscrit dans un contexte de soutien public renforcé, notamment via le Programme d'Appui au Secteur de l'Agriculture – Pôle Soummam, qui cible la filière huile d'olive dans les wilayas de Béjaïa, Bouira et Tizi Ouzou. qui en font un cas d'étude privilégié pour examiner l'articulation entre politiques publiques, structuration de la filière et développement territorial.

2.2. Méthode de collecte des données

Une enquête par questionnaire a été menée auprès de 146 exploitations oléicoles de la daïra de M'Chedallah (soit environ 16% de la population mère), durant les campagnes 2022-2023 et 2023-2024, afin d'identifier les facteurs qui constituent les forces, les faiblesses, les opportunités et les

menaces (SWOT) de la filière. La sélection des exploitations reposait sur des critères d'activité commerciale, de taille (exclusion des très petites exploitations moins de 1 ha), de caractère résidentiel des producteurs et d'accessibilité. Les données collectées portent sur les pratiques culturales, les techniques de récolte et de stockage, ainsi que l'organisation des acteurs en amont.

Par ailleurs, 28 huileries (34% de la population mère), dont trois exportateurs, ont fait l'objet d'entretiens et d'observations directes des processus de transformation (trituration, stockage, équipements, relations avec les producteurs). Les entretiens avec les exportateurs ont également porté sur le positionnement commercial de l'huile d'olive de M'Chedallah, les stratégies de développement sur le marché national et international.

L'analyse des données qualitatives a été réalisée en deux étapes complémentaires, directement issues du travail terrain. D'abord, l'identification des facteurs SWOT a reposé sur l'exploitation directe des résultats de l'enquête terrain (entretiens semi-directifs auprès de 146 oléiculteurs ; 28 oléifacteurs dont 3 exportateurs et acteurs locaux, observations personnelles, documents secondaires), via un codage thématique manuel itératif permettant de catégoriser les éléments saillants du territoire oléicole. La triangulation

croisée (sources multi-acteurs, méthodes et analyses successives) a ensuite validé ces facteurs en assurant leur saturation et en minimisant les biais interprétatifs. Parallèlement, la quantification et priorisation des stratégies TWOS ont été effectuées via la méthode AHP structurée dans Excel : les experts ont réalisé des comparaisons par paires des facteurs SWOT selon l'échelle de Saaty (1-9), permettant le calcul automatisé des poids relatifs, de la hiérarchie des priorités et du ratio de cohérence ($CR < 0,1$ idéal).

2.3. Méthodologie d'analyse

Dans le cadre de ce travail, un diagnostic d'état des lieux (méthode SWOT) et une analyse hiérarchique et stratégique (matrice TWOS et AHP) ont été menés :

2.3.1. Une analyse diagnostique basée sur la méthode SWOT

Cette méthode a été développée dans les années 1960 par E.P. Learned, C.R. Christensen, K.R. Andrews et W.D. Guth (LCAG) de l'école de Harvard (Puyt *et al.*, 2023). La matrice SWOT est un outil d'analyse qui sert à élaborer des stratégies de développement. Elle combine l'étude des forces (Strengths S) et faiblesses (Weaknesses W) d'une entreprise ou d'un secteur avec celle des opportunités (Opportunities O) et menaces (Threats T) de son environnement afin d'aider à la définition d'une stratégie de développement dans le processus de prise de décision. (Görener *et al.*, 2012 ; Gurel, 2017).

L'identification des éléments d'une analyse SWOT repose sur l'examen des facteurs internes et externes impactant la stratégie à mettre en place. (Görener *et al.*, 2012 ; Gurel, 2017 ; Tuan *et al.* 2022 ; Le Canh, 2025).

Dans notre cas d'étude, la matrice SWOT était élaborée à partir des résultats de l'enquête de terrain. Pour approfondir l'analyse, un panel de 18 experts de la filière huile d'olive issus de différentes institutions d'administration ou recherche et/ou assurent des fonctions de production, de transformation ou d'exportation a été mobilisé dans une démarche participative. La sélection du panel reposait sur trois critères explicites : I) l'expertise : plus de 10 ans d'expé-

rience en oléiculture et travail d'expertise dans le cadre du projet PASA Soummam ; II) la représentativité : une couverture nationale (MADR), régionale (Bouira) et locale (M'Chedallah) et III) la diversité : administration, recherche, production et exportation.

L'échantillon reflète la structure suivante : l'administration dominante avec 67% cumulés ; 9 acteurs locaux (producteurs et/ou transformateurs) soit 50% du panel d'expert et un producteur local, transformateur et exportateur.

La réalisation des entretiens avec les experts locaux, régionaux et recherche a été menée durant la campagne oléicole 2023-2024 (15 entretiens). D'autres entretiens avec des experts de l'administration centrale ou recherche (3 entretiens) ont ensuite été réalisés lors de notre participation au 1^{er} séminaire international sur l'oléiculture méditerranéenne organisé par l'INRAA le mois d'avril 2025. Durant cette rencontre, nous avons échangé avec plusieurs experts et chercheurs du domaine, ce qui nous a permis de recueillir des informations précieuses pour enrichir notre analyse et pour conforter la validation de nos résultats. Ces échanges ont également contribué à une meilleure compréhension des perceptions, des positions et des expériences de chacun et ce, afin d'évaluer les différents facteurs SWOT ainsi que les stratégies proposées. La comparaison des pondérations globales de la matrice SWOT a ensuite été réalisée sur la base des notes attribuées par les experts selon une échelle allant de 1 à 9.

2.3.2. La matrice des stratégies TOWS

La matrice TOWS constitue un cadre conceptuel qui permet d'identifier et d'analyser les menaces (T) et les opportunités (O) dans l'environnement externe, tout en évaluant les faiblesses (W) et les forces (S) au sein de l'environnement interne. Elle aide à établir les liens entre ces éléments (forces, faiblesses, opportunités et menaces) et sert de fondement pour la formulation de stratégies basées sur ces interrelations (Asadpourian *et al.*, 2020 ; Tuan *et al.*, 2022). Cette matrice comprend quatre combinaisons : SO, ST, WO et WT (Asadpourian *et al.*, 2020 ; Tuan *et al.*, 2022). La stratégie (SO) est une stratégie de développement qui utilise les forces internes pour tirer parti des opportunités

externes. La stratégie (ST) est une stratégie qui vise à atténuer les risques externes en s'appuyant sur les forces internes. La stratégie (WO) est une stratégie qui tente de surmonter les faiblesses internes en exploitant les opportunités externes et la stratégie (WT) est une stratégie défensive qui cherche à réduire les inconvénients des faiblesses internes afin de limiter les menaces extérieures.

2.3.3. L'analyse AHP (Analytic Hierarchy Process)

L'Analyse Hiérarchique des Processus, est une méthode d'aide à la décision multicritère développée par Thomas L. Saaty dans les années 1970 (Mantogiannis et Katsigiannis, 2020; Saaty, 1978, 1996, 2005).

L'AHP compare des paires de facteurs afin de les hiérarchiser à l'aide de calculs distincts pour chaque élément (Görener *et al.*, 2012). Cette méthode approche les critères à prioriser en utilisant le calcul de la valeur propre et les vecteurs propres. Selon Saaty (1987), un jugement est l'expression d'une opinion à propos de la dominance (importance, préférence, vraisemblance) d'un facteur en regard d'un autre. C'est cette capacité de quantifier les aspects généralement qualifiés d'intangibles qui lui confère sa grande pertinence pour l'aide à la décision, une échelle de 9 points (voir annexe 2) quantifie les attributs ou critères intangibles en chiffres mesurables en disposant les paires à comparer dans une matrice (Saaty, 1987 ; Saaty, 1978 ; Saaty et Vargas, 2012).

Pour calculer le Ratio de cohérence (CR) et pour capturer l'incertitude dans le jugement, les équations 1 et 2 sont utilisées (Alam et Waluyo, 2024)

$$CR=CI/RI \quad (1)$$

$$CI=\lambda_{max}-n/n-1 \quad (2)$$

Où λ_{max} est la valeur propre maximale de la matrice, n est le nombre de groupes, CI est l'indice de cohérence, et RI est l'indice de cohérence aléatoire.

Une valeur de CR (taux de cohérence) inférieure ou égale à 0,1 (soit 10%) est considérée comme acceptable. Si le CR dépasse 10 %, il est nécessaire de reconsidérer les comparaisons effectuées (Saaty, 1987 et Vargas, 2012 ; Lee, 2013).

2.3.4. Classement et sélection des stratégies prioritaires

La priorité des stratégies dépend du choix des experts, selon une échelle de 0 à 5 (Tuan *et al.*, 2022).

Pour évaluer la sélection prioritaire des stratégies, l'équation 3a été utilisée (Wickramasinghe & Takano, 2010):

$$S_i = \sum_{j=1}^n G_j R_{ij} \quad (3)$$

Où :

- S_i est le poids total de la stratégie i ,
- G_j est le poids global du facteur SWOT j ,
- R_{ij} est le degré de relation entre la stratégie i et le facteur SWOT j ,
- n est le nombre de facteurs SWOT.

Et enfin, la valeur normalisée des poids stratégiques est calculée selon l'équation 4:

$$N_i = \frac{S_i}{\sum_{i=1}^m S_i} \quad (4)$$

Où :

- N_i est le poids normalisé de la stratégie i ,
- m est le nombre total de stratégies.

Tableau 1 - Indice moyen de cohérence aléatoire (RI).

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0,52	0,89	1,11	1,25	1,35	1,40	1,45	1,49

Source : Saaty (1987).

Tableau 2 - Les niveaux d'évaluation des relations.

Degré	Aucun	Très faible	Faible	Moyen	Fort	Très fort
Valeurs	0	1	2	3	4	5

3. Résultats et discussion

3.1. Les atouts et les opportunités, les faiblesses et les menaces de la filière oléicole locale (daïra de M'Chedallah)

Afin de structurer les résultats de l'analyse stratégique, le tableau ci-dessous présente l'ensemble des éléments identifiés dans les quatre volets de la matrice SWOT: les forces et faiblesses internes, ainsi que les opportunités et menaces externes.

3.2. Résultats de la pondération des facteurs

3.2.1. La matrice de comparaison par paires des facteurs globaux SWOT

Dans cette matrice, nous examinons dès le départ quel est le focus de la hiérarchie des facteurs SWOT globaux. La comparaison des

pondérations des facteurs Forces (S), Faiblesses (W), Opportunités (O) et Menaces (T), fondée sur la sélection et la notation des experts est présentée dans le Tableau 4.

La matrice de comparaison des paires de facteurs globaux de la matrice SWOT indique que le taux de cohérence (CR) de cette comparaison est acceptable, avec $CR=0,00011$ ($CR \leq 0,1$).

- La comparaison des forces (S) aux facteurs WOT donne une pondération de 0,375 (rang 1).
- La comparaison des faiblesses (W) aux facteurs SOT donne une pondération de 0,292 (rang 2).
- La comparaison des opportunités (O) aux facteurs SWT donne une pondération de 0,208 (rang 3).
- La comparaison des menaces (T) aux facteurs SWO donne une pondération de 0,125 (rang 4).

Tableau 3 - La matrice SWOT.

<i>Strengths (S) Forces</i>	<i>Weakness (W) Faiblesses</i>
(S1). Existence d'un potentiel oléicole important (S2). La dominance de la variété Chemlal, à productivité élevée. (S3). Conduite agro-écologique de la culture de l'olivier. (S4). Des innovations adoptées par les exportateurs pour améliorer la qualité de l'huile d'olive produite. (S5). Disponibilité d'une main d'œuvre féminine bon marché. (S6). Exportation de l'huile d'olive vierge et vierge extra par des leaders.	(W1). La qualité de la plupart des huiles d'olives produites ne répond pas aux normes internationales. (W2). L'alternance de l'olivier provoque la fluctuation de la production d'une année à l'autre. (W3). Faible taux d'irrigation (W4). L'oléiculture est une activité secondaire pour les exploitants. (W5). Absence ou insuffisance d'organisation de la filière (coopératives et associations). (W6). Les vergers oléicoles dans la région de M'Chedallah sont âgés. (W7). Les techniques de récolte, de stockage et de transformation sont inadaptées.
<i>Opportunity (O) Opportunités</i>	<i>Threats (T) Menaces</i>
(O1). Une forte demande sur le marché local et international. (O2). Des programmes étatiques soutiennent la modernisation des huileries PNDA, FNDA, Renouveau Rural et PIL. (O3). Existence d'une expérience de jumelage et d'assistance technique dans le cadre de PASA Soummam. (O4). Valorisation des sous-produits.	(T1). Les changements climatiques. (T2). La concurrence déloyale due à la vente informelle d'huile mélangée. (T3). Le morcellement des exploitations oléicoles dans la région de M'Chedallah. (T4). La structure foncière des exploitations surtout familiale en indivision et le non vendu (avoir des oliviers dans une exploitation d'un autre exploitant). (T5). Les maladies de l'olivier et attaque des insectes tels que la tuberculose, la mouche d'olivier.

Source : Réalisé par nous-mêmes à partir des résultats des enquêtes, 2023.

3.2.2. Les facteurs Forces

Les résultats de l'évaluation ont été démontrés par une comparaison interne des facteurs forces, avec un taux de cohérence (CR) égale 0,0076% inférieur à 10%.

Les résultats montrent que l'existence d'un potentiel oléicole important (S1) occupe la première place, les innovations adoptées par les exportateurs pour améliorer la qualité de l'huile d'olive produite (S6) sont classées en deuxième position et l'exportation de l'huile d'olive vierge et vierge extra par des leaders (S4) occupe la troisième place, avec des pondérations respectives de 0,310, 0,244 et 0,172.

3.2.3. Les facteurs Faiblesses

Les résultats de l'évaluation ont été démontrés par une comparaison interne des facteurs faiblesses, avec un taux de cohérence (CR) égale 0,0046%, inférieur à 10% donc la matrice est cohérente.

La pondération du groupe des faiblesses montre que le facteur lié à l'absence ou l'insuffi-

sance d'organisation de la filière (coopérative et association) est considéré comme le plus important parmi les faiblesses, occupant la première place avec une pondération de 0,239 (W5), vient ensuite le problème des techniques de récolte, de stockage et de transformation inadaptées (W7) avec une pondération de 0,186. Quant à la qualité de la plupart des huiles d'olives produites qui ne répond pas aux normes internationales (W1), elle est classée en troisième position, avec une pondération de 0,159.

3.2.4. Les facteurs Opportunités

Les résultats de l'évaluation ont été démontrés par une comparaison externe des facteurs opportunités, avec un taux de cohérence (CR) égale 0,011%, inférieur à 10% donc la matrice est cohérente.

Les résultats du groupe des opportunités ont montré que (O1) est classée en première position grâce l'existence d'une forte demande de l'huile d'olive de M'Chedallah sur le marché local et international avec une pondération de 0,310. En deuxième position (O2) liée au soutien de la po-

Tableau 4 - La matrice de comparaison par paires des facteurs globaux SWOT.

Facteurs	S	W	O	T	Poids	Classement
S	1	9/7	9/5	3	0,375	1
W	7/9	1	7/5	7/3	0,292	2
O	5/9	5/7	1	5/3	0,208	3
T	1/3	3/7	3/5	1	0,125	4
CR=0,00011						

Source : Nos résultats d'après la notation des experts.

Tableau 5 - La matrice de comparaison par paires des forces (S).

S	S1	S2	S3	S4	S5	S6	poids	Classement
S1	1	3	9	9/5	9/4	9/7	0,310	1
S2	1/3	1	3	3/5	3/4	3/7	0,103	5
S3	1/9	1/3	1	1/5	1/4	1/7	0,034	6
S4	5/9	5/3	5	1	5/4	5/7	0,172	3
S5	4/9	4/3	4	4/5	1	4/7	0,137	4
S6	7/9	7/3	7	7/5	7/4	1	0,244	2
CR=0,000076								

Source : Nos résultats d'après la notation des experts.

Tableau 6 - La matrice de comparaison par paires des faiblesses (W).

<i>W</i>	<i>W1</i>	<i>W2</i>	<i>W3</i>	<i>W4</i>	<i>W5</i>	<i>W6</i>	<i>W7</i>	<i>W8</i>	<i>Poids</i>	<i>Classement</i>
<i>W1</i>	1	2	6/5	3	3/4	2/3	6	6/7	0,159	3
<i>W2</i>	½	1	3/5	3/2	3/8	1/3	3	3/7	0,080	5
<i>W3</i>	5/6	5/3	1	5/2	5/8	5/9	5	5/7	0,133	4
<i>W4</i>	1/3	2/3	2/5	1	1/4	2/9	2	2/7	0,053	6
<i>W5</i>	3/2	3	9/5	9/2	9/8	1	9	9/7	0,239	1
<i>W6</i>	1/6	1/3	1/5	1/2	1/8	1/9	1	1/7	0,027	7
<i>W7</i>	7/6	7/3	7/5	7/2	7/8	7/9	7	1	0,186	2
CR=0,000046										

Source : Nos résultats d'après la notation des experts.

Tableau 7 - La matrice de comparaison par paires des opportunités (O).

<i>O</i>	<i>O1</i>	<i>O2</i>	<i>O3</i>	<i>O4</i>	<i>Poids</i>	<i>Classement</i>
<i>O1</i>	1	9/8	9/7	9/5	0,310	1
<i>O2</i>	8/9	1	8/7	8/5	0,276	2
<i>O3</i>	7/9	7/8	1	7/5	0,241	3
<i>O4</i>	5/9	5/8	5/7	1	0,172	4
CR=0,00011						

Source : Nos résultats d'après la notation des experts.

Tableau 8 - La matrice de comparaison par paires des menaces.

<i>T</i>	<i>T1</i>	<i>T2</i>	<i>T3</i>	<i>T4</i>	<i>T5</i>	<i>Poids</i>	<i>Classement</i>
<i>T1</i>	1	9/7	3	9/5	9	0,360	1
<i>T2</i>	7/9	1	7/3	7/5	7	0,280	2
<i>T3</i>	1/3	3/7	1	3/5	3	0,120	4
<i>T4</i>	5/9	5/7	5/3	1	5	0,200	3
<i>T5</i>	1/9	1/7	1/3	1/5	1	0,040	5
CR=0,00064							

Source : Nos résultats d'après la notation des experts.

litique nationale d'appui au développement de filière oléicole par ces différents programmes avec une pondération de 0,276 et en troisième position (O3) c'est l'assistance technique grâce au programme PASA Soummam avec une pondération de 0,241. La valorisation des sous-produits est classée en dernière position (O4) avec une pondération de 0,172.

3.2.5. Les facteurs Menaces

Les résultats de l'évaluation ont été démontrés par une comparaison externe des facteurs menaces, avec un taux de cohérence (CR) égale 0,064%, inférieur à 10%.

La pondération du groupe des menaces montre que le facteur lié aux changements climatiques est considéré comme le plus impor-

tant parmi les menaces, occupant la première place avec une pondération de 0,360 (T1). Vient en seconde position la concurrence déloyale due à la vente informelle d'huile d'olive mélangée à d'autres huiles végétales (T2) avec une pondération de 0,280. Le problème du foncier (T4) occupe la troisième position avec une pondération de 0,2.

3.3. Score pondéré global du groupe SWOT avec l'analyse AHP

L'analyse SWOT et la méthode AHP (Analytic Hierarchy Process) est un modèle considéré

comme plus objectif et plus robuste pour l'élaboration de stratégies (Malik (2013).

À la fin de l'analyse AHP, l'étude a déterminé le poids de chaque facteur dans le groupe SWOT. Toutefois, selon les experts, il est nécessaire de calculer l'importance globale des éléments individuels en tenant compte du poids du groupe auquel appartient chaque facteur. Ainsi, le poids global d'un facteur particulier est calculé en multipliant les poids locaux par les poids du groupe (Lee, 2013 ; Wickramasinghe et Takano, 2010). Les résultats du calcul des poids globaux sont détaillés dans le Tableau 9.

Tableau 9 - Score pondéré global du groupe SWOT avec l'analyse AHP.

Groupe SWOT	Poids du groupe	Facteurs SWOT	Poids local	Poids global
S	0,375	S1	0,310	0,116
		S2	0,103	0,039
		S3	0,034	0,013
		S4	0,172	0,065
		S5	0,137	0,051
		S6	0,244	0,092
W	0,292	W1	0,159	0,046
		W2	0,080	0,023
		W3	0,133	0,039
		W4	0,053	0,015
		W5	0,239	0,070
		W6	0,027	0,008
		W7	0,186	0,040
O	0,208	O1	0,310	0,064
		O2	0,276	0,057
		O3	0,241	0,050
		O4	0,172	0,036
T	0,125	T1	0,360	0,045
		T2	0,280	0,035
		T3	0,120	0,015
		T4	0,200	0,025
		T5	0,040	0,005

Source : calculé par nous-mêmes à partir des résultats du poids du groupe SWOT et des poids des facteurs d'analyse AHP.

3.4. Les options stratégiques de développement de la filière oléicole locale

La consultation avec des experts nous a permis la proposition des stratégies de développement de la filière oléicole dans notre région d'étude.

3.5. Classement et sélection des stratégies prioritaires

La priorité des stratégies dépend du choix des experts sur une échelle de 0 à 5. La pondération relationnelle des facteurs SWOT et des stratégies a été calculée à partir de recherches antérieures sur la méthode DCMD (Fabac & Zver, 2011 ; Malik, 2013 ; Wickramasinghe & Takano, 2010).

Dans le présent travail, nous avons combiné les modèles SWOT-AHP-TOWS pour sélectionner une stratégie prioritaire en matière de développement de la filière oléicole au niveau de la région de M'Chedallah. Les résultats sont récapitulés dans le Tableau 11 (voir Annexe 3 pour plus de détails).

Cette étude a efficacement mobilisé une approche méthodologique mixte pour identifier les facteurs qui influencent l'engagement en faveur d'un développement durable de la filière oléicole dans la région de M'Chedallah, bien que des études antérieures aient proposé des stratégies pour le développement de la filière oléicole algérienne. Les résultats confirment l'importance

de l'organisation collective (WO1), identifiée comme le levier principal pour surmonter les faiblesses structurelles. La coopération organisationnelle (WO1) corrige la faiblesse prioritaire W5 (organisation filière, pondération (0,239), mutualisant les coûts de production, de stockage et de distribution.

Cette observation rejoint les travaux de Hadjloune *et al.* (2021) ; Lamani *et al.* (2016), Hadjou *et al.* (2013) sur la nécessité de l'adoption d'une approche participative et professionnaliser la filière huile d'olive en Algérie.

Cette recommandation a été aussi le résultat de plusieurs travaux menés sur la filière huile d'olive dans les pays méditerranéens, lesquels soulignent le rôle essentiel des organisations collectives dans le développement durable de la filière en favorisant l'innovation, la résilience ainsi que la valorisation économique et sociale. Les coopératives et les projets d'innovation sociale jouent un rôle clé dans la diffusion des bonnes pratiques, la sensibilisation à la qualité et l'adoption de nouvelles technologies (Parrilla-González & Ortega-Alonso, 2021a), améliorant ainsi la structuration et le développement de la filière. Leur action collective permet le renforcement de la résilience face aux risques climatiques et économiques, notamment via la mutualisation des ressources et la proximité géographique (Colamartino *et al.*, 2025 ; Sánchez-Martínez *et al.*, 2020), l'amélioration de la qualité de la commercialisation grâce à l'innova-

Tableau 10 - La matrice des stratégies TOWS.

Strategy: SO	Strategy: WO
(SO1). Formation du capital humain pour produire une huile de qualité. (SO2). Etendre le marché des coproduits.	(WO1). Organisation des agriculteurs en coopérative (organisation de la filière) (WO2) : Stratégie de la gestion de la qualité (un guide pratique pour les bonne pratique au long de la chaîne de valeur.
Strategy: ST	Strategy: WT
(ST1). La mise en place de système de garantie de qualité l'AOP ou label de valorisation du produit de terroir avec une stratégie marketing. (ST2). Adopter les innovations pour faire face à la sécheresse.	(WT1). Ajuster la structure foncière. (WT2). Développer des programmes d'alerte et surveillance des maladies et changements climatiques.

Source : Réalisé par nous-mêmes à partir des dires des experts 2024-2025.

Tableau 11 - Le classement des stratégies.

N°	Stratégie	Explication
1	WO1	Organisation des agriculteurs en coopérative (organisation de la filière).
2	WO2	Stratégie de la gestion de la qualité (un guide pratique pour les bonnes pratiques au long de la chaîne).
3	SO1	Formation du capital humain pour produire une huile de qualité.
4	ST1	La mise en place de système de garantie de qualité l'AOP ou label de valorisation du produit de terroir avec une stratégie marketing.
5	ST2	Adopter les innovations pour faire face à la sécheresse.
6	WT1	Ajuster la structure foncière.
7	SO2	Etendre le marché des coproduits.
8	WT2	Développer des programmes d'alerte et surveillance des maladies.

vation technique, la modernisation des installations et la gestion collective des moulins (Sánchez-Martínez *et al.*, 2020 ; Parrilla-González & Ortega-Alonso, 2021a ; Parrilla-González & Ortega-Alonso, 2021b), l'ancrage territorial et la cohésion sociale, en maintenant la population rurale et en améliorant les conditions de vie locales (Sánchez-Martínez *et al.*, 2020a ; Parrilla-González & Ortega-Alonso, 2021b), ainsi que la promotion des objectifs du développement durable (ODD), en intégrant des valeurs de durabilité, de sécurité alimentaire, de valorisation du patrimoine et d'égalité de genre (Parrilla-González & Ortega-Alonso, 2022 ; Parrilla-González & Ortega-Alonso, 2021a ; Parrilla-González & Ortega-Alonso, 2021b).

Par ailleurs, la stratégie de la gestion de la qualité (WO2) et la formation technique du capital humain et transfert des technologies pour produire une huile de qualité (SO1) sont classées en deuxième et troisième position. Ces recommandations ont été identifiées dans les travaux de Khelfaoui *et al.* (2018) et Lamani *et al.* (2016). La combinaison d'une gestion de la qualité structurée, d'une formation technique continue et du transfert de technologie innovantes est déterminante pour produire une huile d'olive compétitive et durable. La qualité de l'huile d'olive dépend fortement de la gestion de la récolte, du stockage, de l'extraction et de la conservation. Des méthodes innovantes

comme le tri optique des olives, l'utilisation de chambres froides, et la maîtrise des paramètres d'extraction permettent d'optimiser la qualité, même pour les petits producteurs (Violino *et al.*, 2022 et Juliano *et al.*, 2023). La formation, notamment en technologies de l'information et de la communication (TIC), favorise l'innovation organisationnelle et technique, essentielle pour l'amélioration de la qualité (Mozas-Moral *et al.*, 2020). La formation technique permet d'aligner la production sur les exigences du marché (traçabilité, certification, export), renforçant la compétitivité (Mozas-Moral *et al.*, 2020 ; Parrilla-González & Ortega-Alonso, 2021a).

La labellisation (ST1, 4^e rang) renforce S6 (export leaders) face à T2 (concurrence informelle) via traçabilité/marketing, malgré coûts/délais certification, son rang intermédiaire s'explique par les coûts de structuration, les délais d'obtention du label et la nécessité d'une coordination étroite entre acteurs et autorités. Dans ce contexte, la labellisation (ST1), émerge comme une stratégie clé pour différencier l'huile de M'Chedallah sur les marchés, conformément aux recommandations de Lamani *et al.* (2016) ; Hadjou *et al.* (2013) ; Boudi *et al.* (2016) et Hadjloune *et al.* (2021). Les labels tels que l'Appellation d'Origine Protégée (AOP), l'Indication Géographique Protégée (IGP) et le label biologique permettent de distinguer l'huile d'olive locale par son origine, ses méthodes de production

et ses qualités sensorielles. Ces labels sont associés à une meilleure perception de la qualité et à une volonté de payer plus chez les consommateurs (Spognardi et al., 2021 ; Pérez et al., 2020 et García-Moral et al., 2023).

L'adaptation climatique (ST2, 5^e rang) réduit l'effet de la menace T1 (sécheresse) et renforce l'opportunité S1 (potentiel oléicole) par des innovations pour l'irrigation, compte tenu des contraintes d'investissement.

Ces leviers complémentaires, structurels (WO1), commerciaux (ST1) et résilients (ST2) répondent aux questions centrales de recherche, en identifiant les atouts et contraintes du système oléicole de M'Chedallah et en priorisant les actions qui renforcent sa compétitivité, sa valorisation et sa durabilité.

4. Conclusion

L'analyse intégrée (SWOT-AHP-TOWS) de la filière oléicole de M'Chedallah a permis d'identifier des stratégies prioritaires pour renforcer sa compétitivité et son développement durable. Les résultats soulignent l'importance de capitaliser sur les atouts naturels et le savoir-faire local tout en surmontant les faiblesses structurelles, notamment le manque d'organisation collective et les défis qualitatifs.

Les stratégies hybrides issues de la matrice TOWS, combinant opportunités externes et forces internes, offrent des implications convergentes à trois niveaux d'intervention :

Au niveau managérial : il convient d'encourager l'organisation collective des acteurs de la filière notamment par le renforcement des coopératives afin de mutualiser les capacités productives, moderniser les outils de transformation et instaurer des dispositifs de traçabilité garants d'une qualité maîtrisée.

Au niveau marketing : la valorisation par la différenciation géographique et la certification constitue un vecteur stratégique permettant de positionner l'huile d'olive de M'Chedallah sur des segments de marché à forte valeur ajoutée, tant à l'échelle nationale qu'internationale.

Au niveau territorial : les collectivités locales et les institutions publiques sont appelées à jouer un rôle de catalyseur, en soutenant la structura-

tion de la filière, en facilitant l'accès aux mécanismes de financement et en impulsant une gouvernance partagée susceptible d'inscrire durablement la valorisation de ce produit dans une logique de développement local intégré.

En outre, l'approche multicritère SWOT-AHP-TOWS a permis de hiérarchiser ces stratégies, confirmant que la structuration collective et l'amélioration de la qualité sont des leviers incontournables pour une filière résiliente.

Si ces actions sont mises en œuvre de manière coordonnée, avec l'appui des institutions et des acteurs locaux, la filière oléicole de M'Chedallah pourrait se positionner comme un pilier du développement socio-économique régional. Elle deviendrait ainsi un modèle de durabilité, alliant performance économique, préservation de l'environnement et équité sociale, tout en répondant aux défis actuels et futurs du marché.

Néanmoins, l'étude présente des limites : panel d'experts restreint, temporalité courte (2 ans), généralisation limitée à d'autres bassins oléicoles, et biais subjectifs inhérents aux approches participatives. Des recherches futures pourraient étendre cette démarche à d'autres territoires algériens, intégrer des indicateurs agroécologiques (eau, climat) et mettre en place un suivi longitudinal avec panel élargi pour tester la transférabilité du modèle.

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Annexe 1 – Composition du panel d'experts qui ont participé à l'évaluation des facteurs SWOT et des options stratégiques

<i>Maillon de la chaîne</i>	<i>Nombre d'experts</i>	<i>%</i>	<i>Organisme /domaine d'expertise</i>
Administration centrale/régionale	4	22.2	MADR, DSA Bouira
Recherche et vulgarisation	4	22.2	INRAA, INVA, ITAFV, INPV
Production locale/Administration agricole régionale	1	5.5	CAW Bouira
Production locale/Administration agricole locale	7	39	Oléiculteurs locaux et cadres dans les subdivisions agricoles (Ahnif ou M'Chedallah)
Production locale/Transformation/Administration agricole locale	1	5.5	Oléiculteur local, oléifacteur et ex-subdivisionnaire agricole (Ahnif)
Production/Transformation/Export	1	5.5	Oléiculteur, oléifacteur et exportateur privé local (Ahnif) et propriétaire du site de démonstration PASA
Total	18	100	

Source : Réalisé par les auteurs.

Annexe 2 – L'Échelle d'évaluation de Saaty (1996)

<i>Échelle de notation</i>	<i>Définition</i>	<i>Explication</i>
1	Importance égale	Ces deux valeurs contribuent également à l'objectif.
3	Faible importance	L'expérience et le jugement sont quelque peu plus sensibles à une activité qu'à une autre.
5	Plus important	L'expérience et le jugement sont davantage en place dans une activité que dans d'autres.
7	Très important	Une activité intense et une influence ont été démontrées en pratique.
9	Extrêmement important	Les preuves en faveur d'une activité par rapport à une autre sont aussi fortes que possible.
2, 4, 6, 8	Intermédiaire entre deux jugements adjacents	Un compromis est nécessaire entre les commentaires.

Annexe 3 – La matrice de sélection des stratégies prioritaires

<i>Facteurs SWOT</i>	<i>SO1</i>	<i>SO2</i>	<i>WO1</i>	<i>WO2</i>	<i>ST1</i>	<i>ST2</i>	<i>WT1</i>	<i>WT2</i>
S1	2	3	5	4	2	3	3	3
S2	0	1	0	2	4	3	0	0
S3	1	0	1	1	3	1	0	1
S4	5	0	5	4	3	2	0	1
S5	5	0	4	3	1	0	0	0
S6	3	0	5	4	4	0	2	0
W1	4	0	3	5	2	0	3	0
W2	0	1	0	0	0	4	0	0
W3	0	0	4	0	0	5	4	1
W4	3	0	4	1	2	1	0	0
W5	4	2	5	1	4	0	4	0
W6	0	0	0	1	0	3	0	5
W7	4	0	3	5	4	0	0	1
O1	4	1	5	5	5	0	2	0
O2	3	4	5	1	4	4	4	2
O3	5	4	5	5	2	3	0	3
O4	3	5	4	3	0	0	0	0
T1	0	0	1	1	0	5	0	2
T2	1	0	4	1	5	0	0	0
T3	0	0	2	0	0	3	5	1
T4	0	0	3	0	0	0	5	0
T5	2	0	0	2	0	1	0	5
Poids total	2,600	1,222	3,695	2,684	2,426	1,729	1,662	0,939
Poids de relation	0,153	0,072	0,218	0,158	0,143	0,102	0,098	0,055
Classement	3	7	1	2	4	5	6	8

Source : Réalisé par les auteurs à partir des notations des experts 2024-2025.

Legumes: A powerful remedy for the current fertilizer crisis

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Among the many consequences of the recent conflict in the Middle East, one of the most unexpected but particularly critical for food security and world hunger is the fertilizer crisis. Global food production relies heavily on crop fertilization, especially nitrogen fertilizers. Rising fertilizer prices directly translate into increased food production costs, higher prices for consumers, and stronger inflationary pressures in the economy, creating the risk of a new global recession. The United Nations has already warned that instability in energy and fertilizer markets could have serious consequences for agricultural production, especially in the most vulnerable regions of the planet (UN News, 2026). Recent European Commission data highlight the persistent vulnerability of fertilizer markets to geopolitical disruptions (Figure 1). Similar patterns emerged during the 2021-2022 geopolitical and energy crisis, when fertilizer prices experienced unprecedented increases, particularly for nitrogen and phosphorus. The renewed upward pressure observed in 2026 suggests that these structural vulnerabilities remain largely unresolved. Notably, nitrogen fertilizers recorded by far the strongest increase, rising by 51% between October 2025 and April 2026, compared with 15% for phosphorus and only 1% for potassium fertilizers. This divergence is particularly important given the central role of nitrogen fertilizers in modern agricultural production and their strong link to both energy markets and production costs. (European Commission-Directorate-General for Agriculture and Rural Development, 2026a). Meanwhile, the value of EU fertilizer imports increased from around €5-8 billion annually to more than €17 billion in 2022, highlighting the dependence of the agri-food system on external inputs and international markets (European Commission-Directorate-General for Agriculture and Rural Development, 2026b).

Undoubtedly, a geopolitically stable world, with free and smooth movement of raw materials and goods, could be the most immediate solution. However, restoring a cheap and stable flow of fertilizers takes time and depends on factors that go beyond the agri-food sector. Studies have already pointed out that a large part of the world's population depends directly on synthetic nitrogen fertilizers for food security, while their production is closely linked to the use of natural gas and fossil fuels (Crews & Peoples, 2004; Palmero *et al.*, 2022; Stagnari *et al.*, 2017). In this unstable environment, nutrition and dietary patterns themselves can offer more immediate, resilient and sustainable solutions for agri-food systems.

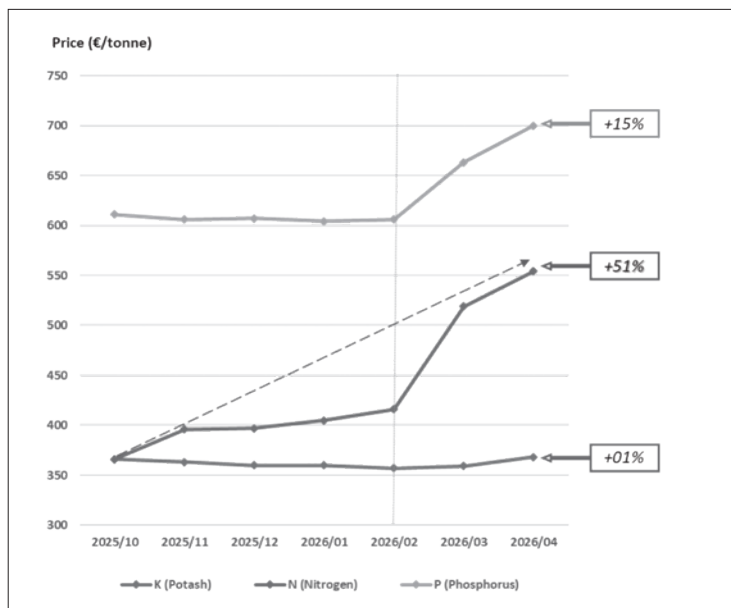


Figure 1 - Fertilizer prices in the EU, October 2025-April 2026.

Source: European Commission DG AGRI, adapted by the authors.

The Mediterranean Diet is now an internationally recognized model of healthy eating, while several modern dietary models, such as the DASH and MIND diets, are based on its principles. Moreover, it has been shown that the Mediterranean Diet is associated not only with benefits for human health, but also with positive effects on the environment, biodiversity and sustainability of agri-food systems (Mattas *et al.*, 2023). In this context, the cultivation of legumes takes on particular importance, as it offers a kind of “self-replenishing” soil fertility to agricultural systems through natural nitrogen fixation.

Legumes have long been a key source of plant protein in the Mediterranean Diet and in many traditional diets worldwide. They are widely used both for human consumption and for animal feed. Their special value, however, is not limited to their nutritional contribution. Legumes contribute substantially to improving soil fertility through biological nitrogen fixation, reducing the need to use synthetic fertilizers and maintaining the productivity of subsequent crops in the context of crop rotations. In some cases, the biological nitrogen fixation by legumes can exceed 100 kg N/ha, significantly reducing the need for synthetic nitrogen fertilizers (Palmero *et al.*, 2022; Stagnari *et al.*, 2017). In addition, they enhance biodiversity and support important ecosystem functions, such as pollination (Crews & Peoples, 2004).

Above all, however, the wider integration of legumes into agri-food systems could significantly reduce agriculture’s overall dependence on nitrogen fertilizers. In this light, the current crisis may constitute not only a serious threat, but also an opportunity to redefine agricultural and food policy. Strengthening the production, processing and consumption of pulses could be a strategic priority for more resilient and sustainable food systems. The strategic importance of pulses is now also reflected in the new CAP 2023-2027, where approximately 13.5% of the total Coupled Income Support (CIS) budget is directed to protein crops and pulses, while the related support is expected to increase by approximately 25% compared to the previous programming period (European Commission, 2026).

Therefore, legumes have fed humans and animals for centuries across the world, while also contributing to soil fertility. Their role deserves to be revisited and reconsidered in modern diets. The Mediterranean Diet offers numerous ways to incorporate legumes into contemporary food systems. Furthermore, at a time when our planet is facing a continuous decline in biodiversity, the wider cultivation of legumes may contribute to a new era of more sustainable agriculture. In this respect, several EU-funded projects are currently working in this direction. Among these initiatives, the Horizon Europe project LEGENDARY (LEGENDARY project, 2024) reflects the growing recognition of legumes as a strategic component of sustainable and resilient European agri-food systems.

This requires policies that support the entire value chain of legumes, from production and research to processing, marketing and consumption. Legumes can make a significant contribution to a more efficient and environmentally friendly model of resource use, while supporting both public health and agricultural sustainability. In an environment where geopolitical conflict directly affects access to energy, fertilizers and agricultural inputs, strengthening legume cultivation could reduce the EU's dependence on both imported protein feed and external fertilizer inputs. In a period of increasing environmental and geopolitical pressures, legumes can be an essential pillar of resilience against climate change, food insecurity, and future input crises.

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