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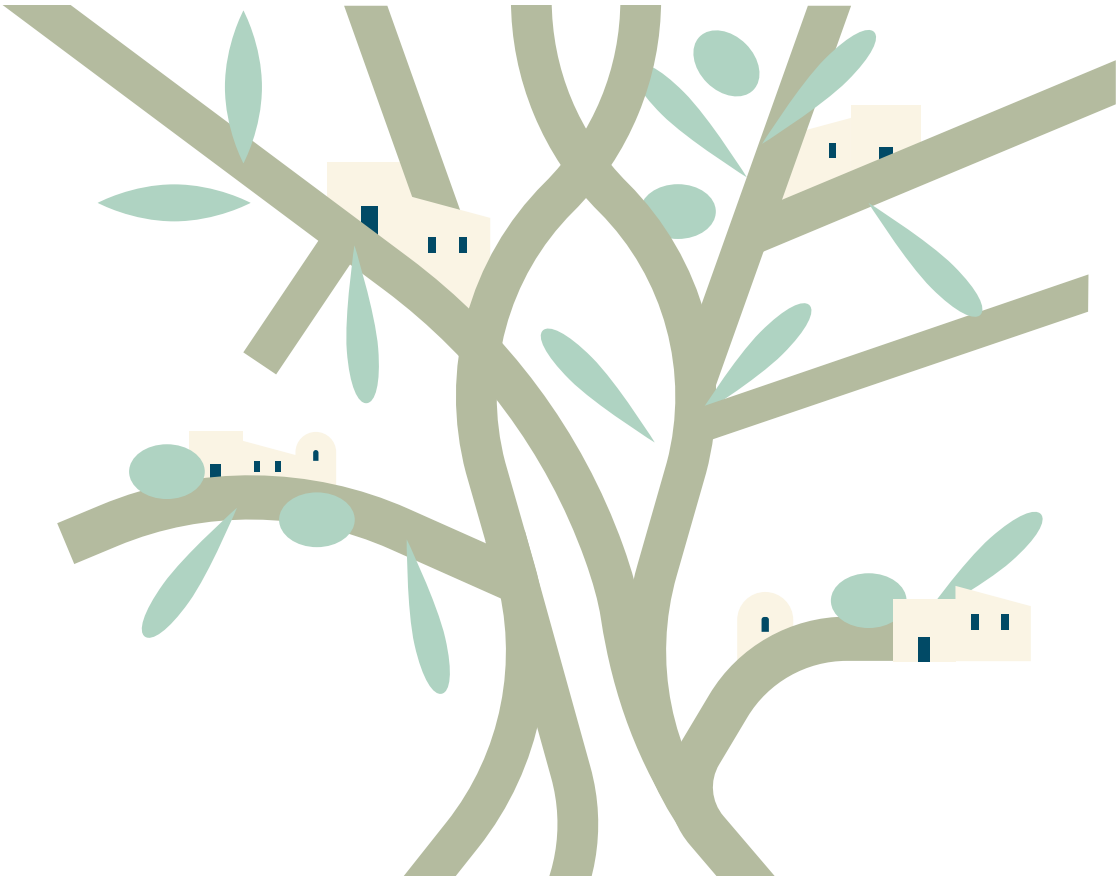


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Contents

Editorial Note

Teodoro Miano
Secretary General, CIHEAM

It is with immense pride and anticipation that I announce the re-launch of NEW MEDIT as a CIHEAM corporate international peer-reviewed journal. This marks a significant milestone in our organization's long-standing commitment to fostering knowledge exchange, scientific research and collaboration across the Mediterranean region.

For decades, CIHEAM has been dedicated to advancing agricultural research, education, and cooperation in the Mediterranean. NEW MEDIT embodies this mission by providing a robust platform for the dissemination of cutting-edge research, insightful analyses, and diverse perspectives on the multifaceted challenges and opportunities facing our region.

This journal aims to be a dynamic space where scholars, policymakers, practitioners, and civil society actors can converge to share their findings, exchange ideas, and engage in constructive dialogue. We envision NEW MEDIT as a catalyst for innovation and sustainable development, contributing to the advancement of knowledge and the formulation of evidence-based policies. For this purpose, the subtitle of the journal now includes 'Food' to highlight CIHEAM's dedication to sustainable food systems.

In this inaugural issue, we present a collection of articles that reflect the breadth and depth of research being conducted in the Mediterranean. These contributions span a range of topics and highlight the interconnectedness of these issues and the urgent need for integrated and collaborative solutions.

We are particularly excited about the journal's emphasis on interdisciplinary research and its commitment to bridging the gap between science and policy. NEW MEDIT will strive to make research accessible and relevant to a wide audience, including decision-makers, farmers, and other stakeholders.

The Mediterranean region is a unique and vibrant area with a rich history and a diverse cultural heritage. It is also a region facing significant challenges, including climate change, water scarcity, and socio-economic disparities. By providing a platform for dialogue and knowledge sharing, NEW MEDIT seeks to contribute to the development of sustainable and equitable solutions to these challenges.

I extend my sincere gratitude to the newly composed editorial board, to the reviewers, and to the authors who have contributed to this first issue. Their dedication and expertise have been invaluable in supporting the NEW MEDIT relaunch. Additional contributions by CIHEAM member states representatives and experts will be highly appreciated.

We invite you to join us on this exciting journey and to contribute to the ongoing conversation about the future of the Mediterranean. We look forward to receiving your submissions and engaging with you in the pages of NEW MEDIT.

Foreword

Ferretti, Capone and Malorgio explore the macroeconomic impact of the Mediterranean-style diet in reducing the risk of premature death from non-communicable diseases (NCDs). They investigate whether adopting the Mediterranean-style diet has a measurable country-level protective effect. The positive effects of the Mediterranean-style diet are outweighed by the negative ones of unhealthy dietary patterns. These findings emphasize the need to promote the Mediterranean-style diet to curb the burden of NCDs.

García-Moral et al. examine the factors influencing the price at origin of certified products, which condition the sector's profitability and the future of PDO-certified production.

The results show that age, export to non-EU countries and oleotourism positively affect the product's value. These findings should be taken into account in the design of possible actions by companies, PDO Regulatory Councils (RCs) and influential institutions in the sector, at European, national and regional levels.

Amouzay and El Ghini examine the impact of climate variability on agricultural production in 12 Moroccan regions, differentiating between rain-fed and irrigated crops.

The results highlight the sensitivity of various crops to variations in temperature and precipitation, revealing significant spillover effects due to omitted variables or shocks not observed in a spatial pattern. The authors underscore the urgent need for targeted regional public policies rather than standardized national policies to mitigate the effects of climate variability on Moroccan agriculture and ensure its long-term sustainability.

The assessment of the asymmetries in tail dependence between agricultural commodity prices (i.e., cereals and meats) and production input prices (i.e., fertilizers, seeds, animal feed and energy) investigated by *Rokopanos, Bersimis and Trivellas*. The findings suggest that the protective nature of CAP has led to moral hazard effects depriving farmers from the incentives that enhance the sector resilience.

Fort et al. analyzed the effects on sustainability of EU Tunisia trade relations, with a focus on Tunisian olive oil value chain, considering both the current Free Trade Agreement (FTA) impacts and the future DCFTA agreement expected effects. Main actions needed encompass an inclusive renovation of Tunisian olive oil sector, a rethinking of exports' tariff quota system to the EU, with special attention to organic olive oil, and water efficient cultivation systems interventions.

Consolaro, Uclés and Vena Oya examine the communication of blockchain information related to olive oil on websites. The findings highlight the proactive communication efforts of organizations that cultivate organic olive oils and embrace sustainable cultivation and production practices. This insight can assist the olive oil sector management in gaining a competitive edge and bridging the information gap between consumers and supply chain operators.

Çiftci and Oğuz analised the most effective irrigation systems for agricultural enterprises producing maize due to decreasing water resources. The results revealed that the most important criteria are energy cost, labor requirement and price, respectively. The authors underline the importance of irrigation systems that provide energy efficiency and labor saving playing a critical role for the sustainability of agricultural production.

Chaami et al. show the amplification of agricultural labor shortages in Algerian farmers in recent years. A labor shortage is reported on 56.80% of farms. The primary causes, as identified by the analysis, are poor working and living conditions and low wages, which are considered insufficient by both workers and new settlers. However, human capital, personal behavior and the socio-economic situation of the young workforce explain their negative work perception of work in agriculture.

Assessing the impact of the Mediterranean-style diet in preventing non-communicable diseases

FABRIZIO FERRETTI*, ROBERTO CAPONE**, GIULIO MALORGIO***

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Abstract

This paper explores the macroeconomic impact of the Mediterranean-style diet in reducing the risk of premature death from non-communicable diseases (NCDs). By utilizing an aggregate health production function approach, we investigate whether adopting the Mediterranean-style diet has a measurable country-level protective effect. Our analysis draws on data from 178 countries and develops two composite indexes to measure i) adherence to the Mediterranean-style diet and ii) the prevalence of metabolic syndrome. Our results show a departure from the Mediterranean-style diet in favor of the Western-style diet across countries in the Mediterranean region during the last decades. However, we find that adhering to the Mediterranean-style diet significantly reduces the prevalence of metabolic syndrome (after controlling for major potential confounding factors, such as health system performance and the implementation of WHO-recommended NCD prevention measures). The positive effects of the Mediterranean-style diet are, however, outweighed by the negative ones of unhealthy dietary patterns. These findings emphasize the need to reduce unhealthy food consumption by promoting a Mediterranean-style diet to prevent the health and economic burden of the leading NCDs.

Keywords: *Aggregate health production function, Mediterranean-style diet, Food consumption models, Non-communicable diseases, Preventable risk factors.*

1. Introduction

According to the World Health Organization (WHO), Non-Communicable Diseases (NCDs) are currently responsible for almost 74% of all deaths worldwide. The latest figures show that NCDs kill each year about 17 million people in the prime of their lives (i.e., between the ages of 30 and 69 years). Alarmingly, around four-fifths of these 'premature' deaths occur in low- and middle-income countries (WHO, 2023). The burden of such chronic diseases is mainly due to the four leading NCDs – that is, cardiovascular diseases, cancer, diabetes, and chronic respiratory diseases – which together account for over 80% of all premature NCD deaths globally (PAHO, 2020).

A large number of these premature NCD deaths, however, can be avoided by providing effective and equitable healthcare services – es-

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pecially early diagnosis and treatments – and by implementing primordial and primary prevention measures (WHO, 2013). Along with some non-modifiable risk factors (i.e., sex, age, and heredity), these chronic diseases share indeed a well-known set of key modifiable risk factors, namely, tobacco use, alcohol abuse, unhealthy diets and eating habits, physical inactivity, environmental pollution, and long-term psychological stress (WHO, 2014).

In other words, the rising prevalence of NCDs in both advanced and emerging economies is largely influenced by avoidable unhealthy lifestyle factors, with dietary habits playing a key role in prevention. A large amount of literature has consistently shown that unhealthy eating habits, such as regularly consuming ultra-processed foods – high in added sugars, unhealthy fats, sodium, and additives – processed meats and sugar-sweetened beverages, are major contributors to the global NCD epidemic (Lane *et al*., 2023). Conversely, research shows that embracing healthier diets, such as those based on the daily consumption of unprocessed and minimally processed home-prepared whole and plant-based foods, can significantly diminish the risk of developing one or more NCDs (Cerf, 2021). A crucial role in preventing NCDs through proper eating habits is played by the Mediterranean-style diet. This kind of diet, rich in fruits, vegetables, whole grains, lean proteins, and healthy fats, among the many benefits, can help in managing body weight, controlling cholesterol levels, and stabilizing blood sugar. More generally, by improving metabolic health, the Mediterranean diet reduces chronic inflammation, thus protecting against the onset of NCDs (Sánchez-Sánchez *et al*., 2020).

This paper investigates the impact of the Mediterranean-style diet in preventing NCDs from a macroeconomic perspective. Our primary focus is to answer the following research question: Does adopting the Mediterranean-style diet reduce the overall risk of premature death from NCDs at the country level? To deal with this issue, epidemiologists (Rothman *et al*., 2012) usually rely on the concepts of amenable mortality (i.e., deaths from causes that should not occur in the presence of effective medical care) and attributable fraction (i.e., the proportion of disease in a given population that can be attributed to a specific risk factor), (GBD, 2017; 2020). Instead, in economics, this question is typically framed within a health production function approach, where health is viewed as an output (i.e., a durable good) that people can produce starting with a set of medical and non-medical inputs (Auster *et al*., 1969; Grossman, 1972).

In the following pages, we use a health production function approach to determine if the Mediterranean-style diet has a measurable protective health impact at the macro level. So far, a relatively large number of studies have examined the impact of selected preventable (e.g., environmental, socio-economic, and behavioral) risk factors and various medical inputs on different types of health outcomes, such as life expectancy, mortality rates, quality or disability-adjusted life years, etc. (Maynard, 1983; Wagstaff, 1986; Thornton, 2010). To the best of our knowledge, however, our paper presents five main distinguishing features compared to prior empirical studies on the aggregate health production function.

First, we specifically address the role of the Mediterranean-style diet on the average overall risk of premature death from any of the four main NCDs. Second, we provide a country-level perspective using the most recent data available for 178 countries worldwide. Third, as explanatory variables, we develop two composite indexes to measure in each country: 1) the degree of adherence to the Mediterranean-style diet and 2) the prevalence of metabolic syndrome. Fourth, in order to control for the effects of potentially confounding variables, we also include in the quantitative analysis a robust metric of the performance of the national health systems, the so-called Healthcare Access and Quality Index (GBD, 2022). Fifth and finally, we take into account the country's progress in implementing the WHO set of 'best buys' interventions to prevent and control NCDs (WHO, 2022) to capture the impact of various public health measures on the risk of premature death from NCDs.

The remainder of the paper is structured as follows. Section 2 gives a brief overview of the main features of the Mediterranean-style diet

and its several health implications. Section 3 introduces some basic concepts of NCD epidemiology. Section 4 describes the data used and presents the model specifications. Section 5 discusses the main findings. Finally, Section 6 concludes with some implications for food policy and public health.

2. The Mediterranean-style diet: A pathway in preventing NCDs

The Mediterranean-style diet originates from the traditional culinary and eating habits of people living in countries such as Greece, Italy, and Spain. Over the last few decades, it has gained global recognition for its numerous health benefits. The Mediterranean-style diet (and its health impacts) have been extensively studied in the literature (Guasch-Ferré *et al*., 2021). This section provides just a brief overview of key concepts relevant to our purposes.

This diet focuses on plant-based foods, healthy fats, and lean proteins and is accompanied by a lifestyle that includes regular physical activity and social interactions. However, the Mediterranean-style diet is more than just a way of eating; it represents a holistic approach to life that emphasizes the pleasure of home-preparing and consuming meals based on fresh and minimally processed ingredients, following traditional culinary techniques. Its primary ingredients include whole grains and pulses, fresh vegetables and fruits, olive oil, nuts, and seeds. It is also based on a moderate consumption of dairy products (with cheese and yogurt preferred over butter and milk), and the use of blue fish and poultry instead of red meat. Wine, especially red wine, is regularly but moderately consumed, usually with meals. Herbs and spices are used to flavor food, reducing the need for salt (Dinu *et al*., 2017).

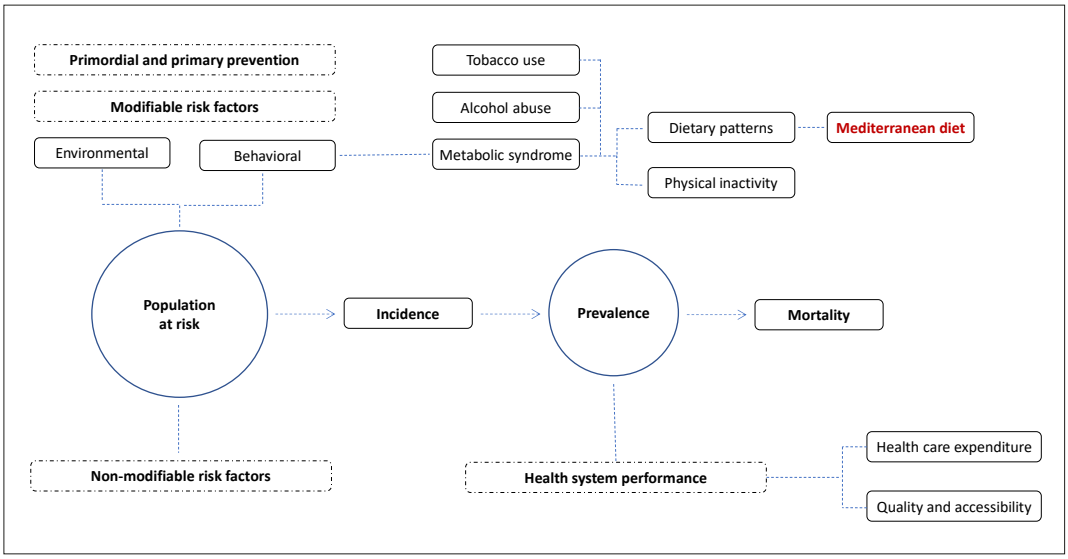
By avoiding industrial formulations and also limiting the consumption of processed foods from animal sources, the Mediterranean-style diet is widely recognized for its potential to prevent chronic diseases. For instance, numerous studies have demonstrated that lifelong adherence to this diet helps with weight management – this is why it is usually associated with a lower body mass index and reduced waist circumference – and significantly limits the risk of heart disease and stroke by helping reduce and increase cholesterol LDL and HDL, respectively. Moreover, being high in fiber and healthy fats, the Mediterranean-style diet not only promotes satiety and reduces overeating episodes but also helps lower blood pressure and improves insulin sensitivity, allowing cells to use blood sugar more effectively so as to lower the risk of developing type 2 diabetes. Finally, thanks to its anti-inflammatory foods, the Mediterranean-style diet has also been linked to a reduced risk of the onset of various types of cancers, including breast and colorectal cancer (an action mainly due to the high content of antioxidants and phytochemicals with anti-carcinogenic solid properties), (Gerber *et al*., 2015). Overall, the comprehensive health benefits of the Mediterranean-style diet are associated with a greater healthy life expectancy, as people who adhere to this diet in their lifetime tend to live longer and healthier (Martinez-Lacoba *et al*., 2018).

3. Some basic concepts of NCD epidemiology

The four leading NCDs have a multifaceted and complex origin. Figure 1 illustrates the interconnections among three fundamental concepts in NCD epidemiology: incidence, prevalence, and mortality. Incidence and mortality are flow variables, representing the number of new NCD cases and the number of NCD-related deaths occurring in a specific at-risk population over a defined period (e.g., one year). Prevalence is a stock variable, indicating the number of existing NCD cases in a specific population at a particular point in time (Porta, 2014).

These stock and flow relationships show that – other things being equal – the likelihood of premature death from any of the four leading NCDs is mainly influenced by two factors: 1) people's exposure to modifiable (avoidable) risk factors and 2) the provision of quality and equitable health care. On the one hand, exposure to risk factors impacts the number of new cases (incidence of NCDs) within a population at risk. On the other hand, access to effective healthcare determines the number of deaths (mortality due to

Figure 1 - The role of Mediterranean-style diet in preventing mortality from the leading NCDs.



NCDs) by affecting the patient's life expectancy (Bonita *et al*., 2006).

For our purposes, NCD modifiable risk factors can be broken down into environmental (e.g., air pollution, toxic chemicals, radiation, etc.) and behavioral risk factors (the so-called SNAP risk factors, that is, smoking, nutrition, alcohol, and physical activity). In turn, unhealthy nutrition and lack of physical activity usually result in a cluster of intermediate (metabolic) risk factors – such as raised blood glucose, raised blood pressure, overweight and obesity (particularly, excess body fat around the waist), and abnormal triglyceride and cholesterol levels – that underlies the metabolic syndrome, a condition significantly associated with an increased risk of developing one or more NCDs (Saklayen, 2018).

Finally, the health outcomes of those who live with one or more NCDs (i.e., the survival rates, and thus the mortality rates) crucially depend on three main factors: 1) the amount of resources allocated to the health system to tackle NCDs, 2) the allocative and productive efficiency of these resources, and 3) the effectiveness and fairness of the health services delivered. Given the existing stock of medical knowledge, the latter two factors can be summarized by the population's access to quality and equitable healthcare services (Bonita *et al*., 2006).

4. Methods

4.1. *Data*

Table 1 provides a short description of each variable used in this study, along with basic descriptive statistics. The WHO provides country data on the risk of dying prematurely from any of the four main NCDs (hereafter, *rdp*), defined as the age-adjusted percentage of 30-year-old-people who would die before their 70th birthday from these diseases, assuming that he or she would experience current mortality rates at every age and would not die from any other cause of death (WHO, 2019a). Hereafter, we use multivariate linear regression models with cross-sectional data from 178 countries worldwide to assess the impact of the Mediterranean-style diet on the country's average overall risk of dying prematurely from cardiovascular diseases, cancer, diabetes, and chronic respiratory diseases. To this aim, we collected data from several sources about the following explanatory variables.

The total country spending on healthcare goods and services, expressed as a percentage of GDP (hereafter, *hce*), was collected from the World Bank indicator database. This data is used as a proxy variable to account for differences in the amount of resources allocated to addressing NCDs (World Bank, 2022). The performance

Table 1 - Variables definitions and descriptive statistics.

Variable	*Definition*	*Mean*	*SD*	*Min.*	*Max.*	*n*
rdp	Probability of dying from any of CVD[1], cancer, diabetes, and CRD2 between age 30 and exact age 70, both sexes (%).	19.13	5.86	8.30	36.10	178
hce	Health expenditure as a percentage of GDP (%).	6.68	2.66	2.53	18.32	178
haq	Healthcare access and quality index (0 = min, 100 = max).	0.61	0.22	0.19	0.97	178
smoke	Prevalence of daily smoking, age-stand. rate, both sexes, person 18+ years.	17.76	8.38	3.30	42.60	177
drink	Prevalence of current drinkers, both sexes, person 15+ years.	39.68	23.01	0.38	92.20	178
obese	Prevalence of obesity (BMI[3] ≥ 30), age-stand. rate, both sexes, person 18+ years.	18.72	9.75	2.10	48.20	178
rbpre	Prevalence of raised blood pressure (SBP[4] ≥ 140 or DBP[5] ≥ 90), age-stand. rate, both sexes, person 18+ years.	24.51	4.57	11.00	33.40	178
rbglu	Prevalence of raised fasting blood glucose (≥ 7.0 mmol/L or on medication), age-stand. rate, both sexes, person 18+ years.	9.26	3.81	4.00	24.60	178
msi	Metabolic syndrome index: Composite index of *obese*, *rbglu* and *rbpre* (0 = min, 100 = max).	0.81	0.45	0.13	2.21	178
dietmed	Average calorie intake from plant-based foods (kcal/capita/day)[6].	1,361.25	363.94	459.00	2,373	178
dietwest	Average calorie intake from animal-derived foods plus sugars (kcal/capita/day)[7].	759.66	379.59	63.00	1,746.00	178
gdppc	Gross domestic product per capita (PPP, current international $, 2017).	18,912.13	19,435.01	766.59	113,365.18	178
A	Residual of estimated health production function (Equation 5, author calculation).	20.92	5.53	11.78	40.15	178
medit	Countries in the Mediterranean region (dummy variable)[8].					178
who	Country's achievements in implementing the WHO set of "best buy" interventions to prevent and control NCDs (dummy variable)[9].					178

Notes. [1] CVD = Cardiovascular diseases. [2] CRD = Chronic respiratory diseases. [3] Body mass index. [4] Systolic blood pressure. [5] Diastolic blood pressure. [6] Including cereals, pulse, vegetables, and fruits. [7] Including meat products, dairy products, eggs, and sugars. [8] 1 if the country is located in the Euro and Eastern Mediterranean region and 0 otherwise. [9] 1 if the country's achievements in implementing the WHO set of 'best buys' interventions to prevent and control NCDs reach at least a score of 3 out of 6 and 0 otherwise.

of national health systems was measured using the Healthcare Access and Quality Index (*haq*). This index, developed by Fullman *et al*. (2018), utilizes data from the Global Burden of Disease (GBD) study and is calculated on a scale from 0 to 100 (where higher scores indicate better access to quality healthcare). Specifically, for each country, the *haq* index measures healthcare quality and accessibility by evaluating the death rates from causes that could have been prevented through timely and effective medical care (also known as 'amenable mortality'). This evaluation offers insights into the effectiveness of healthcare systems across different regions or countries.

As outlined in Figure 1, in order to capture people's smoking and drinking behaviors as leading NCD risk factors, data on tobacco use and alcohol consumption were included in the study

Table 2 - Steps to calculate the Metabolic syndrome index (*msi*).

Indicator	*Minimum*	*Maximum*
Prevalence of obesity (*obese*)	1	50
Prevalence of raised blood pressure (*rbpre*)	10	35
Prevalence of raised fasting blood glucose (*rbglu*)	1	25
Example: Greece		
Actual values: Obesity = 24.90; Raised blood pressure = 19.10; Raised blood glucose = 6.60		
Dimension Index = (actual value – minimum value)/(maximum value – minimum value)		
Obesity = (24.90 – 1)/(50 – 1) = 0.49		
Raised blood pressure = (19.10 – 10)/(35 – 10) = 0.36		
Raised blood glucose = (6.60 – 1)/(25 – 1) = 0.23		
The *msi* index is the geometric mean of the dimensional indices of *obese*, *rbpre*, and *rbglu*:		
Metabolic syndrome index (*msi*) = $(0.49 \times 0.36 \times 0.23)^{1/3} = 0.35$		

by the country's age-adjusted prevalence rates of daily smoking (Ng *et al*., 2014; WHO, 2024) and current drinkers (WHO, 2019b), respectively. We denoted these two explanatory variables *smoke* and *drink*, respectively. The spread of the metabolic syndrome was measured by a composite index of the average country's prevalence rates of three fundamental NCD intermediate risk factors: 1) obesity, 2) raised blood pressure, and 3) raised blood glucose (again, all rates are age-standardized and hereafter denoted as *obese*, *rbpre*, and *rbglu*, respectively). The value of each of these variables was transformed into a corresponding normalized value according to the standard UN Development Programme methodology to compute the Human Development Index (UNDP, 2024). The geometric mean of the resulting three sub-indexes was thus used to compute a summary measure (denoted *msi*) of the country-level prevalence of the metabolic syndrome. All data required to compute *msi* were taken from the WHO Global Health Observatory data repository (WHO, 2019a). Table 2 summarizes the methodology and goalposts (i.e., each metric's maximum and minimum limits) applied to compute the composite index *msi*.

Despite the challenges of summarizing in a single variable a complex phenomenon such as the Mediterranean-style diet, we follow the current literature in measuring the adherence to the Mediterranean diet by computing – from the FAO Balance foods sheets (FAO, 2024) – the daily consumption of per capita calories derived from two kinds of foods. On the one hand, plant-based foods and fish (i.e., whole cereals, pulses, vegetables, fresh and dried fruit, fishery products, and olive oil). On the other hand, foods from animal sources (i.e., meat, milk, cheese, eggs, and animal fats), plus margarine sugars and sugary drinks. (Alberti-Fidanza *et al*., 1999; Fidanza *et al*., 2004; Lepellere *et al*., 2019). These two new variables are measured in kcal/person/day and denoted *dietmed* and *dietwest*, respectively. We emphasize that *dietmed* and *dietwest* are merely raw proxy variables used here to capture a very complex phenomenon that is hard to synthesize in quantitative analysis.

Because the Mediterranean-style diet involves shared know-how about several interrelated environmental, technical, cultural, and social factors (Capurso, 2024), we also introduce a dummy variable (denoted *medit*) that assumes a value equal to 1 if the country is located in the Euro and Eastern Mediterranean regions and 0 otherwise. The list of countries included in these two regions, according to the WHO country classification, is collected in Table 1A in the Appendix. Furthermore, given the crucial role of prevention in tackling NCDs, in order to promote accountability in monitoring countries'

progress against NCDs, the WHO (2022) has defined a set of national progress indicators in the form of standardized questions, such as 'Has the Member State set time-bound national targets based on WHO guidance?'. Based on the results of the last NCD progress country monitor report (WHO, 2022), we assigned a score of 1, 0.5, and 0 according to the following level of achievement in six main indicators: 1 = fully achieved, 0.5 = partially achieved, and 0 = not achieved, respectively. This variable is labelled *who* and the complete list of indicators used in the paper is presented in Table 2A in the Appendix. Finally, we include the GDP per capita, measured in PPP international dollars from the World Bank open data repository (World Bank, 2022), to account for overall differences in living standards between countries.

4.2. *Model's specifications*

Health is a key component of human capital. Similarly to the accumulation of knowledge, achieving and maintaining a good health status requires an ongoing production process based on a combination of medical and non-medical inputs. In this context, health can be seen as a durable asset that provides life-long benefits (for a given set of hereditary factors). At a country level, an aggregate health production function – such as $H = f(M, NM)$, where H is some measure of the population's health conditions, and M and NM are vectors of medical and non-medical (i.e., social, economic, lifestyle, *etc*.) factors – summarize this concept by indicating the maximum amount of health that, *ceteris paribus*, can be generated in a given population from a specific set of inputs, given the state of medical knowledge and technologies (Grossman, 1972).

According to the stock and flow relationships briefly described in Figure 1, in order to assess the impact of health-related behaviors on the overall risk of dying prematurely from NCDs, one should regress the age-adjusted risk of dying prematurely (i.e., *rdp*) on a comprehensive measure of eating, drinking, smoking and others NCD health-related behaviors, by controlling for the main potential confounding factors (such as the amount of resources devoted to the health sector, the quality and accessibility of the health care delivered, the country's effort to tackle NCDs and so forth). However, developing a comprehensive measure of NCD health-related behaviors can be challenging, even from a conceptual standpoint. Furthermore, using a set of single indicators (i.e., one for each leading NCD risk factor) can invalidate the regression model. These indicators tend to be highly correlated (Ferretti, 2015), generating severe multicollinearity problems.

This is why we followed an approach similar to that used in growth theory to investigate the determinants of total factor productivity, or the so-called Solow's residual (Weil, 2016). Specifically, we carried out a three-step analysis that proceeded from the metabolic to the behavioral risk factors. First, we assessed the impact of the health system performance by estimating the following aggregate health production function:

$$(1) \quad rdp = A(hce^{\alpha} \times haq^{\beta}) \quad \rightarrow \quad \ln(rdp_i) = \ln(A) + \alpha\ln(hce_i) + \beta\ln(haq_i) + \varepsilon_i$$

where ln denotes the natural log of the variable of interest, and the subscript i refers to the i^{th} country. In Equation (1), the coefficients α and β measure the elasticity of *rdp* with respect to the country's health expenditure (*hce*) and the quality and fairness of the health care delivered (*haq*). Conversely, A can be interpreted as a sort of Solow's residual (i.e., it collects the portion of the risk of dying prematurely from NCDs that changes in *hce* and *haq* cannot adequately explain).

In estimating a standard aggregate production function (with labor and capital as inputs), differences in Solow's residual, which measures total factor productivity, can be attributed to disparities in human capital, technology, and institutions. Similarly, we hypothesize that NCD health-related behaviors are the fundamental determinants of A in the health production function described by Equation (1). As a second step, we, therefore, focus on non-medical causes of the risk of dying prematurely from NCDs. To investigate this, we computed the value of A for each country as $A = rdp/(hce^{\alpha} \times haq^{\beta})$, using the estimated coefficients α and β from Equation (1), along with the observed data on *rdp*, *hce*, and

haq. Given the set of country's data on *A*, we thus performed the following regression:

$$(2) \quad \ln(A_i) = \beta_0 + \beta_1 \ln(msi_i) + \beta_2 \ln(smoke_i) + \\ + \beta_3 who_i + \beta_4 medit + \varepsilon_i$$

to assess the role played by metabolic risk factors. In Equation (2), *msi* is the index of the prevalence of the metabolic syndrome (as computed in Table 2), *smoke* measures the prevalence rate of daily smoking, and *who* and *medit* are two dummy variables to control for the county's effort in preventing NCDs and its geographical location within the Euro and Eastern Mediterranean region. In other words, by estimating Equation (2) we test whether the prevalence of metabolic risk factors helps in understanding the variation in the risk of dying prematurely from NCDs that is not explained by variations in healthcare expenditures and the quality and accessibility of the healthcare delivered by the national health system, by controlling for a lading behavioral risk factor (i.e., smoking habits), the role of prevention measures (*who*), and the impact of the Mediterranean economic, natural and socio-cultural environment (*medit*).

Third, and finally, since our main focus is on the role of the Mediterranean-style diet as a protective factor in preventing NCDs, we investigate whether diet composition affects the prevalence of metabolic syndrome with the following equation:

$$(3) \quad \ln(msi_i) = \beta_0 + \beta_1 \ln(dietmed_i) + \\ + \beta_2 \ln(dietwest_i) + \beta_3 \ln(drink_i) + \\ + \beta_4 \ln(gdppc_i) + \beta_4 \ln(gdppc_i)^2 + \varepsilon_i$$

In Equation (3), eating and drinking habits are related to the metabolic syndrome index. Specifically, we tested the impact of our two measures of adherence to the Mediterranean-style diet (that is, *dietmed* and *dietwest*) and alcohol consumption (*drink*) on the spread of metabolic syndrome among the general population. Here, income per capita, as measured by the GDP per person (*gdppc*), is used as an explanatory variable to control for cross-country differences in the overall level of economic development. GDP per person is introduced in a quadratic specification to capture the empirical evidence that indicates non-linear Engel's curves for income and the consumption of several food categories, such as animal-sources foods (Cole & McCoskey, 2013; Kmetkova & Scasny, 2022). All equations were estimated in double-log form to directly measure the elasticity of the corresponding regressor on the dependent variable. Heteroskedasticity-consistent standard errors were used to control for heteroskedasticity (Huber-White-Hinkley (HC1) procedure in EViews 11) (IHS, 2020).

5. Results

5.1. *The decreasing adherence to the Mediterranean-style diet*

Despite its global recognition for its many health benef its, which greatly contributed to the region's historically high life (and healthy life) expectancy, the Mediterranean-style diet has declined in Mediterranean countries during the last decades. This ongoing shift in dietary patterns raises many concerns not only about public health but also about the preservation of cultural traditions and the sustainability of agro-food systems (Dernini *et al*., 2013). The long-term declining trend is illustrated in Figure 2, which displays the changes in the ratio between the variables *dietmed* and *dietwest* from the early sixties to the present day in the Mediterranean region in comparison to Northern Europe and the Americas. Although this ratio can be used only as a proxy variable for measuring adherence to the Mediterranean-style diet, data show a one-third decrease in the *dietmed*/*dietwest* ratio for countries included in the Mediterranean region (the red line, labeled *medit*), similar to what happened in South American countries. Conversely, the ratio has steadily increased in Northern European and American countries, thus reducing their gap with the Mediterranean countries.

Figures 3 and 4 provide an explanation for this decline of the Mediterranean-style diet in its own areas of origin and first diffusion. Except for Eastern European countries, starting from the 1960s, there has been an increasing worldwide trend in the average calorie intake from plant-based sources (Figures 3*a* and 3*b*).

However, as illustrated in Figures 4*a* and 4*b*,

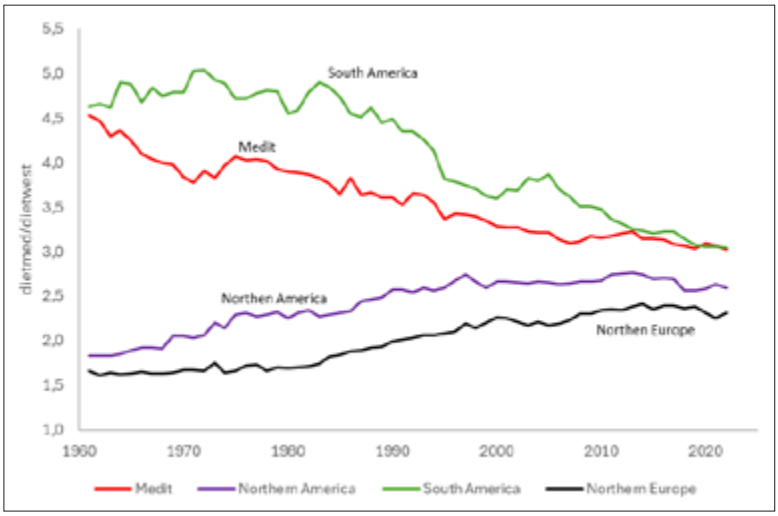


Figure 2 - The ratio between daily calorie intake from plant- and animal-based foods (*dietmed*/*dietwest*).

the Mediterranean region is among the areas where the consumption of animal-based foods has increased the most. Whereas in many other areas (such as other European regions and North America), the consumption of animal-sourced products has remained nearly constant, in the Mediterranean countries it has more than doubled, from 400 to 900 kcal/person/day. This sharp increase overcame the growth that occurred in the consumption of food derived from fruits and vegetables (which during the same time period increased by around 55%), resulting in a changed food landscape for the Mediterranean countries.

There are several reasons for this decreasing adherence to the Mediterranean-style diet. One major factor is the growing globalization and urbanization of Mediterranean societies. The spread of multinational fast food chains and ultra-processed foods and drinks implies that more convenient but less nutritious alternatives are currently replacing traditional meals. Busy lifestyles and the increase of dual-income households leave less time for cooking fresh, wholesome meals, leading to a greater reliance on quick, processed foods that do not align with the core principles of the Mediterranean-style diet (Godos, 2023).

Some of these complex phenomena are partially captured in Figure 5, where the average yearly consumption of ultra-processed foods and drinks – estimated by Vandevijvere *et al*. (2019) and measured in total kg/person/year – is plotted against the ratio between *dietmed* and *dietwest*, following the WHO world countries classification in six main geographic regions, plus our own created *medit* region. The graph indicates that a lower *dietmed*/*dietwest* ratio is linked to higher consumption of ultra-processed foods and drinks (*upfd*). Countries in the Mediterranean region (represented by the red dots) and those in other world areas seem to follow the same trend, although the phenomenon is more marked in developing countries, such as those included in the African region (the light-blue rectangles).

Complex economic structural changes also influence the evolution of dietary patterns. Data in Figure 6 illustrate an Engel's curve for the adherence to the Mediterranean-style diet (as measured by the ratio between *dietmed* and *dietwest*) and the level of economic development (as measured by the GDP per capita). As income rises, countries tend to shift toward a diet based mainly on animal-source foods. For countries within the Mediterranean region, a ten percent increase in per capita GDP decreases the *dietmed*/*dietwest* ratio by 6.5%. However, prices also play a role as economic factors that encourage changes in diet. Fresh, high-quality ingredients like olive oil, fish, and organic vegetables, central to the Mediterranean-style diet, have become more expensive in many Mediterranean countries. Fam-

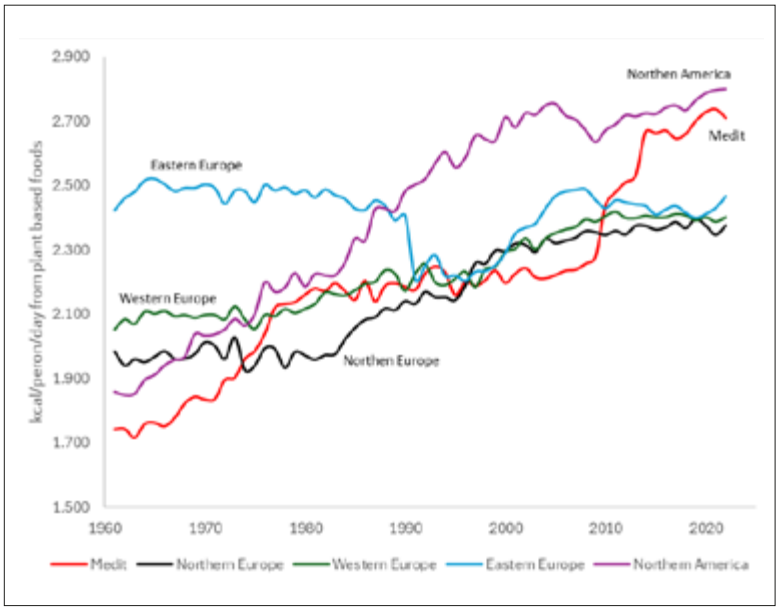


Figure 3a - Evolution of daily calorie intake from plant-based foods.

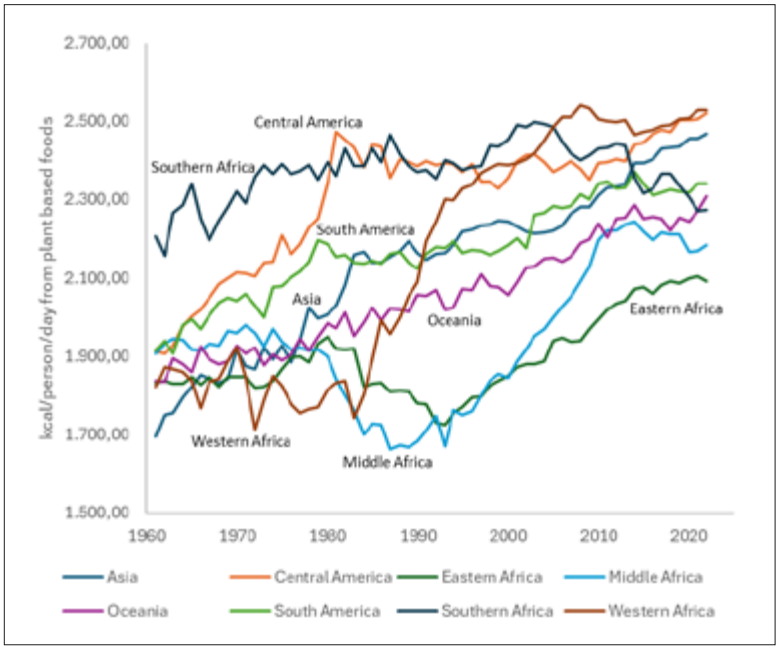


Figure 3b - Evolution of daily calorie intake from plant-based foods (world regions).

ilies may opt for cheaper, less healthy food options in times of economic hardship, prioritizing affordability over nutritional value. This trend can also be exacerbated by economic crises in countries such as Greece and Italy, where the cost of living has risen sharply, making it harder for people to maintain a diet rich in fresh but expensive local products (Colaprico *et al*., 2019).

Moreover, cultural shifts and evolving tastes, particularly among younger generations, have contributed to the decline of the Mediterranean-style diet. As adolescents and young adults in Mediterranean countries are increasingly exposed to global food trends – promoted and

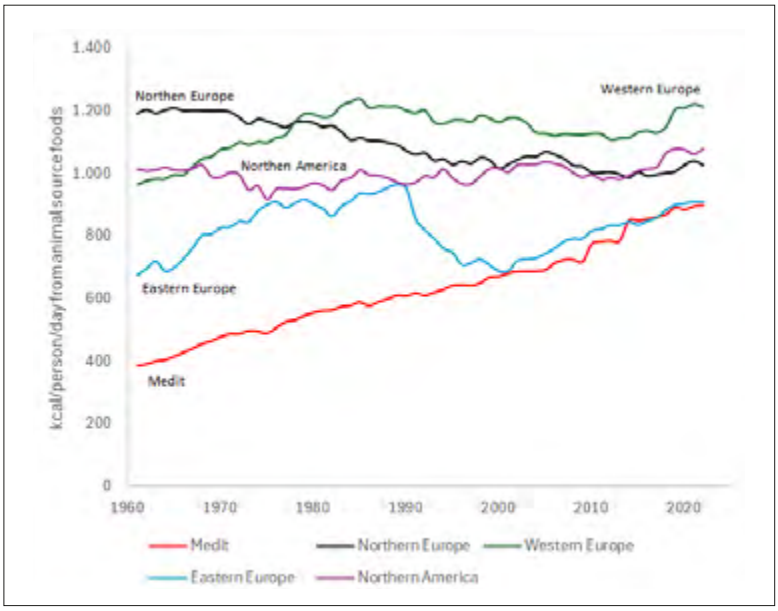


Figure 4a - Evolution of daily calorie intake from animal-based foods.

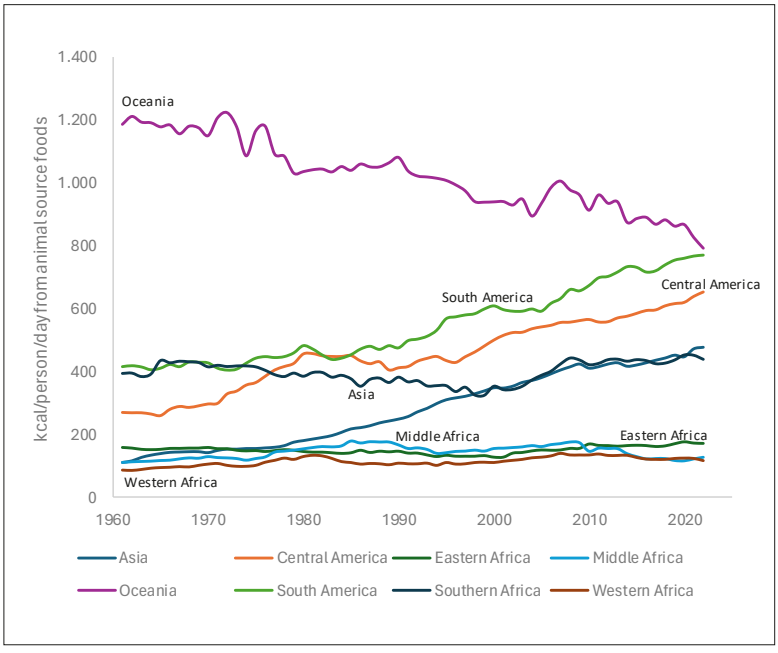


Figure 4b - Evolution of daily calorie intake from animal-based foods (world regions).

highly marketed by world-leading multinational food corporations – their diets tend to shift toward industrial processed food and beverages. This transition not only results in adverse health effects but also diminishes the region's cultural and culinary heritage, as traditional Mediterranean dishes are being prepared and consumed less frequently. Reversing this trend may require a mix of public health initiatives, educational campaigns, and policies that support access to fresh, locally sourced foods while preserving the long-standing Mediterranean culinary traditions that have contributed to the health and well-being of these populations (Vilarnau, 2019).

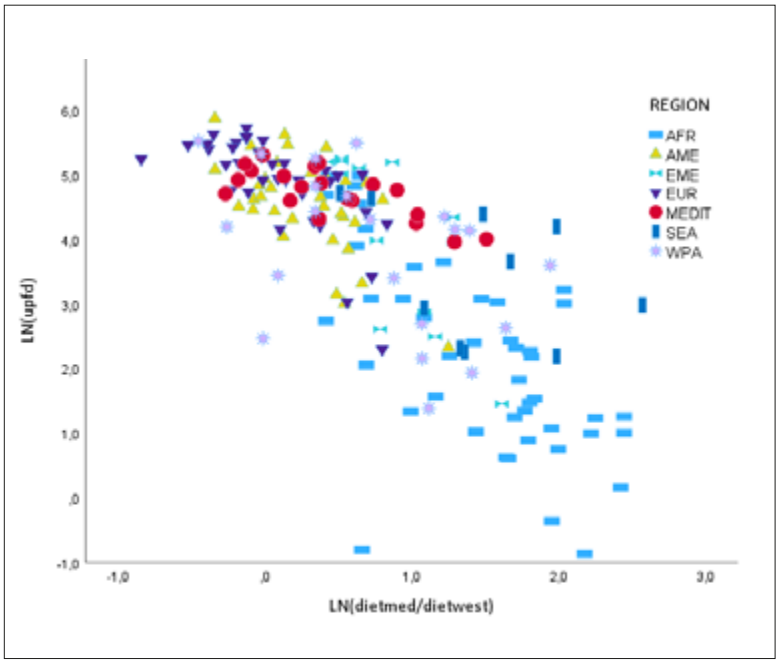
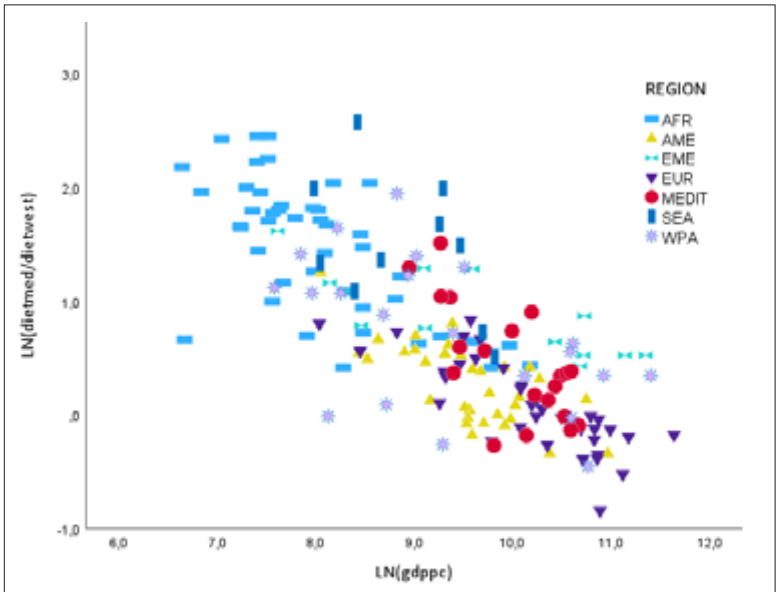


Figure 5 - Relationship between the adherence to the Mediterranean diet (as measured by the *dietmed/dietwest* ratio) and the consumption of ultra-processed foods and drinks.



Note. WHO regions: Africa (AFR), Americas (AME), Euro Mediterranean, except Medit (EME), Europe, except Medit (EUR), South-East Asia (SEA), and Western Pacific (WPA).

Regression result: Ln(dietmed/dietwest) = 6.97 – 0.65Ln(gdppc)

(0.15)

N = 20 $R^2 = 0.50$ t = -4.27

Estimated error in parentheses.

Figure 6 - Economic development (GDP per capita) and the *dietmed/dietwest* ratio.

Table 3 - OLS regression results.

Eq. 1), dependent variable: ln(*rdp*)			
rdp is the probability of dying between ages 30 and 70 years from any of the four main NCDs			
Independent variables		Coefficient	Std. Error[1]
Health expenditure as a share of GDP	*ln*(*hce*)	-0.198***	0.045
Healthcare access and quality index	*ln*(*haq*)	-0.431***	0.049
Constant		3.011	0.103
Adjusted *R*-squared = 0.42			
No. of observations = 178			
Eq. 2), dependent variable: ln(*A*)			
A is the residual of the estimated health production function (Eq. 1)			
Independent variables		Coefficient	Std. Error[1]
Metabolic syndrome index	ln(*msi*)	0.385***	0.047
Prevalence of daily smoking	ln(*smoke*)	0.161***	0.027
Country's achievements in preventing NCDs	who	-0.131***	0.030
Countries in the Mediterranean region	medit	-0.156***	0.043
Constant		3.040	0.080
Adjusted *R*-squared = 0.40			
No. of observations = 177			
Eq. 3), dependent variable: ln(*msi*)			
msi is the metabolic syndrome index			
Independent variables		Coefficient	Std. Error[1]
Average calorie intake from plant-based foods	ln(*dietmed*)	-0.245***	0.078
Average calorie intake from animal-derived foods plus sugars	ln(*dietwest*)	0.322***	0.052
Prevalence of current drinkers	ln(*drink*)	-0.145***	0.028
Gross domestic product per capita	ln(*gdppc*)	0.824***	0.304
Square of Gross domestic product per capita	ln(*gdppc*)^2	-0.048***	0.017
Constant		-4.222	1.307
Adjusted *R*-squared = 0.41			
No. of observations = 177			

*Notes: *** denote p < 0.001. [1] Huber-White-Hinkley (HC1) heteroskedasticity consistent standard errors.*

5.2. *Regression results*

The results from estimating Equations (1), (2), and (3) are presented in Table 3.

About Equation (1), the model explains about two-fourths of the cross-country variation in the risk of dying prematurely from any of the four main NCDs. This indicates that while the model is somewhat effective, a significant portion of the unexplained variation is probably due to the impact of behavioral risk factors. Both coefficients have the expected negative sign and are statistically significant at the 1% level. However, the elasticity of *haq* is nearly twice that of *hce*, indicating that increasing health spending can have a limited impact on people's health if these greater resources are not used to provide effective and equitable healthcare services. Our hypothesis about the determinants of the Solow residual in Equation (1) is corroborated by the results obtained from Equation (2). Again, all coefficients have the expected sign and are statistically significant at the 1% level. Specifically, differences in *A* – which measures variation in the age-adjusted risk of dying prematurely from any of the four main

NCDs not explained by variation in *hce* and *haq* – can be explained by differences in the prevalence of the metabolic syndrome (*msi*), country's effort in preventing NCDs, and the geographical collocation within the Euro and Eastern Mediterranean region, as measured by the dummy variables *who* and *medit*, respectively.

Finally, and more importantly, for our purposes, diet composition significantly affects the prevalence of metabolic syndrome. According to Equation (3), a 1% increase in the average daily intake of calories that characterizes the Mediterranean- and the Western-style diets (measured by the variables *dietmed* and *dietwest*) decreases and increases the prevalence of metabolic syndrome by 0.25% and 0.32%, respectively. The positive and negative signs of linear and squared GDP per capita support the idea of a sort of Kuznets curve for NCDs' eating-related behaviors, not captured by our proxy variables *dietmed* and *dietwest*. The idea is that as real income per capita increases, it initially tends to promote unhealthy eating and drinking habits until a certain income level is reached. Beyond this threshold, consumers start to prioritize healthier food choices (Ferretti, 2015). As in the previous equations, all coefficients are statistically significant at the 1% level, and the adjusted R^2 is around 0.40. Regarding the responsiveness of *msi*, one main finding is worth noting. The positive elasticity of *dietwest* is greater than the negative of *dietmed*. In other words, the Mediterranean-style diet does have a protective impact in preventing NCDs. However, the adverse effects of unhealthy eating habits overcome the positive ones, stressing the importance of avoiding the daily consumption of unhealthy foods, even in small amounts.

6. Discussion and conclusions

These findings corroborate the results of much previous work regarding the crucial role of eating patterns and, especially, of the Mediterranean-style diet as leading preventable risk factors to tackle NCDs (Zupo, 2023). From a policy perspective, this study supports the approach developed by the WHO (2014) in planning and implementing effective strategies to curb the current NCD epidemic (Budreviciute, 2020).

The regression results indicate the need to promote the Mediterranean-style diet. Unfortunately, today, the Mediterranean-style diet, as well as any other type of sustainable diet, is rarely practiced (defending it from the danger of "erosion" is the reason why the Mediterranean diet was recognized by UNESCO as an intangible heritage of humanity). It is not enough to inform and educate the consumer because, especially outside the home, they would not find the necessary conditions to practice the Mediterranean-style diet. The Food Environment[1] approach recognizes the fact that our food choices, and therefore the consequences of such choices, are strongly influenced by the contexts in which they are made. Therefore, it assumes that the most effective way to change the eating habits of individuals is to act on the structural elements that determine food choices. Obviously, strategic and political elements intervene above them. Promoting the Mediterranean-style diet requires a complex holistic strategy that intertwines public health policies, educational efforts, community initiatives, and effective partnerships across various sectors along the entire supply chain (and especially between agriculture and distribution). At the forefront, public health campaigns can be launched to raise awareness of the diet's benefits through media and the development of educational initiatives in key community locations (Bach-Faig *et al.*, 2011). Schools and workplaces play a crucial role, too, with healthy meal programs being introduced to both educate children and provide adults with better food choices by involving not only healthcare professionals but also farmers and local producers (Joubert & Szurek, 2012). Government policies are vital for ensuring that the Mediterranean-style diet is woven into na-

[1] According to the High-Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security (the United Nations body for assessing the science related to world food security and nutrition), the Food Environment is defined as the: "…physical, economic, political and sociocultural context in which consumers engage with the food system to make their decisions about acquiring, preparing and consuming food" (HLPE, 2017).

tional nutritional guidelines, with clear food labeling and subsidies encouraging the production and consumption of healthy foods (Dernini & Berry, 2015). However, this strategy should be centered on supporting local farmers by providing technological assistance and financial subsidies, improving market access to distribution, and organizing farmers' markets and direct sales platforms. Additionally, a strategy for promoting the Mediterranean-style diet effectively must include infrastructure investments and training programs in sustainable farming practices to support the foundation of local agriculture (European Commission, 2020; Capone *et al*., 2021).

This paper examined the macroeconomic impact of the Mediterranean-style diet in preventing NCDs, explicitly asking whether adopting the Mediterranean diet reduces the risk of premature death from NCDs at the country level. The findings can guide public health policies by highlighting the importance of implementing effective healthcare spending and prevention strategies for NCDs, such as promoting healthier dietary patterns, particularly in higher-income countries where Western diets tend to dominate. There are, however, limitations to this study that need to be acknowledged. First, the Mediterranean-style diet encompasses more than just eating patterns. It also includes each population's cultural and social features, which we attempted to capture with a simple dummy variable (e.g., *medit*). The regression output indicates that *medit* is statistically significant. However, this result does not allow us to understand the specific impact of each factor that makes up the complex societies of the Mediterranean regions. Second, to measure adherence to the Mediterranean-style diet, it is not sufficient to calculate the average calorie intake from different sources (i.e., plant or animal). This distinction, commonly made in the current literature, focuses solely on raw ingredients and fails to capture the significant role of the degree of food formulation and processing (i.e., it ignores the role of ultra-processed foods). Third, metabolic syndrome is a more complex phenomenon than our index (i.e., *msi*), as it also includes abnormal cholesterol or triglyceride levels and a measure of excess body fat around the waist (rather than increased BMI). Fourth, there is a missing variable concerning a measure of personal income distribution since an unequal income distribution plays a crucial role in determining the risk of dying from NCDs within each country. Fifth and finally, due to a lack of comprehensive data, we did not consider the role of fiscal policies, such as taxes and subsidies, on food production and consumption. Further research should be carried out to overcome these critical limitations of our work.

Abbreviations

FAO: Food and Agriculture Organization of the United Nations.
GFRP: Global Food Research Program.
HLPE: High-Level Panel of Experts on Food Security and Nutrition.
MSD: Mediterranean-Style Diet.
NCDs: Non-Communicable Diseases.
PAHO: Pan American Health Organization.
PEN: Pan-European Policy Evaluation Network.
UNDP: United Nations Development Programme.
UPFs: Ultra-processed foods.
WHO: World Health Organization.

References

Alberti-Fidanza A., Fidanza F., Chiuchiù M., Verducci G., Fruttini D., 1999. Dietary studies on two rural Italian population groups of the Seven Countries Study. 3. Trend of food and nutrient intake from 1960 to 1991. *European Journal of Clinical Nutrition*, 53(11): 854-860. https://doi.org/10.1038/sj.ejcn.1600865.

Auster R., Leveson I., Sarachek D., 1969. The production of health, an exploratory study. *Journal of Human Resources*, 4: 411-436.

Bach-Faig A., Berry E.M., Lairon D., Reguant J., Trichopoulou A., Dernini S., Xavier Medina F., Battino M., Belahsen R., Miranda G., Serra-Majem L., 2011. Mediterranean diet pyramid today. *Public Health Nutrition*, 14(12A): 2274-2284. DOI: 10.1017/S1368980011002515.

Bonita R., Beaglehole R., Kjelistrom T., 2006. *Basic Epidemiology*. Geneva: World Health Organization.

Budreviciute A., Damiati S., Sabir D.K., Onder K., Schuller-Goetzburg P., Plakys G., Katileviciute A., Khoja S., Kodzius R., 2020. Management and prevention strategies for non-communicable diseases (NCDs) and their risk factors. *Frontiers in Public Health*, 8. DOI: 10.3389/fpubh.2020.574111.

Capone R., Fersino V., Stamataki E., Cerezo M., Kessari M., Dernini S., El Bilali H., 2021. Sustainability of

food systems in the Mediterranean region. *New Medit*, 20(3): 131-143. DOI: 10.30682/nmsi21i.

Capurso A., 2024. The Mediterranean diet: a historical perspective. *Aging Clinical and Experimental Research Article*, 36, 78(2024). DOI: 10.1007/s40520-023-02686-3.

Cerf M.E., 2021. Healthy lifestyles and noncommunicable diseases: Nutrition, the life-course, and health promotion. *Lifestyle Medicine*, 2(2). DOI: 10.1002/lim2.31.

Colaprico C., Crispini D., Rocchi I., Kibi S., De Giusti M., La Torre G., 2024. Cost and cost-effectiveness of the Mediterranean diet: An update of a systematic review. *Nutrients*, 16(12): 1899. DOI: 10.3390/nu16121899.

Cole J.R., McCoskey S., 2013. Does global meat consumption follow an environmental Kuznets curve? *Sustainability: Science, Practice and Policy*, 9(2): 26-36. DOI: 10.1080/15487733.2013.11908112.

Dernini S., Berry E.M., 2015. Mediterranean diet: From a healthy diet to a sustainable dietary pattern. *Frontiers in Nutrition*, 2(15): 1-10. DOI: 10.3389/fnut.2015.00015.

Dernini S., Meybeck A., Burlingame B., Gitz V., Lacirignola C., Debs P., Capone R., El Bilali H., 2013. Developing a methodological approach for assessing the sustainability of diets: The Mediterranean diet as a case study. *New Medit*, 12(3): 28-37.

Dinu M., Pagliai G., Casini A., Sofi F., 2017. Mediterranean diet and multiple health outcomes: an umbrella review of meta-analyses of observational studies and randomized trials. *European Journal of Clinical Nutrition*, 72(1): 30-43. DOI: 10.1038/ejcn.2017.58.

European Commission, 2020. *Farm-to-fork strategy*. Bruxelles: The European Commission.

FAO, 2024. *Food balance sheets 2010-2022. Global, regional, and country trends*. Rome: Food and Agriculture Organization of the United Nations.

Ferretti F., 2015. Unhealthy behaviors: An international comparison. *PLoS ONE*, 10(10): e0141834. DOI: 10.1371/journal.pone.0141834.

Fidanza F., Alberti A., Lanti M., Menotti A., 2004. Mediterranean Adequacy Index: Correlation with 25-year mortality from coronary heart disease in the seven countries study. *Nutrition, Metabolism and Cardiovascular Diseases*, 14(5): 254-258. https://doi.org/10.1016/s0939-4753(04)80052-8.

Fullman N., Yearwood J., Abay S., […], Lozano R., 2018. Measuring performance on the Healthcare Access and Quality Index for 195 countries and territories and selected subnational locations: A systematic analysis from the Global Burden of Disease Study 2016. *The Lancet*, 391(10136): 2236-2271. DOI: 10.1016/s0140-6736(18)30994-2.

GBD, 2017. Healthcare Access and Quality Index based on mortality from causes amenable to personal health care in 195 countries and territories, 1990-2015: a novel analysis from the Global Burden of Disease Study 2015. *The Lancet*, 390(10091): 231-266. DOI: 10.1016/s0140-6736(17)30818-8.

GBD, 2020. Global burden of 87 risk factors in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. *The Lancet*, 396(10258): 1223-1249. DOI: 10.1016/s0140-6736(20)30752-2.

GBD, 2022. Assessing performance of the Healthcare Access and Quality Index, overall and by select age groups, for 204 countries and territories, 1990-2019: a systematic analysis from the Global Burden of Disease Study 2019. *The Lancet Global Health*, 10(12): e1715-e1743. DOI: 10.1016/s2214-109x(22)00429-6.

Gerber M., Hoffman R., 2015. The Mediterranean diet: health, science, and society. *British Journal of Nutrition*, 113(S2): S4-10. DOI: 10.1017/s0007114514003912.

Godos J., 2023. Decreasing adherence to the Mediterranean diet: health and environmental foe. *International Journal of Food Sciences and Nutrition*, 74(8): 797-798. DOI: 10.1080/09637486.2023.2290439.

Grossman M., 1972. *The Demand for health: A theoretical and empirical investigation*. New York: NBER - National Bureau of Economic Research.

Guasch-Ferré M., Willett W.C., 2021. The Mediterranean diet and health: a comprehensive overview. *Journal of Internal Medicine*, 290(3): 549-566. DOI: 10.1111/joim.13333.

HLPE, 2017. *Nutrition and food systems. A report by the High-Level Panel of Experts (HLPE) on Food Security and Nutrition*. Rome: Committee on World Food Security (CFS) of the United Nations, FAO.

HIS, 2020. *Eviews 11 User's Guide*. Irvine, CA: HIS Global Inc.

Joubert L.M., Szurek M., 2012. Farm to school programs: Improving child nutrition in the United States. *Public Health Reports*, 127(6): 704-707.

Kmetkova D., Scasny M., 2022. *Income elasticity for animal-based protein and food supply*. Working Papers IES 2022/23, Charles University Prague, Faculty of Social Sciences, Institute of Economic Studies (revised September 2022).

Lane M.M., Gamage E., Du S., Ashtree D.N., McGuinness A.J., Gauci S., Baker P., Lawrence M., Rebholz C.M., Srour B., Touvier M., Jacka F.N., O'Neil A., Segasby T., Marx W., 2023. Ultra-processed food exposure and adverse health outcomes: An umbrella review

of epidemiological meta-analyses. *BMJ*, 2024 Feb 28, 384: e077310. DOI: 10.20944/preprints202308.

Lepellere M.A., Chang T.F.M., Droli M., Iseppi L., 2019. The hidden turning points of the Mediterranean diet: a tool for health and agro-food policies. Rating out of fifty years, and 22 countries. *New Medit*, 18(2): 71-88. DOI: 10.30682/nm1902e.

Martinez-Lacoba R., Pardo-Garcia I., Amo-Saus E., Escribano-Sotos F., 2018. Mediterranean diet and health outcomes: a systematic meta-review. *European Journal of Public Health*, 28(5): 955-961. DOI: 10.1093/eurpub/cky113.

Maynard A., 1983. The production of health and health care. *Journal of Economic Studies*, 10(1): 31-45. DOI: 10.1108/eb002550.

Ng M., Freeman M.K., Robinson M., Dwyer-Lindgren L., Thomson B., Wollum A., Sanman E., Wulf S., Lopez A.D., Murray C.J.L., Gakidou E., 2014. Smoking prevalence and cigarette consumption in 187 countries, 1980-2012. *JAMA*, 311(2): 183-192. DOI: 10.1001/jama.2013.284692.

PAHO, 2020. *Noncommunicable diseases*. Washington, D.C.: PAHO/WHO Pan American Health Organization. https://www.paho.org/en/topics/noncommunicable-diseases (accessed: 7 August 2024).

Porta M., 2014. *A Dictionary of Epidemiology*. Oxford: Oxford University Press.

Rothman K.J., Greenland S., Lash T.L., 2012. *Modern epidemiology*, 3rd ed. Philadelphia: Lippincott Williams & Wilkins.

Saklayen M.G., 2018. The global epidemic of the Metabolic Syndrome. *Current hypertension reports*, 20(2): 12. DOI: 10.1007/s11906-018-0812-z.

Sánchez-Sánchez M.L., García-Vigara A., Hidalgo-Mora J.J., García-Pérez M.Á., Tarín J., Cano A., 2020. Mediterranean diet and health: A systematic review of epidemiological studies and intervention trials. *Maturitas*, 136: 25-37. DOI: 10.1016/j.maturitas.2020.03.008.

Thornton J., 2002. Estimating a health production function for the US: some new evidence. *Applied Economics*, 34(1): 59-62. DOI: 10.1080/00036840010025650.

United Nations Development Programme, 2024. *Human development report. Technical notes*. New York: UNDP.

Vandevijvere S., Jaacks L.M., Monteiro C.A., Moubarac J.-C., Girling-Butcher M., Lee A.C., Pan A., Bentham J., Swinburn B., 2019. Global trends in ultra-processed food and drink product sales and their association with adult body mass index trajectories. *Obesity Reviews*, 20(S2): 10-19. DOI: 10.1111/obr.12860.

Vilarnau C., Stracker D.M., Funtikov A., da Silva R., Estruch R., Bach-Faig A., 2019. Worldwide adherence to the Mediterranean Diet between 1960 and 2011. *European Journal of Clinical Nutrition*, 72: 83-91. DOI: 10.1038/s41430-018-0313-9.

Wagstaff A., 1986. The demand for health: theory and applications. *Journal of Epidemiology and Community Health*, 40: 1-11

WHO, 2013. *Global action plan for the prevention and control of noncommunicable diseases 2013-2020*. Geneva: World Health Organization.

WHO, 2014. *Global status report on noncommunicable diseases 2014*. Geneva: World Health Organization.

WHO, 2019a. *The Global Health Observatory*. Geneva: World Health Organization, https://www.who.int/data/gho/data/indicators/indicator-details/GHO/probability-of-dying-between-exact-ages-30-and-70-from-any-of-cardiovascular-disease-cancer-diabetes-or-chronic-respiratory-(-) (accessed: 20 August 2024).

WHO, 2019b. *Global information system on alcohol and health*. Geneva: World Health Organization.

WHO, 2022. *Noncommunicable diseases Progress monitor*. Geneva: World Health Organization.

WHO, 2023. *Noncommunicable diseases*. WHO Fact sheets, 16 September 2023. Geneva: World Health Organization. https://www.who.int/news-room/fact-sheets/detail/noncommunicable-diseases (accessed: 5 August 2024).

WHO, 2024. *Global report on trends in prevalence of tobacco use 2000-2030*. Geneva: World Health Organization.

World Bank, 2022. *World Bank open data*. Washington, D.C.: The World Bank Group. https://data.worldbank.org /indicator/SH.XPD.CHEX.GD.ZS. (accessed 20 August 2024).

Zupo R, Castellana F., Piscitelli P., Crupi P., Desantis A., Greco E., Severino F.P., Pulimeno M., Guazzini A., Kyriakides T., Vasiliou V., Trichopoulou A., Soldati L., La Vecchia C., De Gaetano G., Donati M.B., Colao A., Miani A., Corbo F., Clodoveo M.L., 2023. Scientific evidence supporting the newly developed one-health labeling tool "Med-Index": an umbrella systematic review on health benefits of Mediterranean diet principles and adherence in a planeterranean perspective. *Journal of Translational Medicine*, 21(1). DOI: 10.1186/s12967-023-04618-1.

Appendix

Table 1A - List of countries in the Mediterranean region.

HDIG	*WBIG*	*Country*
H	UMI	Albania
H	UMI	Algeria
H	UMI	Bosnia and Herzegovina
VH	HI	Croatia
VH	HI	Cyprus
M	LMI	Egypt
VH	HI	France
VH	HI	Greece
VH	HI	Israel
VH	HI	Italy
H	UMI	Lebanon
H	UMI	Libya
VH	HI	Malta
VH	UMI	Montenegro
M	LMI	Morocco
VH	HI	Portugal
VH	HI	Slovenia
VH	HI	Spain
H	LMI	Tunisia
H	UMI	Turkey

Notes:
HDIG, Human Development Index group (VH = very high, H = High, M = Medium HDI group)
WBIG, The World Bank income group (HI = High, UMI = Upper-middle, LMI = Lower-middle income group.

Table 2A - WHO progress monitoring indicators used to compute the dummy variable.

1. National NCD targets: "Member State has set time-bound national targets based on WHO guidance".
2. Risk factor surveys: "Member State has a STEPS survey or a comprehensive health examination survey every 5 years".
3. National integrated NCD policy/strategy/action plan: "Member State has an operational multisectoral national strategy/action plan that integrates the major NCDs and their shared risk factors".
4. Public education and awareness campaign on physical activity: "Member State has implemented at least one recent national public awareness and motivational communication for physical activity, including mass media campaigns for physical activity behavioural change".
5. Guidelines for management of cancer, CVD, diabetes and CRD: "Member State has evidence-based national guidelines/protocols/standards for the management of major NCDs through a primary care approach, recognized/approved by government or competent authorities".
6. Drug therapy/counselling to prevent heart attacks and strokes: "Member State has provision of drug therapy, including glycaemic control, and counselling for eligible persons at high risk to prevent heart attacks and strokes, with emphasis on the primary care level".

Key factors driving PDO olive oil prices at origin in Spain

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Abstract

Spain, the world's leading producer of extra virgin olive oil (EVOO), has 29 protected designations of origin (PDOs) in this sector in 2021. The objectives of this research are, first, to analyse the differences in the origin value of this product with differentiated quality, based on the geographic area of origin; and, secondly, using panel data methodology, to research how certain variables such as the age of the PDO, the production volume, the orientation of part of the supply towards international markets or the development of oleotourism activities in a territory influences the average price paid to the producer. The results show that age, export to non-EU countries and oleotourism positively affect the product's value. These findings should be taken into account in the design of possible actions by companies, PDO Regulatory Councils (RCs) and influential institutions in the sector, at European, national and regional levels. This article contributes to the evaluation of EU's agri-food product quality policy and examines the factors influencing the price at origin of certified products, which condition the sector's profitability and the future of PDO-certified production.

Keywords*: Extra virgin olive oil (EVOO), Protected Designation of Origin (PDO), Spain, Price at origin, Export, Oleotourism.*

1. Introduction

Foods with differentiated quality covered by a Protected Designation of Origin (PDO) or Protected Geographical Indications (PGI) have peculiar and specific characteristics due to the origin of the raw materials used (MAPA, 2014). European regulation 2024/143 on quality schemes for agricultural and food products defines "designation of origin" as a name identifying a product: a) from a specific place, region, or country; b) whose quality is due to its geographical environment; and c) all production stages occur there. It defines "geographical indication" as a name identifying a product: a) from a specific place, region, or country; b) with qualities attributable to its origin; and c) with at least one production stage there. The PDO and PGI recognize a product's origin, associating it with quality or reputation. This information differentiates goods in the market and can help develop a brand linked to its origin. Studies show these indications can contribute to rural development under suitable conditions (Bowen, 2010; Cei *et al.*, 2018), although not always (Neilson *et al.*, 2018), and promote the sale of local products

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Table 1 - Registered area and production of EVOO-PDO by designation of origin in Spain in 2021.

	PDO	*Registered area (ha)*		*Production of EVOO-PDO*	
		Ha	*%*	*Tn*	*%*
1	Aceite de La Rioja	1,256.00	0.17	315.61	0.29
2	Aceite de Navarra	2,691.00	0.37	173.27	0.16
3	Aceite de L'Empordà	884.00	0.12	75.88	0.07
4	Les Garrigues	16,260.00	2.22	3,890.00	3.52
5	Siurana	8,559.00	1.17	3,761.42	3.41
6	Aceite de Terra Alta	2,600.00	0.35	456	0.41
7	Aceite del Bajo Aragón	22,300.00	3.04	1,980.00	1.79
8	Aceite del Baix Ebre-Montsià	12,111.00	1.65	186.59	0.17
9	Aceite de Mallorca	40,114.00	5.47	349	0.32
10	Gata-Hurdes	30,000.00	4.09	57.58	0.05
11	Aceite de La Alcarria	28,335.00	3.87	193.74	0.18
12	Montes de Toledo	35,000.00	4.78	14,500.00	13.13
13	Aceite de la Comunitat Valenciana	4,248.00	0.58	0	0.00
14	Aceite Monterrubio	12,500.00	1.71	28	0.03
15	Aceite Campo de Montiel	26,325.00	3.59	7,638.00	6.92
16	Aceite Campo de Calatrava	22,123.00	3.02	112	0.10
17	Sierra de Segura	35,064.00	4.78	7,564.00	6.85
18	Montoro-Adamuz	22,546.00	3.08	272	0.25
19	Sierra Mágina	60,000.00	8.19	10,225.00	9.26
20	Sierra de Cazorla	37,700.00	5.14	3,500.00	3.17
21	Aceite Sierra del Moncayo	2,500.00	0.34	83.25	0.08
22	Montes de Granada	37,252.00	5.08	503.32	0.46
23	Poniente de Granada	39,407.00	5.38	1,460.00	1.32
24	Priego de Córdoba	29,628.00	4.04	6,704.00	6.07
25	Baena	60,000.00	8.19	41,066.71	37.20
26	Estepa	39,516.00	5.39	3,800.00	3.44
27	Aceite de Lucena	38,233.00	5.22	72	0.07
28	Antequera	42,606.00	5.81	1,617.60	1.47
29	Sierra de Cádiz	28,000.00	3.82	375	0.34

Source: MAPA (2023b).

in national and international markets (Galati *et al.*, 2017; Lubinga *et al.*, 2020). The right to use geographical indications belong to regional producers, adding value and protecting traditional knowledge. They also generate significant secondary benefits in tourism and gastronomy (Marcoz *et al.*, 2016), emphasizing that certified quality agriculture is presented as one of the main opportunities for the development of these rural environments (Consejo Económico y Social de España, 2018).

Spain, located on the western shores of the Mediterranean and with an olive grove area of 2,468 million hectares for the production of olive oil for oil mills, has traditionally been the world's leading producer of this foodstuff (Bull, 1936; García-Moral *et al.*, 2023). In 2021, the extent of olive plantations registered under a PDO is estimated at 732,927 hectares, representing 29.69% of the total area. This area is unevenly distributed across the different regions, as shown in Table 1 and Figure 1. This country, however, is not the EU partner with the highest number of PDOs in this agroindustry as of the

Figure 1 - EVOO from Spain with PDO.

Source: MAPA (2023b).

end of 2021 (12/31/2021), a position held by Italy with 42. Behind Spain, Greece ranks with 20, followed by France with 8.

In all cases, Spanish olive oil produced under a PDO must be of superior category—specifically, extra virgin olive oil (EVOO) — and the certified product must meet the specifications set out by the European Commission in the EU's legal register of names of agricultural products and foodstuffs "eAmbrosia"[1]. However, the fact that a product is certified by a PDO does not necessarily imply a homogeneous origin price, as it is noted in the case of coffee (Conley and Wilson, 2020). On the contrary, there are significant differences, which affect the income of olive producers and also the effectiveness of the PDO as an instrument of differentiated quality and economic growth of the territories in which they are located. Specifically, in 2021, the average price at origin of EVOO with PDO Priego de Córdoba reached 12.36 €/kg, while the corresponding price of EVOO with PDO Montes de Granada was 2.82 €/kg.

Based on the data provided by the Spanish Ministry of Agriculture, Fisheries and Food (MAPA) on different variables for the PDO-certified olive oil sector, data published by the RCs of the different PDOs in Spain and the arguments drawn from the literature review, this research aims, firstly, to analyse the heterogeneity in the average price of the PDO EVOO produced in the different territories between 2008 and 2021 and, secondly, using panel data methodology, to examine how the price paid at origin for the product is influenced by the age of the PDO, the production volume, the orientation towards international markets, the number of companies registered in the RC that produce and sell olive oil and the development of oleoturism activities. This research contributes to a better understanding of the effects of the EU's agri-food product quality policy, extending the existing evidence in several directions. In particular, the study aims to determine the factors that positively and negatively influence the price at origin of PDO EVOO produced in Spain. In contrast to much of the research on olive oil PDOs in Spain, Italy, Greece or Turkey, which largely consists of qualitative studies dealing with specific cases (Erraach *et al*., 2014; Egea and Pérez, 2016; Morillas and García-Quero, 2022; Kizos and Vakoufaris, 2011; Nizam, 2017; Tempesta and Vecchiato, 2019), this paper offers an aggregated view of the olive oil agro-industry with PDO-certified quality in the country that is the world's leading supplier of this foodstuff. The results obtained provided conclusions on the sector as a whole, which are useful for decision-making by companies and RCs, as well as by national and supranational institutions, such as the national government or the European Commission, whose actions and policies are aimed at the entire olive oil agro-industry.

2. Related literature and hypotheses

Geographical indications are linked to the notion of territory, under the assumption that the special quality and characteristics of an agri-food product are determined by the geographical place from which it originates (Gade, 2004; Bingen, 2012; Bowen and Mutersbaugh, 2014; Conley

[1] https://ec.europa.eu/info/food-farming-fisheries/food-safety-and-quality/certification/quality-labels/geographical-indications-register/.

and Wilson, 2020). Roquefort cheese, Argan oil, French champagne, Mexican tequila, Galapagan island coffee or Darjeeling tea have qualities or a reputation derived specifically from their place of origin, which differentiate them in the market (WIPO, 2021; Zinsli, 2023; Besky, 2014). Likewise, EVOO has qualities derived from its place of production, influenced by specific local factors such as the variety of olive grown in the territory, the oil production system or the climate or type of soil, there being a link between the product and its origin, which is perceptible in its attributes and can influence consumer preferences (Caporale *et al.*, 2006; Espejel *et al.*, 2008, Kalogeropoulos and Tsimidou, 2014).

The main advantage of the system of valuation and protection of PDOs/PGIs and Traditional Specialty Guaranteed created by the EU in 1992, revised in 2006[2], 2012 and 2024, is that their production parameters or standards are published in a single harmonized register. The label or seal that certifies the product's quality informs consumers about it, as governmental and non-governmental institutions endorse the process that verifies the real origin of the product, the specific raw materials used and the traditional technical procedure applied in its production in a specific territorial area (Resano *et al.*, 2012; Mutersbaugh *et al.*, 2005; Moschini *et al.*, 2008). Such certification can give the producer an exclusive right to use the label, in principle offering a clear advantage over other producers (Teil, 2017; Sgroi and Modica, 2022). PDO foods are produced following specific processes, linked to local culture and traditions dating back at least 25 years (Sgroi and Modica, 2022). The valorization process starts with a clear definition of the values that revolve around the product, including its history, the identification of the geographical area in which it is produced, the process followed and the particularity of the territorial resources used (Mariani *et al.*, 2022). The combination of these elements determines the product's characteristics and enhances the reputation of products from the defined area, allowing producers to employ differentiation strategies, as argued by Altomonte *et al.* (2016).

Food certification by the RC favorably influences the quality perceived by the consumer (Aytop and Çankaya, 2022; Toma *et al.*, 2023). The consumer's knowledge of the certified product has a negative influence on the perceived risk and a positive influence on satisfaction (Fandos Herrera and Flavián Blanco, 2011), contributing to their preference for the certified food and willingness to pay a premium price (Aytop and Çankaya, 2022; Van Ittersum *et al.*, 2007; Van Zyl *et al*., 2013; Albayram *et al*., 2014). This in turn boosts the value of the product, the producers' income and the economic development of the territory (Crescenzi *et al.*, 2022; Poetschki *et al.*, 2021). Based on the reviewed arguments, it can be stated that the age or number of years a product has been marketed with the PDO label positively influences the potential consumer's knowledge of that food and, in parallel, its valuation and the price they are willing to pay. Therefore, the longer the PDO certifying the quality of the EVOO has been in effect, the more well-known it becomes, which favourably affects demand and, consequently, the price at origin. The hypothesis posed is as follows:

H1. The number of years that the EVOO has been marketed with the PDO label has a positive influence on the price at origin of the product.

The quality of the agri-food product associated with its certification by a PDO/PGI is perceived in many cases by consumers in other countries, fostering the growth of sales in international markets, both in traditional destinations such as EU countries and in new markets outside the EU, and is associated with higher prices (Raimondi *et al.*, 2020; De Filippis *et al.*, 2022). Such an effect is commonly seen in wine sector (Galati *et al.*, 2017, Lubinga *et al.*, 2020), es-

[2] The Council of the European Union. Council Regulation (EC) No 510/2006 of 20 March 2006 on the Protection of Geographical Indications and Designations of Origin for Agricultural Products and Foodstuffs. 2006. Available online: https://eur-lex.europa.eu/eli/reg/2006/510/oj (accessed on 6 November 2020).

pecially French wines (Agostino and Trivieri, 2016), but also in cheese sector (Duvaleix *et al.*, 2021), bourbon (Zhang *et al.*, 2023) or olive oil (Menapace *et al.*, 2011). However, other studies are less conclusive and vary according to the country of export destination (Sorgho and Larue, 2014) or the type of product (Chilla *et al.*, 2020). In line with the studies of Raimondi *et al.* (2020) and De Filippis *et al.* (2022), The sale of part of the AOVE-PDO production in international markets, both in EU countries and the rest of the world, increases the demand for the product and positively impacts the price paid at origin. Based on this, the hypotheses posed are as follows:

H2. The value of sales in EU markets has a positive influence on the price per kilogram of PDO EVOO paid at origin.

H3. The value of sales in non-EU markets has a positive influence on the price per kilogram of PDO EVOO paid at origin.

PGI and PDO certification can play a role in driving the local development of rural areas (Bonanno *et al.*, 2020; Crescenzi *et al.*, 2022), thus fostering the growth and diversification of the local economy toward higher value-added sectors, including gastronomy and tourism (Arjona-Fuentes and Amador-Hidalgo, 2017; Ciani *et al.*, 2019; Hadelan *et al.*, 2021). Tourists, in many cases city dwellers, value the quality certification represented by the PDO/PGI label and have shown a greater willingness to pay a higher price than local consumers for the certified product (Marcoz *et al.*, 2016, Sgroi and Modica, 2022). In addition, when they return to their place of origin, tourists may want to continue consuming these traditional food and beverage products (Alamanos *et al.*, 2013; Folgado-Fernandez *et al.*, 2019), positively influencing demand (Pulido-Fernández *et al.*, 2022). Based on the reviewed research, it is deduced that the purchase of AOVE-PDO by tourists visiting the production area or by those with whom they interact (family, friends, acquaintances, etc.) increases the product's recognition outside the region of origin, which positively affects demand and, in parallel, the price paid at origin for this food. Therefore, the following hypothesis is proposed:

H4. When companies registered in the RC of the PDO are involved in olive oil tourism activities, which attract citizens from other cities and countries, contributing positively to the price at origin of the product.

Spain, Italy and Greece, three EU countries, which account for 64.17% of world olive oil production in the 2021/2022 campaign, do not share a single market for this foodstuff, which leads to differences in the price per kilogram (kg) of virgin olive oil depending on the country of origin, as confirmed by Emmanouilides *et al.* (2014) and Panagiotou and Stavrakoudis (2023). The same situation is observed at the national level, particularly in Spanish PDO EVOO. In this country, the olives produced for milling are predominantly rainfed (MAPA 2023a) and the price charged by the producer depends on the yield of the fruit, its quality (Gutiérrez-Salcedo *et al.*, 2016; Mozas and Parra, 2018) and, above all, the total volume of production in each season in the sector as a whole. This amount is directly linked to the climatic conditions experienced in the different stages of the agricultural process in the different production areas (Rodrigo-Comino *et al.*, 2021; Arfaoui *et al.*, 2021), with an inverse relationship between the total number of tons produced in the sector and the price per kg paid to the producer. Thus, a higher volume of production increases the available supply and negatively affects the price paid at origin. Extrapolating this evidence to the Spanish olive oil agroindustry with differentiated quality, the following hypothesis is established, which inversely links two variables: tons of AOVE-PDO produced and the value at origin of the product. The following hypothesis is formulated:

H5. A higher production of AOVE-DOP increases the available supply, negatively affecting the price paid at origin for the product.

European regulations on quality regimes for agri-food products establish that PDO EVOO must be bottled in the area where it is produced.

This requirement breaks with the strategy followed by most of the mills located in rural areas of origin, which sell most of their supply in bulk, to be bottled and sold outside the territory where it is produced (Mozas-Moral, 2020; Gutiérrez-Salcedo *et al.*, 2016). The bottled PDO EVOO can be sold directly from the mill, but also through third-party trading companies registered in the RC of the PDO. In principle, a larger number of trading companies can have a direct effect on competition at origin and, therefore, on the price paid per kg of PDO EVOO. The works of Bonnet and Bouamra-Mechemache (2016) and Orsini *et al.* (2020) on organic products confirm a greater bargaining power of producers over retailers for products with the organic label, which positively influences the price perceived by the producer. In the case of AOVE-PDO, the bargaining power of olive mills over companies that only engage in commercial activities may have a direct effect on competition at origin, positively influencing the price paid per kg of AOVE-PDO. Based on this reasoning, the following hypothesis is proposed:

H6. A higher number of trading companies registered with the PDO Regulatory Council has a positive influence on the price at origin of PDO EVOO.

3. Material and methods

3.1. *Information and data*

The statistical information comes mainly from the report: "Data on Protected Designations of Origin (PDO) and Protected Geographical Indications (PGI) of Agri-Food Products", which is prepared each year by the Subdirectorate General for Food Quality Control and Agri-Food Laboratories of the General Directorate of the Food Industry (MAPA) in collaboration with the Regulatory Councils of Protected Designations of Origin and Protected Geographical Indications and similar entities. The time period of analysis is determined by MAPA's publication of data on the different variables: number of PDOs, number of industries, production, economic value of production and exports. In the case of EVOO, there is no PGI in Spain recognized by the Commission that registered production during the time period considered, so the study focuses on the productive and commercial activity between 2008 and 2021, both included, of 22 PDOs with activity in each of the years considered. These PDOs are the following: Aceite Campo de Montiel, Aceite Campo de Calatrava, Aceite de a Alcarria, Aceite de Mallorca, Aceite de Navarra, Aceite Terra Alta, Aceite Terra Alta, Aceite del Baix Ebre-Montsià, Aceite del Bajo Aragón, Antequera, Baena, Estepa, Les Garrigues, Montes de Granada, Montes de Toledo, Montoro-Adamuz, Poniente de Granada, Priego de Córdoba, Sierra de Cádiz, Sierra de Cazorla, Sierra de Segura, Sierrra Mágina and Siruana. PDOs that have not produced in two or three consecutive years, such as Aceites de la Comunitat Valenciana, Aceite de la Rioja, Aceite de Lucena, Aceite de l`Empordà, Aceite Monterrubio, Aceite Sierra del Moncayo and Gata-Hurdes, are not included.

The EU eAmbrosia Register provides information on the year the PDO was approved by the competent national body. Likewise, the information published by the RCs and the different entities registered in each PDO (mills, bottlers and trading companies) indicates whether or not they carry out oleotourism activities.

It should be noted that the information recorded in official statistics is in some cases incomplete or based on estimates, since, as Török *et al.* (2020) and different studies carried out by AND-International (2012a, 2012b) have shown, there is limited availability data to evaluate the effectiveness of EU PDOs/PGIs.

The dependent variable is the average price paid at origin per kg of PDO EVOO each year by the entities registered in the RC of the 22 PDOs considered, between 2008 and 2021. The determinants are specified in Table 2.

3.2. *Panel data analysis*

The aim of the study is to identify the factors that influence the average price paid at origin per kg of PDO EVOO, by carrying out an analysis of the relevant variables and testing the association between the independent variables and the dependent variable. The study sample consists of

Table 2 - Definition of variables.

Age	*Age of the PDO or years since its initial approval, indicative of its history*
Exports-EU	Value of production that all the entities registered in the RC export each year to EU-28 countries (in 2021, the UK was considered a member of the EU), expressed in millions of euros.
Exports-nonEU	Value of production that the set of entities registered in the RC exports each year to countries outside the EU-28—which allows for less dependence on the local and national market—expressed in millions of euros.
Oleotourism	Development of oleotourism activities by some of the entities registered in the RC, which promotes familiarity with the product among consumers outside the territory; a dummy variable.
Certified production	Volume of production certified by the RC each year, which quantifies the supply available each year, expressed in tons.
Olive oil trading companies	Number of olive oil trading companies registered in the PDO.

data from the 22 PDOs between 2008 and 2021. This time period was chosen due to the unavailability of data from 2021 onwards. A descriptive analysis of the variables was performed, as well as a panel data analysis, following the methodology applied in previous articles (Gallego-Valero *et al.*, 2018). The dependent variable in the model is the value of PDO EVOO, defined as the average price paid at origin of PDO EVOO, expressed in euro per kg. The six explanatory variables, which are presented in Table 1, were selected according to the hypotheses set out in the previous section. The following equation tests the relation between the independent variables and the dependent variable:

$$\text{PDO-EVOOvalue}_{it} = \alpha it + \alpha 1\text{Age}_{it} + \\ + \alpha 2\text{Exports-EU}_{it} + \alpha 3\text{Exports-nonEU}_{it} + \\ + \alpha 4\text{Olive-oil-tourism}_{it} + \alpha 5\text{Certified-prod}_{it} + \\ + \alpha 6\ \text{Olive-oil-trading-comp}_{it} + \alpha eit$$

where:
$\text{PDO-EVOOvalue}_{it:}$ is the price paid at origin per kg of PDO EVOO each year by the companies
$\alpha 1\text{Age}_{it:}$ age of the PDO or years since its approval
$\alpha 2\text{Exports-EU}_{it:}$ value of production exported to EU-28 countries
$\alpha 3\text{Exports-nonEU}_{it:}$ value of production exported to countries outside the EU-28
$\alpha 4\text{Oleotourism}_{it}$: development of oleotourism activities
$\alpha 5\text{Certified-prod}_{it}$: volume of production certified by the PDO
$\alpha 6\ \text{Olive-oil-trading-comp}_{it:}$ number of olive oil trading companies registered in the PDO
α: estimated coefficients
Finally, αit measures the influence of other exogenous variables not included in the model, and αeit is the error term.

A panel data approach is appropriate due to the inclusion of time periods and the likely presence of unobserved individual effects. The use of this technique has multiple advantages, such as the fact that it reduces collinearity between variables, enables the construction of more complex models, eliminates or reduces bias in results when aggregating information, and identifies and evaluates effects not detected by cross-sectional or time-series analysis (Baltagi, 2005). However, drawbacks include problems with design and data collection, cross-sectional dependence and short time series. Stata software was used for the analysis.

4. Results

4.1. *Descriptive analysis*

Table 3 shows the descriptive statistics of the different variables considered. First and foremost, the high degree of dispersion in these variables stands out, particularly in the case of exports to the EU and non-EU countries. The minimum value registered is 0, representing no commercial activity in these destinations; by contrast, amounts of more than 15 million euros are registered for all the entities registered

Table 3 - Descriptive statistics of the variables.

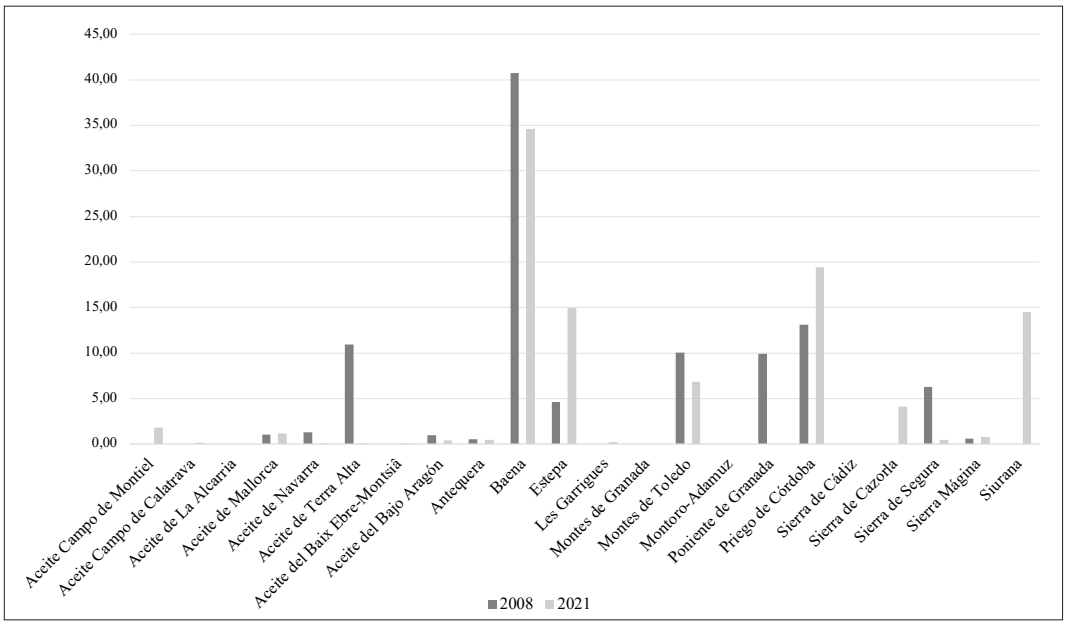
Variables	*Observations*	*Mean*	*Coefficient of variation*	*Minimum*	*Maximum*
Mean price (Y)	308	4.53 (2.16)	47.65	2.19	15.90
Age (X1)	308	4,229.26 (8439.98)	199.56	0	25.00
Production (X2)	308	11.87 (6.01)	50.65	0	62.03
Exports-EU (X3)	308	0.56 (1.43)	252.16	0	15.02
Exports-nonEU (X4)	308	0.73 (2.03)	278.31	0	15.61
Oleotourism (X4)	308	0.59 (0.49)	83.34	0	1.00
Olive oil trading companies (X5)	308	15.59 (12.08)	77.52	1	45.00

Source: Own elaboration based on MAPA (2023a), MAPA (2023b), eAmbrosia and the information from the RCs.

in the Baena PDO or Les Garrigues PDO. At the same time, the volume of PDO-certified production registers a minimum value of 0 tons, due to years with adverse weather conditions or the producers' decision; on the contrary, the highest volume of PDO-certified production is 62.03 tons. For the period as a whole, the average price paid at origin was 4.53 €/kg, with a coefficient of variation of 47.65%.

Figure 2 shows the percentage share of the different PDOs in the total production of PDO EVOO in Spain in 2008 and 2021. Two facts stand out. First, the high volume of supply concentrated in the PDO Baena, which accounts for

Figure 2 - Distribution by PDO of differentiated quality EVOO produced in Spain in 2008 and 2021 (in %).



Source: MAPA (2023b).

Table 4 - Average price paid at origin per kg of certified EVOO in the different PDOs of Spain between 2008 and 2021.

	2008	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*2021*
Aceite Campo de Montiel	3.52	2.60	2.80	2.20	2.60	3.73	3.68	3.70	3.71	3.90	3.80	2.99	3.01	3.81
Aceite Campo de Calatrava	6.67	5.75	5.82	4.95	3.50	3.25	3.39	3.82	4.59	4.66	4.48	3.96	4.45	4.29
Aceite de La Alcarria	4.44	5.50	5.62	3.18	2.97	3.49	3.32	3.85	4.58	5.91	6.56	5.13	4.68	5.55
Aceite de Navarra	3.69	4.00	4.25	4.40	4.22	4.21	4.09	4.60	4.19	3.99	4.02	3.14	3.18	3.41
Aceite de Terra alta	4.30	4.00	3.80	3.90	4.00	3.80	4.00	3.92	3.82	4.50	4.61	4.50	4.61	4.80
Aceite del Baix Ebre-Montsiâ	4.55	4.47	3.90	3.91	4.75	5.03	5.01	5.83	5.51	5.60	4.86	5.53	5.52	5.63
Aceite de Mallorca	10.65	12.10	10.41	11.88	12.81	12.59	13.08	11.93	15.80	15.90	15.71	11.84	11.64	11.04
Aceite del Bajo Aragón	4.00	3.75	3.30	3.20	4.00	4.00	4.51	4.20	3.56	3.50	3.50	3.50	3.50	3.60
Antequera	3.21	3.21	4.08	3.74	4.16	4.58	4.19	5.37	4.19	3.74	3.26	2.36	2.43	3.26
Baena	4.26	2.94	2.87	2.87	2.79	4.30	4.80	5.00	4.00	4.20	5.70	5.50	4.80	5.00
Estepa	3.20	3.50	3.00	3.80	4.00	4.40	5.00	4.80	5.00	4.30	3.30	2.60	2.78	2.90
Les Garrigues	4.80	4.80	4.59	3.24	4.47	4.47	4.47	4.58	3.45	3.60	5.24	5.24	3.83	4.22
Montes de Granada	2.98	2.98	2.35	2.76	4.55	2.57	2.78	3.46	3.87	5.10	5.09	2.31	2.54	2.82
Montes de Toledo	3.51	3.40	3.52	3.51	4.00	4.11	4.25	4.70	4.81	5.21	6.80	6.50	7.21	7.29
Montoro-Adamuz	5.79	5.81	5.00	4.47	3.25	3.36	3.30	5.71	5.83	5.22	4.00	3.60	3.60	3.60
Poniente de Granada	3.46	4.16	3.48	3.30	2.53	3.00	3.03	3.91	3.48	4.11	3.60	2.61	2.51	3.23
Priego de Córdoba	3.10	3.40	3.40	3.40	5.10	5.10	5.75	5.75	5.75	6.80	6.80	6.80	10.49	12.36
Sierra de Cádiz	3.00	2.60	2.38	2.50	2.80	2.71	2.75	2.88	3.29	3.63	3.59	3.66	3.80	4.02
Sierra de Cazorla	2.80	2.40	2.60	2.60	4.25	4.00	4.25	6.00	6.00	6.50	6.00	2.60	2.80	3.19
Sierra de Segura	4.00	4.01	4.01	4.02	3.54	3.67	3.84	5.05	5.16	6.05	6.04	6.04	3.68	4.19
Sierra Mágina	3.00	3.50	3.00	3.30	3.00	3.60	3.80	4.01	3.64	4.40	3.50	3.10	3.70	4.05
Siurana	4.40	4.40	4.40	4.40	4.40	4.00	4.21	4.40	5.00	5.00	5.00	4.38	5.00	5.00
Max	*10.65*	*12.10*	*10.41*	*11.88*	*12.81*	*12.59*	*13.08*	*11.93*	*15.80*	*15.90*	*15.71*	*11.84*	*11.64*	*12.36*
Mín	*2.80*	*2.40*	*2.35*	*2.20*	*2.53*	*2.57*	*2.75*	*2.88*	*3.29*	*3.50*	*3.26*	*2.31*	*2.43*	*2.82*
Average	*4.24*	*4.24*	*4.03*	*3.89*	*4.17*	*4.27*	*4.43*	*4.88*	*4.97*	*5.27*	*5.25*	*4.45*	*4.53*	*4.87*
Coef variation	*40.55*	*47.32*	*42.66*	*49.29*	*49.58*	*46.18*	*46.76*	*36.48*	*51.56*	*48.64*	*49.75*	*48.44*	*53.07*	*50.33*

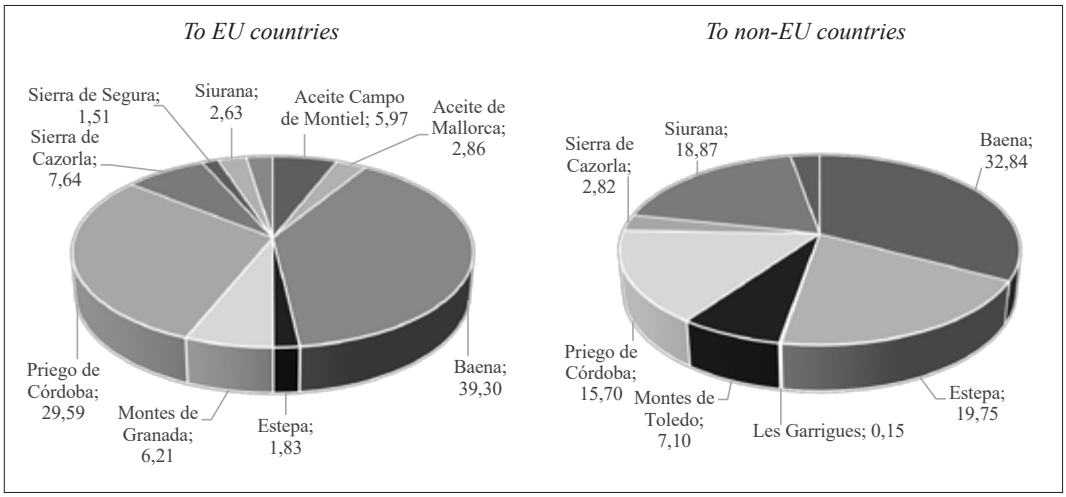
Source: MAPA (2023b).

37.22% of the total in 2021, followed by the PDO Montes de Toledo (13.14%) and Sierra Mágina (9.27%). A second group, with a percentage of the total between 3% and 8%, includes A. Montiel, Estepa, Les Garrigues, Priego de Córdoba, Sierra de Cazorla, Sierra de Segura and Siruana. The rest register a production in 2021 of less than 1,700 tons. Secondly, there are contrasting trends: some PDOs increase their weight in the total national of volume of certified EVOO, including A. Campo de Montiel, Baena and Montes de Toledo, Priego de Córdoba and Sierra de Segura; conversely, in many other cases the share of the certified volume in 2021 is lower than in 2008. This is the case in A. Campo de Calatrava, A. de Navarra, A. de Terra Alota, Montes de Granada, Sierra de Cádiz and Sierra Mágina.

Table 4 presents the average value per kg of AOVE-DOP paid at origin in Spain between 2008 and 2021 across the 22 PDOs analysed. The data first confirm the overall upward trend of the variable, reaching an average value of €4.24/kg in 2008 and €4.87 at the end of the period. However, the increase varies significantly across different cases, and in seven instances (A. De Campo de Calatrava, A. de Navarra, A. del Bajo Aragón, Estepa, Les Garrigues, Montro-Adamuz, Poniente de Granada), the price of AOVE-DOP in 2008 was higher than in 2021. In contrast, A. de La Alcarria, A. del Baix Ebre-Montsià, Mones de Toledo, Priego de Córdoba, and Sierra Mágina show increases of over 20% in the value of the variable between 2008 and 2021. Secondly, the significant dispersion in the average prices paid at origin is again evident, with significant differences depending on the geographical location of the production area and the conditions that influence both the supply and demand of the product in the local market, as will be discussed in the next section. A. de Mallorca is, by far, the PDO with the highest values in every year analysed, reaching a peak of €15.90/kg in 2017, compared to a low of €10.41/kg in 2010, with its value in 2021 being €11.04/kg. In contrast, Estepa and Montes de Granada did not exceed €3/kg in 2021, with values of €2.90/kg and €2.82/kg, respectively. This situation raises concerns about the business's viability, as according to Parras *et al.* (2023), the estimated average production and packaging cost for the 2020/21 season was €3.38/kg.

Figure 3 shows the distribution of Spanish PDO EVOO exports among the different PDOs considered, both to the EU and to countries outside the EU in 2021. Although Baena, with a high volume of production, accounts for almost 40% of total exports to the EU and 32.84% of exports to countries outside the EU, the large share corresponding to Priego de Córdoba is

Figure 3 - Distribution of PDO EVOO exports among the different PDOs in Spain in 2021.



Source: Own elaboration based on MAPA (2023b).

striking, both in sales to the EU and to non-EU countries. Also significant is the prominence of Siruana in sales of PDO EVOO to countries outside the EU, and, on the contrary, the minimal presence of Sierra Mágina in total exports, with this PDO being the source of just 9.27% of the total certified production in Spain in 2021.

4.2. *Panel data*

Table 5 shows the results of the estimations, using the feasible generalized least squares model (FGLS). The model is estimated using data from 22 entities, with a total of 308 observations, for the period 2008 to 2021. The optimum model is chosen by testing a number of econometric models to identify the best one:

a) *Pooled data estimation, Random Effects (RE) and Fixed Effects (FE) models*. First, the model is estimated with pooled data, comparing it with the RE model. To know whether to use the RE model or the clustered data model, Breusch and Pagan formulated the test known as the Lagrange Multiplier Test for RE. The null hypothesis of this test is that the variance is equal to zero. If the test is rejected, there is a difference between the model estimated with pooled data and the RE model, and it is preferable to use the RE method. As can be seen in Table 5, the p-value indicates that the null hypothesis can be rejected; therefore, the RE are relevant, and it is preferable to use the RE estimation rather than the pooled estimation. The same applies when using the FE model. The F test for the significance of the FE is used to assess whether this model or the pooled model is preferable. The p-value indicates that we can reject the null hypothesis, making the FE method more preferable than the pooled model.

b) *FE vs. RE model*. The FE model is another way to model the "individual" nature of each state. This model does not assume that the differences between states are random, but rather constant or "fixed." Once estimated, the Hausman test is used to choose between the FE model and the RE model. The null hypothesis of the Hausman test is that the RE and FE estimators do not differ significantly. If the null hypothesis is rejected, the estimators do differ, and the conclusion is that FE are more appropriate than RE. In this case, as Table 5 shows, the null hypothesis is not rejected; therefore, it is preferable to use the RE method.

c) *Detection of problems in the model*. Once the RE model has been chosen, it is necessary to check for the existence of autocorrelation, heteroscedasticity and contemporaneous correlation problems to correct them if their existence is confirmed. To control autocorrelation or first-order serial correlation we need to apply the Wooldridge test, for groupwise heteroscedasticity the modified Wald test has been used and the Breusch-Pagan test for cross-sectional independence (for contemporaneous heteroscedasticity). The null hypothesis of this tests is that these problems do not exist. Table 5 shows the absence of autocorrelation (Wooldridge test) and heteroscedasticity (Wald test). However, the Breusch-Pagan test for cross-sectional independence shows that the correlation matrix of residuals is singular, meaning it is not possible to use this test. In this case, the Pesaran's test for cross-sectional independence has been used, as it is a valid alternative, robust, and can be used to assess autocorrelation in panel data models, especially when the model has a complex structure that could lead to issues in estimating the residual correlation matrix. Table 5 indicates that it is necessary to correct the contemporaneous correlation.

d) *FGLS: preferred model*. The detected problems can be solved jointly with Feasible Generalized Least Squares (FGLS) estimators, or with Panel Corrected Standard Errors (PCSE). To solve the contemporaneous correlation in this case, the FGLS model is applied, since it is the recommended option for RE (Andreß *et al.*, 2013).

The variables capturing age, exports to non-EU countries and oleoturism are all significant at 5%. The variable certified production is also significant at 5%, showing a negative relationship with the average price paid at origin per kg of PDO EVOO. All of them confirm the expected relationship.

Table 5 - Panel data estimates.

PDO-EVOOvalue	*FGLS*		
	Coef.	*Z*	*P-value*
Age	0.04	3.21	0.001
Exports-EU	- 0.03	-1.83	0.068
Exports-nonEU	0.16	9.29	0.000
Olive-oil-tourism	0.98	2.25	0.024
Certified-prod	- 0.01	-4.42	0.000
Olive-oil-trading-comp	- 0.01	-0.58	0.564
Constant	3.53	25.42	0.000
Observations	308		
N. of entities	22		
Breusch and Pagan Lagrangian multiplier test for RE	$Chi^2(1) = 1102.25$ $Prob > chi^2 = 0.0000$		
F test for FE	F(4,282) = 13.08 Prob > F = 0.0000		
Hausman test	$Chi^2(4) = (b-B)'[(V\_b-V\_B)^{(-1)}](b-B) = 3.17$ $Prob>chi^2 = 0.53$		
Wooldridge test	F(1, 21) = 74.341 Prob > F = 0.0000		
Wald test	Wald chi^2 (22) = 5060.97 $Prob>chi^2 = 0.00$		
Pesaran's test	5.445, Pr = 0.0000		

Source: Own elaboration.

- The variables age and certified production both present a strong and significant relationship with the dependent variable, supporting hypotheses 1 and 5.
- Exports to non-EU countries and oleotourism have a direct impact on the average price paid for PDO EVOO. Hypotheses 3 and 4 are thus confirmed.
- Finally, there are two variables with a non-significant relationship with the dependent variable, which are exports to EU countries and number of olive oil trading companies, meaning that hypotheses 2 and 6 are not supported.

5. Discussion

The quality policy for agricultural products and foodstuffs in the EU, established in Regulation (EU) No 1151/2012, which regulates the PDO regime, aims to highlight the attributes of these products as a result of the agricultural techniques used, processing methods or place of origin (Mutersbaugh *et al.*, 2005; Moschini *et al.*, 2008). This differentiated quality should contribute to the producers receiving a higher price at origin for their harvest (Poetschki *et al.*, 2021). Spain, the world's leading producer of olive oil, had 29 PDOs in this sector in 2021, 22 of which have been continuously developing their production and commercial activity since 2008. In this country, the average paid at origin for PDO EVOO presents important differences depending on the origin of this foodstuff (García-Moral *et al.*, 2023). This paper studies the variables that may influence this situation.

The analysis supports hypotheses 1, 3, 4 and 5. On the contrary, hypothesis 2, on exports to the EU, and hypothesis 6, referring to the number of olive oil trading companies registered in the PDO RC are not supported, because these variables are not found to have a significant influence. The

development of oleotourism activities in the production area helps to improve visitors' familiarity with the product. This means that tourists—from other regions in Spain or other countries—are well aware of the specific characteristics of the product, learn to value them (Folgado-Fernández *et al.*, 2019) and are willing to pay a higher price, which in turn has a positive impact on the average price at origin. These results coincide with the arguments made by Marcoz *et al.* (2016) for the case of Fontina cheese. Additionally, oleotourism helps to diversify the activity of olive oil mills and improve their total income (Arjona-Fuentes and Amador-Hidalgo, 2017).

The age of the PDO, and therefore its history, contributes to the dissemination of knowledge about the differentiating features of the food and, specifically, among those consumers interested in buying the product, this knowledge makes them more willing to pay a higher price, as concluded by Van Ittersum *et al.* (2007), Van Zyl *et al.* (2013) and Albayram *et al.* (2014). Likewise, the fact that part of the PDO-certified production is destined for markets outside the EU contributes positively to the price at origin. Countries outside the EU that receive Spanish exports of PDO EVOO include economies with a high per capita income, such as the USA, Japan, Switzerland, South Korea and Canada (Menapace *et al.*, 2011) and also other high middle-income countries such as China, Brazil and Mexico, where there is a growing demand for this food, largely justified by the health benefits it offers (Mili and Bouhaddane, 2021). The positive relationship identified between exporting PDO EVOO to non-EU countries and the average price paid at origin aligns with the research results of Raimondi *et al.* (2020).

The fact that the variable "export to the EU" is not significant may be due to three different situations or realities that, together, determine a limited role of demand in EU partner countries and, simultaneously, the lack of influence of this component on the value at origin of the product. On the one hand, in countries with a long tradition of producing PDO EVOO—such as Italy and Greece—consumers may prefer the local product to the one imported from Spain (Aprile *et al.*, 2012; Perito *et al.*, 2019), negatively influencing the price they are willing to pay for the foreign product, which has an impact on the price of Spanish PDO EVOO at origin. On the other hand, in non-producing EU countries or those with low levels of olive oil production—such as Germany, the United Kingdom or France—Italian olive oil is more prevalent (Tasdogan, 2005; Pomarici and Vecchio, 2013; Ali *et al*., 2018), which can negatively influence the degree of knowledge, appreciation and willingness to pay for the Spanish PDO EVOO. Lastly, it is worth taking into account the lower tradition of PDO food consumption in in Northern and Eastern European countries (Krystallis *et al.*, 2017; Kos Skubic *et al.*, 2018), which negatively influences the import of these types of products (Sorgho and Larue, 2014).

Contrary to the arguments put forward by Bonnet & Bouamra-Mechemache (2016) and Orsini *et al.* (2020) for organic food producers, in the Spanish olive oil agroindustry with PDO labels, there is no confirmation of greater market power by the olive mills (producers) over the retail entities that only commercialize the product, which would positively influence the price perceived by producers at origin. The diversity of situations across the PDOs in the sector helps to explain these results. In some cases, the majority of the product is distributed and sold directly by the producers or an entity they are associated with, with no companies solely dedicated to bottling and commercializing the product. This is the case for A. Campo de Calatrava, A. Campo de Montiel, A. de la Alcarria, Sierra de Segura, or Estepa. In the latter case, there are 17 olive mills registered in the PDO, with 2 companies responsible for commercializing the entire product, both domestically and internationally. In contrast, the PDO Baena, the largest in national production, has 19 registered factories and more than thirty bottling and marketing companies. However, further research in this area is warranted.

Among the 22 Spanish PDOs of AOVE that form the basis of this research, there are significant differences, including in their size, registered olive grove area, number of registered agricultural, industrial, and commercial producers, production volume, market diversity in which their offer is commercialized, and the age

of the PDO. However, the analysis developed in the preceding pages allows us to affirm that certain variables, both on the demand side and the supply side, condition the price paid at origin for AOVE certified by a PDO in Spanish territory. On the demand side, this includes the consumer's knowledge of the product, which is enhanced by the PDO's temporal history and the presence of olive tourism activities in the production area. On the supply side, the commercial activity carried out by PDO operators in distant markets outside the EU has a favourable influence, while the production volume has a negative effect on the product's price at origin.

6. Conclusions

In Spain the price paid per kg of PDO EVOO shows wide dispersion, with variations ranging in 2021 from 12.36 €/kg in the PDO Priego de Córdoba to 2.90 €/kg. for the EVOO from the PDO Estepa. Based on the data provided by MAPA, the information from the RCs of the PDOs and using panel data analysis, this study aims to identify the variables that influence the price. The results obtained allow to conclude that the price paid at origin for this foodstuff is positively influenced by oleotourism in the producing areas, which promotes familiarity with and knowledge of the certified product; the ongoing tradition of the PDO, maintained year after year through a strict control procedure for which the RC is responsible; and the sale of PDO-certified EVOO outside the EU. On the other hand, exports to EU markets, which are closer but more competitive and where the Italian product is the most sought-after and increases in the volume of production in the PDO do not lead to higher prices at origin.

Several economic implications can be drawn from the results. First of all, the production efforts needed to achieve a certified quality food must be accompanied by a clear promotion and marketing strategy from the place of origin. It is only consumers' familiarity with the product that will build their trust, set the product apart from others, and make them willing to pay a premium price, which will influence the price paid at origin. Secondly, it is advisable to take advantage of promotion linked to oleotourism. To this end, it is essential to collaborate with local companies that run this type of activity and even to implement actions in this field from RCs. Finally, it is a priority to direct part of the production towards markets outside EU, where the demand for EVOO is growing, offering an opportunity to take advantage of this dynamic market.

The main limitation of this study is that it uses data aggregated by PDO, which are published each year by the MAPA in collaboration with the RCs. The information gathered has allowed an analysis of the sector as a whole, although it does not consider particular aspects of the different PDOs, which should be dealt with in further research. In this respect, future research on the determinants of the price paid at origin for PDO EVOO should seek to exploit microdata obtained from entities certified by a PDO. An analysis in this direction could complement the understanding of the mechanisms governing the price paid at origin for products of differentiated quality. Despite this limitation, this study contributes to the knowledge on the PDO-certified olive oil sector in the world's leading supplier of this foodstuff.

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References

Agostino M.R., Trivieri F., 2016. European wines exports towards emerging markets. The role of geographical identity. *Journal of Industry, Competition and Trade*, 16: 233-256.

Alamanos E., Kuznesof S., Ritson C., 2016. The influence of holidays on wine purchasing behaviour: Marketing and tourism insights based on a holiday experience in Greece. *International Journal of Tourism Research*, 18(3): 228-235.

Albayram Z., Mattas K., Tsakiridou E., 2014. Purchasing local and non-local products labeled with geographical indications (GIs). *Oper. Res.*, 14: 237-251.

Altomonte C., Colantone I., Pennings E., 2016. Heterogeneous firms and asymmetric product differentiation. *The Journal of Industrial Economics*, 64(4): 835-874.

AND-International, 2012a. *Study on Economic Value of EU Quality Schemes, Geographical Indications (GIs) and Traditional Specialities Guaranteed (TSGs)*. AND-International.

AND-International, 2012b. *Value of Production of Agricultural Products and Foodstuffs, Wines, Aromatised Wines and Spirits Protected by a Geographical Indication (GI)*. AND-International.

Andreß H., Golsch K., Schmidt A.W., 2013. *Applied panel data analysis for economic and social surveys*. Cham: Springer Science & Business Media.

Aprile M.C., Caputo V., Nayga R.M. Jr., 2012. Consumers' valuation of food quality labels: the case of the European geographic indication and organic farming labels. *International Journal of Consumer Studies*, 36(2): 158-165.

Arfaoui F., Cohen M., Oudin L., Ronchail J., 2021. Évolution, modélisation et cartographie des rendements de l'oliveraie dans la province de Jaen en Espagne (1959-2018). *Climatologie*, 18(4).

Aytop Y., Çankaya D., 2022. Do Consumers Intend to Purchase the Food with Geographical Indication? *New Medit*, 21(4): 41-50.

Baltagi B.H., 2005. *Econometric analysis of panel data*. New York: John Wiley & Sons.

Besky S., 2014. The labor of terroir and the terroir of labor: Geographical indication and Darjeeling tea plantations. *Agriculture and Human Values*, 31: 83-96.

Bingen J., 2012. Labels of origin for food, the new economy and opportunities for rural development in the US. *Agriculture and Human Values*, 29: 543-552.

Bonanno A., Sekine K., Feuer H.N., 2020. *Geographical indication and global agri-food: Development and democratization.* Milton Park: Taylor & Francis.

Bonnet C., Bouamra-Mechemache Z., 2016. Organic label, bargaining power, and profit-sharing in the French fluid milk market. *American Journal of Agricultural Economics*, 98(1): 113-133.

Bowen S., 2010. Embedding local places in global spaces: Geographical indications as a territorial development strategy. *Rural Sociology*, 75(2): 209-243.

Bowen S., Mutersbaugh. T., 2014. Local or localized? Exploring the contributions of Franco-Mediterranean agrifood theory to alternative food research. *Agriculture and Human Values*, 31: 201-213.

Bull W.E., 1936. The olive industry of Spain. *Economic Geography*, 12(2): 136-154.

Caporale G., Policastro S., Carlucci A., Monteleone E., 2006. Consumer expectations for sensory properties in virgin olive oils. *Food Qual Prefer*, 17(1-2): 116-125.

Cei L., Stefani G., Defrancesco E., Lombardi G.V., 2018. Geographical indications: A first assessment of the impact on rural development in Italian NUTS3 regions. *Land Use Policy*, 75: 620-630.

Chilla T., Fink B., Balling R., Reitmeier S., Schober K., 2020. The EU food label 'Protected Geographical Indication': economic implications and their spatial dimension. *Sustainability*, 12(14): 5503.

Ciani S., Mason M.C., Moretti A., 2019. Geographical indications and tourism destinations: An overview. *The Routledge Handbook of Gastronomic Tourism*, 527-537.

Conley J., Wilson B., 2020. Coffee terroir: Cupping description profiles and their impact upon prices in Central American coffees. *GeoJournal*, 85: 67-79.

Consejo Económico y Social de España, 2018. *El medio rural y su vertebración social y territorial.* http://www.ces.es/documents/10180/5182488/Inf0118.pdf/6d616668-0cb8-f58c-075b-2251f-05dad9f (accessed on June, 2023).

Crescenzi R., De Filippis F., Giua M., Vaquero-Piñeiro C., 2022. Geographical Indications and local development: the strength of territorial embeddedness. *Regional Studies*, 56(3): 381-393.

De Filippis F., Giua M., Salvatici L., Vaquero-Piñeiro C., 2022. The international trade impacts of Geographical Indications: Hype or hope? *Food Policy*, 112: 102371.

Duvaleix S., Emlinger C., Gaigné C., Latouche K., 2021. Geographical indications and trade: Firm-level evidence from the French cheese industry. *Food Policy*, 102: 102118.

Egea P., Pérez y Pérez L., 2016. Sustainability and multifunctionality of protected designations of origin of olive oil in Spain. *Land Use Policy*, 58: 264-275.

Emmanouilides C., Fousekis P., Grigoriadis V., 2014. Price dependence in the principal EU olive oil markets. *Spanish Journal of Agricultural Research*, 12(1): 3-14.

Erraach Y., Sayadi S., Gomez A.C., Parra-Lopez C., 2014. Consumer-stated preferences towards Protected Designation of Origin (PDO) labels in a traditional olive-oil-producing country: The case of Spain. *New Medit*, 13(4): 11-19.

Espejel J., Fandos C., Flavián C., 2008. The influence of consumer degree of knowledge on consumer

behavior: the case of Spanish olive oil. *Journal of Food Products Marketing*, 15(1): 15-37.

Folgado-Fernández J.A., Campón-Cerro A.M., Hernández-Mogollón J.M., 2019. Potential of olive oil tourism in promoting local quality food products: A case study of the region of Extremadura, Spain. *Heliyon*, 5(10).

Gade D.W., 2004. Tradition, territory, and terroir in French viniculture: Cassis, France, and Appellation Contrôlée. *Annals of the Association of American Geographers*, 94(4): 848-867.

Galati A., Crescimanno M., Abbruzzo A., Chironi S., Tinervia S., 2017. The premium price for Italian red wines in new world wine consuming countries: the case of the Russian market. *Journal of Wine Research*, 28(3): 181-193.

Gallego-Valero L., Moral-Pajares E., Román-Sánchez I.M., 2018. The tax burden on wastewater and the protection of water ecosystems in EU countries. *Sustainability*, 10: 212.

García-Moral A., Moral-Pajares E., Gallego-Valero L., 2023. The Spanish Olive Oil with Quality Differentiated by a Protected Designation of Origin. *Agriculture*, 13(11): 2169.

Gutiérrez-Salcedo M., Murgado-Armenteros E.M., Torres-Ruiz F.J., 2016. La influencia de la calidad en el precio de los aceites de oliva en origen. *Revista de Estudios Regionales*, 107: 157-175.

Hadelan L., Rogelj M.J., Mikuš O., Zrakić Sušac M., 2021. Food geographical indication in enhancing agricultural and tourism performance. *Sci. Pap. Ser. Manag. Econ. Eng. Agric. Rural. Dev.*, 21: 361-369.

Kalogeropoulos N., Tsimidou M.Z., 2014. Antioxidants in Greek virgin olive oils. *Antioxidants*, 3(2): 387-413.

Kizos T., Vakoufaris H., 2011. Valorisation of a local asset: The case of olive oil on Lesvos Island, Greece. *Food Policy*, 36(5): 705-714.

Kos Skubic M., Erjavec K., Klopčič M., 2018. Consumer preferences regarding national and EU quality labels for cheese, ham and honey: The case of Slovenia. *British Food Journal*, 120(3): 650-664.

Krystallis A., Chrysochou P., Perrea T., Tzagarakis N., 2017. A retrospective view on designation of origin labeled foods in Europe. *Journal of International Food & Agribusiness Marketing*, 29(3): 217-233.

Lubinga M.H., Ngqangweni S., Van der Walt S., Potelwa Y., Nyhodo B., Phaleng L., Ntshangase T., 2020. Geographical indications in the wine industry: does it matter for South Africa*? International Journal of Wine Business Research*, 33(1): 47-59.

MAPA, 2023a. *Anuario de Estadísticas*. https://www.mapa.gob.es/es/estadistica/temas/publicaciones/anuario-de estadistica/default.aspx (accessed on June, 2023).

MAPA, 2023b. *Datos de las Denominaciones de Origen Protegidas (D.O.P.), Indicaciones Geográficas Protegidas (I.G.P.) y Especialidades Tradicionales Garantizadas (E.T.G.) de Productos Agroalimentarios.* https://www.mapa.gob.es/es/alimentacion/temas/calidad-diferenciada/ (accessed on June, 2023).

Marcoz E.M., Melewar T.C., Dennis C., 2016. The value of region of origin, producer and protected designation of origin label for visitors and locals: the case of fontina cheese in Italy. *International Journal of Tourism Research*, 18(3): 236-250.

Mariani M., Cerdan C., Peri I., 2022. Cultural biodiversity unpacked, separating discourse from practice. *Agriculture and Human Values*, 39(2): 773-789.

Menapace L., Colson G., Grebitus C., Facendola M., 2011. Consumers' preferences for geographical origin labels: evidence from the Canadian olive oil market. *European Review of Agricultural Economics*, 38(2): 193-212.

Mili S., Bouhaddane M., 2021. Forecasting Global Developments and Challenges in Olive Oil Supply and Demand: A Delphi Survey from Spain. *Agriculture*, 11(3): 191.

Morillas Del Moral J.A., García-Quero F., 2022. Valorization of food products in a knowledge-based economy: analysis of the PDO "Sierra Mágina" olive oil cooperatives. *Food, Culture & Society*: 1-19.

Moschini G., Menapace L., Pick D., 2008. Geographical indications and the competitive provision of quality in agricultural markets. *American Journal of Agricultural Economics*, 90(3): 794-812.

Mozas-Moral A., 2020. *El Sector Oleícola y el Papel Protagonista del Cooperativismo Como Agente de Cambio*, Instituto de Estudios Giennenses. Valencia: CIRIEC-España.

Mutersbaugh T., Klooster D., Renard M.C., Taylor P., 2005. Certifying rural spaces: quality-certified products and rural governance. *Journal of Rural Studies*, 21(4): 381-388.

Neilson J., Wright J., Aklimawati L., 2018. Geographical indications and value capture in the Indonesia coffee sector. *Journal of Rural Studies*, 59: 35-48.

Nizam D., 2017. Place, food, and agriculture: the use of geographical indications in olive oil production in western Turkey. *New Perspectives on Turkey*, 57: 3-30.

Orsini S., Padel S., Gambelli D., Lernoud J., Sanders J., Solfanelli F., Stolze M., Willer H., Zanoli R., 2020. Beyond "mainstream" and "alternative" in organic food supply chains: Empirical examples of

added value distribution from eight European countries. *British Food Journal*, 122(3): 798-812.

Panagiotou D., Stavrakoudis A., 2023. Price dependence among the major EU extra virgin olive oil markets: a time scale analysis. *Review of Agricultural, Food and Environmental Studies*, 104(1): 1-26.

Parras-Rosa M., Bernal-Jurado E., Colombo S., Gutiérrez-Salcedo M., Mozas-Moral A., Murgado--Armenteros E.M., Torres-Ruiz F.J., Ruz-Carmona A., Vega-Zamora M., 2023. *Cadena de valor del aceite de oliva virgen extra. Campaña 2020-2021*. Ministerio de Agricultura, Pesca y Alimentación. https://www.mapa.gob.es/va/alimentacion/temas/observatorio-cadena/estudiodelacadenadevalor-2020-2021mapadefinitivo_tcm39-650710.pdf. (accessed on June, 2023).

Perito M.A., Sacchetti G., Di Mattia C.D., Chiodo E., Pittia P., Saguy I.S., Cohen E., 2019. Buy local! Familiarity and preferences for extra virgin olive oil of Italian consumers. *Journal of Food Products Marketing*, 25(4): 462-477.

Poetschki K., Peerlings J., Dries L., 2021. The impact of geographical indications on farm incomes in the EU olives and wine sector. *British Food Journal*, 123(13): 579-598.

Pomarici E., Vecchio R. 2013. The Italian olive oil industry in the global competitive scenario. *Agricultural Economics*, 59(8): 361-372.

Pulido-Fernández J.I., Casado-Montilla J., Carrillo--Hidalgo I. Pulido-Fernández M.C., 2022. Evaluating olive oil tourism experiences based on the segmentation of demand. *International Journal of Gastronomy and Food Science*, 27: 100461.

Raimondi V., Falco C., Curzi D., Olper A., 2020. Trade effects of geographical indication policy: The EU case. *Journal of Agricultural Economics*, 71(2): 330-356.

Resano H., Sanjuán A.I., Albisu L.M., 2012. Consumers' response to the EU Quality policy allowing for heterogeneous preferences. *Food Policy*, 37(4): 355-365.

Rodrigo-Comino J., Senciales-González J., Yu Y., Salvati L., Giménez-Morera A., Cerdà A., 2021. Long-term changes in rainfed olive production, rainfall and farmer's income in Bailén (Jaén, Spain). *Euro-Mediterranean Journal for Environmental Integration*, 6(2): 58.

Sgroi F., Modica F., 2022. Localized agri-food systems: the case of Pecorino Siciliano PDO a food product of the tradition of Mediterranean gastronomy. *International Journal of Gastronomy and Food Science*, 27: 100471.

Sorgho Z., Larue B., 2014. Geographical indication regulation and intra-trade in the European Union. *Agricultural Economics*, 45(S1): 1-12.

Tasdogan C., 2005. Country market power in EU olive oil trade. *South-Eastern Europe Journal of Economics*, 3(2): 211-219.

Teil G., 2017. Protecting appellations of origin: one hundred years of efforts and debates. In: Van Caenegem W., Cleary J. (eds), *The importance of place: geographical indications as a tool for local and regional development*. Cham: Springer, pp. 147-171.

Tempesta T., Vecchiato D., 2019. Analysis of the factors that influence olive oil demand in the Veneto Region (Italy). *Agriculture*, 9(7): 154.

Toma P., Manta F., Morrone D., Campobasso F., 2023. Familiar worldwide: how PDO products reflect quality in consumers' appraisal and behaviour. *The TQM Journal*, 35(2): 470-491.

Van Ittersum K., Meulenberg M., Van Trijp H., Candel M., 2007. Consumers' appreciation of regional certification labels: a Pan-European study. *J Agric Econ*, 58(1): 1-23.

Van Zyl K., Vermeulen H., Kirsten J.F., 2013. Determining South African consumers' willingness to pay for certified Karoo lamb: An application of an experimental auction. *Agrekon*, 52(4): 1-20.

WIPO, 2021. *Geographical Indications*. https://www.wipo.int/edocs/pubdocs/en/wipo_pub_952_2021.pdf (accessed on June, 2023).

Zhang W., Saghaian S., Reed M., 2023. Investigation of export-driving forces and trade potentials of the US bourbon whisky industry. *Applied Economics*, 1-21.

Zinsli M.J., 2023. Authorizing the 'taste of place' for Galápagos Islands coffee: scientific knowledge, development politics, and power in geographical indication implementation. *Agriculture and Human Values*, 40(2): 581-597.

Climate variability impact on agricultural production in Morocco: New evidence from a spatial econometric analysis

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Abstract

This paper examines the impact of climate variability on agricultural production in 12 Moroccan regions, differentiating between rain-fed and irrigated crops. Using a spatial panel data model with a 21-year (1999-2019), we analyze the impact of climatic and economic variables on three main crops: cereals, market gardening and rosaceous plants, while taking into account spatial autocorrelation and regional heterogeneity. The results highlight the sensitivity of various crops to variations in temperature and precipitation, revealing significant spillover effects due to omitted variables or shocks not observed in a spatial pattern. Thus, rainfall has a positive impact on rain-fed cereals but a negative impact on irrigated crops, underlining the inefficiencies of irrigation techniques and the need for sustainable water management. Irrigated rosaceae crops show high temperature sensitivity, underlining the urgency of climate-resilient agricultural practices. This finding underscores the urgent need for targeted regional public policies rather than standardized national policies to mitigate the effects of climate variability on Moroccan agriculture and ensure its long-term sustainability.

Keywords*: Climate variability, Agriculture, Spatial panel data, Production function approach, Morocco.*

1. Introduction

The effects of climate change have been increasingly recognized. Observations of climate change in the Mediterranean region, presented in the sixth assessment report (AR6) of IPCC (2022), show a significant increase in temperature (from 0.9 to 5.6°C) and a decrease in precipitation (from 4% to 22%) over the last two decades of the 21st century.

Morocco, like other Mediterranean countries, has experienced a temperature increase of +0.42°C/ decade since 1990, accompanied by a decrease in precipitation of more than 20% between 1961 and 2005 (Driouech *et al*., 2010). More recently, Amouzay *et al*. (2023) identified a significant structural break in temperature in 1993 and another break related to precipitation in 1972. These breakpoints confirm the current trends in climate data. Indeed, a study by Driouech *et al*. (2021) based on data from 30 meteorological stations covering the period from 1960 to 2016 showed that the daily temperature in Morocco has risen at higher rates than the global scale. The depicted trend of

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0.33°C per decade corresponds to a warming of approximately 1.1°C for 1984-2016. However, the annual mean precipitation and standardized drought index showed less spatially consistent tendencies despite the predominance of negative trends. Furthermore, projections of climate trends indicate that this situation is likely to persist (Filahi *et al*., 2017).

The increasing variability in precipitation and high frequency of droughts will likely further reduce the availability of water resources (Woillez, 2019). This, in turn, negatively impacts potential agricultural yields, employment opportunities, and the purchasing power of rural populations (Abdelmajid *et al*., 2021). Indeed, the Moroccan agricultural sector plays a key role in the country's economic fabric given its contribution to gross domestic product (GDP) and its interaction with other economic sectors. According to report of Ministry of Economy (2019), the weight of the Agricultural Gross Domestic Product (AGDP) in GDP varied between 12% and 14% between 2008 and 2018, with an average of 12.8%. The agricultural sector also plays a vital social and territorial role, employing nearly 40% of the active population at the national level, and 74% in rural areas (Ministry of Agriculture, 2019). Agriculture's vital importance to the national economy makes a country vulnerable to climate risks that threaten its food security (Abdelmajid *et al*., 2021; Palatnik and Lourenço Dias Nunes, 2015; Toumi *et al*., 2021).

This study aims to shed further light on the impact of climate variability on Moroccan agriculture using regional data for key agricultural products in both rainfed and irrigated areas. Indeed, climate variability manifests itself heterogeneously in space, with its impact varying significantly across different regions of the globe (Desmet and Rossi-Hansberg, 2024). Consequently, regions whose economies are heavily reliant on agriculture, which is inherently sensitive to temperature variations and extreme weather events, are more likely to experience significant damage than those whose economies are focused on industry or services, which are generally less dependent on climatic conditions (IPCC, 2023). Analyzing the impacts of climate variability on agricultural production necessitates a spatial approach, as effects are not confined to the directly affected regions. Indeed, Chatzopoulos and Lippert (2016) identify five key motivations for this inclusion. First, it minimizes omitted variable bias by incorporating spatial information otherwise neglected. Second, it controls for spatial dependence that can emerge from data aggregation, as aggregated units can be artificially more homogeneous. Third, interactions between landowners, who inform each other about prices and valuations, create spatial dependence. Fourth, land use practices shared by neighboring farms reinforce this dependence. Finally, land investments create external benefits for adjacent plots, which can be modeled using spatial lags of the explanatory variables. Thus, our goal is to emphasize the importance of using spatial panel data models to calculate spatial autocorrelation and spillover effects across regions, thereby providing policymakers with more accurate quantitative information on how Moroccan agriculture adapts to climate risks. By integrating the spatial dimension into our analysis, we can better understand the complex mechanisms linking climate variability to agricultural production in Morocco, and thus develop more effective and sustainable adaptation strategies.

This study's originality lies in its use of recent disaggregated data (spanning three categories: regions, products, and production methods) while explicitly employing spatial econometric techniques applied to panel data to account for spatial effects. Specifically, this article makes three major contributions to the existing national-level literature on the impact of climate variability on agriculture. Firstly, it utilizes a spatial panel data approach, which captures spatial autocorrelation and regional heterogeneity, aspects often overlooked in previous analyses. Literature has demonstrated that the impact of climate variability varies significantly across regions (Auffhammer *et al*., 2013), creating spatial heterogeneity influenced by geographical and economic factors (Chen *et al*., 2016; Coulibaly *et al*., 2020; Karahasan and Pinar, 2023; Vaitkeviciute *et al*., 2019; Zouabi and Peridy, 2015), thus necessitating contextualized solutions adapted to local realities (Desmet and Rossi-Hansberg, 2024). This approach allows us to highlight the geographical spillover effects of climate variability on agricul-

tural production across regions, an aspect ignored by most national studies. This contribution is all the more important as the literature emphasizes the spatial heterogeneity of climate variability impact (Desmet and Rossi-Hansberg, 2024), requiring solutions tailored to local specificities. Taking into account the spatial dimension allows for a better delineation of the areas affected by climate variability and directs adaptation policies towards regionalized solutions, in line with local priorities. To the best of our knowledge, this is the first time such an approach has been adopted to study the impact of climate variability on Moroccan agriculture. Secondly, the study addresses a gap by focusing on an analysis of disaggregated data up to 2019, both at the regional level and for specific crops (cereals, market gardening, and rosaceous crops), allowing for the distinction of differentiated impacts of climate variability on various productions. This multi-level approach, often neglected by national studies that primarily focus on rain-fed cereal crops, offers a finer perspective and provides updated evidence on the vulnerability of the Moroccan agricultural sector, enabling the identification of the most climate-sensitive crops. Finally, the study compares the impacts of climate variability on rain-fed and irrigated production systems, highlighting the limited effectiveness of current irrigation practices and emphasizing the importance of investing in more efficient adaptation strategies. This comparison is essential for developing agricultural policies that consider the specificities of each production system and promote sustainable water resource management.

The remainder of this paper is organized as follows: The literature review and the methodological framework is presented in the Sections 2 and 3. Section 4 describes the study's context, variables, and data sources. It also proposes a spatial exploratory analysis of agricultural production in Morocco using global and local spatial autocorrelation. Section 5. Section 6 concludes the study and provides policy proposals.

2. Literature Review

A large and active body of literature quantifies the impact of weather and climate change on agriculture worldwide (see Ortiz-Bobea [2021] for a recent review of the literature). Indeed, to properly understand existing relationships between climate and agriculture, some analysts (Blanc and Reilly, 2017) emphasize that economists favor statistical approaches based on farmers' experience. In particular, these authors distinguish the Ricardian approach (Mendelsohn *et al*., 1994) and the agricultural production function approach (Deschênes and Greenstone, 2007) as those most frequently used in the empirical literature. On the one hand, the Ricardian approach is a cross-sectional analysis of land value per hectare that assumes that farmers behave optimally in the long term and that land value reflects the future income stream that the farmer would receive from the best land allocation (Mendelsohn *et al*., 1994). On the other hand, the agricultural production function approach is a panel analysis of net revenue/profit/production as a function of weather, and is based on the annual behavior of producers seeking to maximize their revenues (Deschênes and Greenstone, 2007). This is a short-term approach where agricultural revenues in the observed year are affected only by climate variability as measured by weather conditions in the same year (Auffhammer *et al*., 2013; Dell *et al*., 2014). The latter approach is particularly used in developing countries because of insufficient availability of data for the Ricardian approach (Blanc and Reilly, 2017). African countries often find it difficult to apply Ricardian models because of the unavailability of information on private landowners in most countries. In addition, a proportion of agricultural land is held by village communities or the state, resulting in a lack of land transactions to assess land values (Mendelsohn and Dinar, 2009).

A great deal of other work on modeling the impacts of climate change on agriculture on a global or regional scale is available in scientific literature. However, specific studies on Morocco have been conducted (Balaghi *et al*., 2016, 2008; Belcaid and El Ghini, 2019; Fader *et al*., 2016; Giannakopoulos *et al*., 2009; Gommes *et al*., 2009; Ponti *et al*., 2014; Rosenzweig *et al*., 2014; Schilling *et al*., 2012), as indicated in the synthesis and analysis of the literature by Woillez (2019). In particular, we point to a study by the MOSAICC

project (Balaghi *et al*., 2016), which used projections from three different GCMs to simulate the impact of climate change on rain-fed wheat and barley (bour) yields using the Aqua Crop model. According to those authors, increasing temperatures and declining precipitation led to a decrease in simulated yields for the majority of Morocco's major agricultural regions by the mid-century in both the RCP4.5 and RCP8.5. Wheat and barley yields increase only in mountainous regions and in the north of the country, where warming creates more favorable conditions. The aggregation of these yield evolutions and their inclusion in a CGE-type economic model has a rather limited impact on Moroccan GDP. Other studies have focused on the role of public policies, particularly the Green Morocco Plan (GMP), as tools for adaptation to climate risks that can ensure food security for Moroccans (Abdelmajid *et al*., 2021; Akesbi, 2012; Oulhaj *et al*., 2013; Ouraich and Tyner, 2018; Sraïri, 2021). Indeed, Ouraich and Tyner (2018) studied the impact of climate change on productivity shocks in the agricultural sector. Using a regionalized computable general equilibrium model, the authors estimated the potential adaptation of Morocco's current agricultural development and investment strategy, the GPM. The results indicated no major differences between the impacts of climate change with and without the GPM. In the absence of GPM adaptation, the impact on GDP ranged from −3.1% to +0.4%. Including the GPM targets, the impact on the GDP ranges from −2.9% to +0.43%. Very recently, Abdelmajid *et al*. (2021) examined the constraints induced by climate change on natural resources and investigated the extent to which the agricultural sector and GMP can ensure food security in Moroccans under these constraints. These authors argue that the Moroccan agricultural policy pursued until now, and particularly the GMP, may well aggravate the consequences of climate change on natural resources, especially water, and, by extension, the food security of the country as a whole.

Despite the remarkable proliferation of empirical work over the past two decades, econometric models incorporating the spatial dimension have rarely been used to study the impact of climate change on Moroccan agriculture. Indeed, these studies fail to account for the spatial interaction of data, which could potentially introduce estimation biases (Chen *et al*., 2016; Schlenker *et al*., 2006; Vaitkeviciute *et al*., 2019). Thus, our intention is to account for spatial interaction in our modeling, resulting from both the geographical proximity of Moroccan regions and our gridded meteorological data (Auffhammer *et al*., 2013), by utilizing the production function approach initially suggested by Deschênes and Greenstone (2007).

3. Methodology

Our methodology for assessing the potential impacts of climate change on Moroccan agricultural production relies on observing the evolution of meteorological and socioeconomic variables over a defined period. First, we examine the empirical model specification adopted in our case study (3.1), then introduce linear models with spatial interaction on panel data and specify the testing procedures employed (3.2).

3.1. *Empirical Model Specification*

The literature review indicates that the production function approach is dominant in many studies on developing countries owing to data availability. We use specifications similar to those in Zouabi and Peridy (2015). This study analyzes the link between agricultural production and annual weather fluctuations in Tunisian regions using fixed-effects models, which would appear to be appropriate for assessing short-term relationships and should thus be preferred in the production function approach. The latter is based on the Cobb-Douglas type production function assumption (Jones *et al*., 2017). We can estimate the aggregate agricultural production function in Morocco while accounting for the effects of key weather variables on the changes in agricultural production. The basic Cobb-Douglas production function can be written as

$$Y_{it} = F\left(K_{it}, L_{it}, T_{it}, P_{it}\right) = A_{it} K_{it}^{\alpha} L_{it}^{\beta} T_{it}^{\theta} P_{it}^{\gamma}, \quad (1)$$

where Y_{it} denotes the given production in country i and in year t, K_{it} and L_{it} reflect respectively the capital and labor used in agriculture. Capital was represented by three variables: land, irrigation area, and livestock (or Draught animals). Labor is represented by the agricultural labor

force. T_{it} and P_{it} correspond to average temperature and precipitation, respectively. α, β, θ, and γ are the coefficients to be estimated and can be interpreted as elasticities. A_{it} includes unobserved variables (such as soil quality, labor skills, and technical progress) that can influence agricultural production. These unobserved effects can be evaluated using the following equation:

$$A_{it} = Ae^{u_i+\nu_t+\varepsilon_{it}} \quad (2)$$

where u_i, ν_t and ε_{it} represent the specific effects at the regional level, time-specific effects, and idiosyncratic error terms, respectively.

Substituting (2) into (1) yields:

$$Y_{it} = Ae^{\mu_i+\nu_t+\varepsilon_{it}} K_{it}^{\alpha} L_{it}^{\beta} T_{it}^{\theta} P_{it}^{\gamma} \quad (3)$$

After log transformation, the fixed effects model of this study is as follows:

$$log\,(Y_{it}) = log(A) + \alpha log\,(K_{it}) + \beta log\,(L_{it}) + \\ + \theta log\,(T_{it}) + \gamma log\,(P_{it}) + \mu_i + \nu_t + \varepsilon_{it}, \quad (4)$$

This panel-data model can be used to account for irrigated crops. Agronomic research suggests that irrigated crops respond differently to climate than rain-fed crops do (Mendelsohn and Dinar, 2009). Schlenker *et al*. (2006) tests different model specifications by including an irrigation variable in a model for all counties and then separating the sample into irrigated and non-irrigated counties. Deschênes and Greenstone (2007) and Wang *et al*. (2009) build on these results and offer regression analyses on separate samples as well as on the full sample, covering both irrigated and non-irrigated countries. Drawing on these studies, we substitute agricultural production and total land area for irrigated crops in Equation 4 when estimating these types of crops.

3.2. *Panel Spatial Models used in Climate Change impact on Agriculture Studies*

Most empirical studies based on production function use panel data. However, over the past decade, spatial autocorrelation has begun to feature prominently in econometric studies of the impacts of climate change on agriculture (Chatzopoulos and Lippert, 2016; Chen *et al*., 2016; Ortiz-Bobea, 2016; Polsky, 2004; Schlenker *et al*., 2006; Schmidtner *et al*., 2015; Vaitkeviciute *et al*., 2019). Indeed, the inclusion of state-fixed effects could amplify the omitted-variable bias if they operate more strongly within states than across states, as shown in Ortiz-Bobea (2021). Nonetheless, the introduction of the spatial panel model addresses this issue and allows for convincing control of time-invariant confounders. Because our sample is composed of regions that are part of the same country and have common characteristics (in terms of climate, infrastructure, production systems, etc.), it is necessary to consider the interactions caused by geographical proximity, also called spatial interaction, in the modeling. Consequently, we follow Vaitkeviciute *et al*. (2019) and Karahasan and Pinar (2023) in our analysis and adopt a panel Spatial Error Model (SEM), which is the most suitable specification for this type of aggregated data. Indeed, according to Vaitkeviciute *et al*. (2019), a Spatial AutoRegressive (SAR) model and a Spatial Lag to the explanatory X variables (SLX model) are not suitable for our case because the SAR model is interesting in the context of individual (farm)-level data, whereas the SLX model is excluded because of collinearity issues. This leads us to work with an SEM that captures the global spatial autocorrelation. In other words, the spatial autocorrelation of errors implies the possible presence of measurement errors that tend to propagate across aggregated unit boundaries, omitted variables, or unobserved shocks that follow a spatial pattern. In addition, the existence of spatial autocorrelation can be explained by different data as well as by the aggregation process scales.

The SEM model is better suited for aggregated data, mainly because of the possible existence of spatial autocorrelation in the residuals, which in turn can be attributed to the construction of weather data (Vaitkeviciute *et al*., 2019). Therefore, we used an SEM panel model that implies the following residual term:

$$log\,(Y_{it}) = log(A) + \alpha log\,(K_{it}) + \beta log\,(L_{it}) + \\ + \theta log\,(T_{it}) + \gamma log\,(P_{it}) + \mu_i + \nu_t + \varepsilon_{it}, \quad (5)$$

such that $\varepsilon_{it} = \rho \sum_{k=1}^{N} \omega_{ik}\eta_{ik} + \epsilon_{it}$,

where ε_{it} correspond to the residual term which is composed of the spatially autocorrelated error

term, ω_{ik} is the generic element of a nonnegative, $N \times N$ spatial-weight matrix W_N in which neighborhood relationships between regions are defined, ρ is the spatial autocorrelation coefficient that captures a correlated effect of unobservable characteristics, η_{ik} is the spatially correlated error term, and ϵ_{it} is the error term.

The choice between these models is made through specification tests described in the practical bottom-up approach (see Le Gallo [2002] for a summary), which begins with the non-spatial model. We then use Lagrange Multiplier tests (LMLAG and LMERR) and their robustness (Robust-LMLAG and Robust-LMERR) to determine the SAR, SEM, or non-spatial model (Anselin, 1988; Anselin *et al*., 1996).

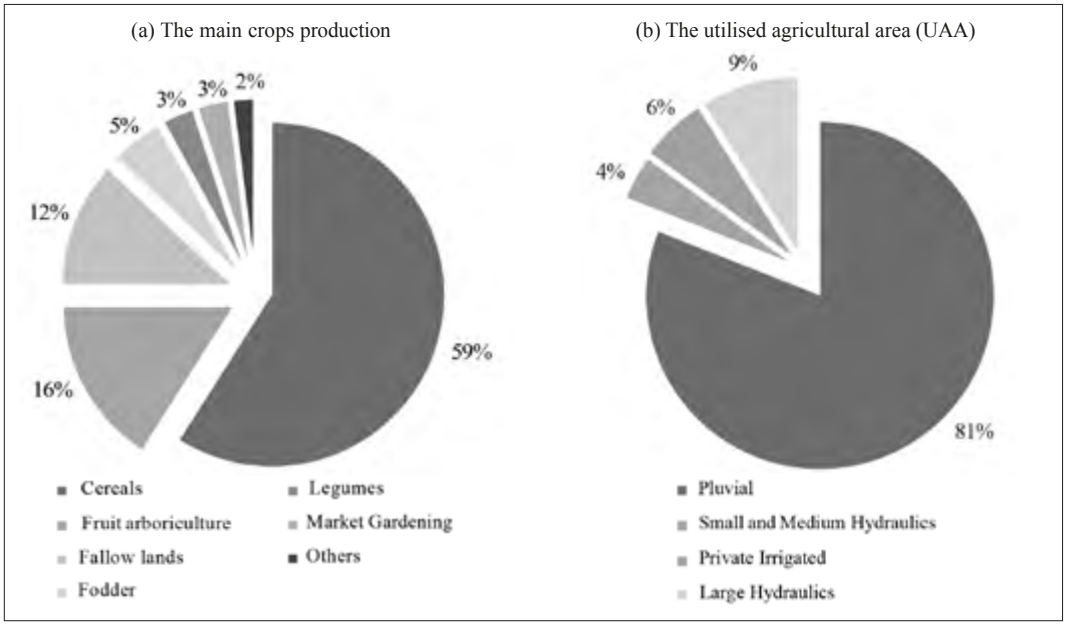
4. Context, Data and Exploratory Analysis

This study leverages panel data collected from a sample of 12 regions within Morocco spanning the period from 1999 to 2019. Our selection of variables and regions was constrained by the availability of consistent data on both climate and agriculture. In this section, we first provide context (4.1) by outlining the Moroccan agricultural landscape, highlighting the predominance of rainfed areas and the importance of cereal production. It also emphasizes the spatial and temporal variability in agricultural production, and underscores the impact of spatial concentration of crops on regional economic performance. The second sub-section (4.2) details the data sources used in the analysis, explaining the origin and measurement of economic and meteorological variables, and emphasizing the importance of accounting for crop-specific growing seasons. Finally, the third sub-section (4.3) focuses on spatial exploratory analysis, using the Moran's I test to identify the spatial autocorrelation of agricultural production across Moroccan regions and exploring potential explanations for this spatial dependence.

4.1. *Contextualizing the Moroccan Agricultural Landscape*

With an area of nearly 8.7 million hectares, Morocco's Useful Agricultural Area (UAA) is rich in agro-climatic systems that allow it to produce a very wide range of crops in Morocco, both irrigated and non-irrigated. These are mainly cereals, fruit crops (generally composed of rosacea,

Figure 1 - Breakdown of the main crops and UAA in Morocco.

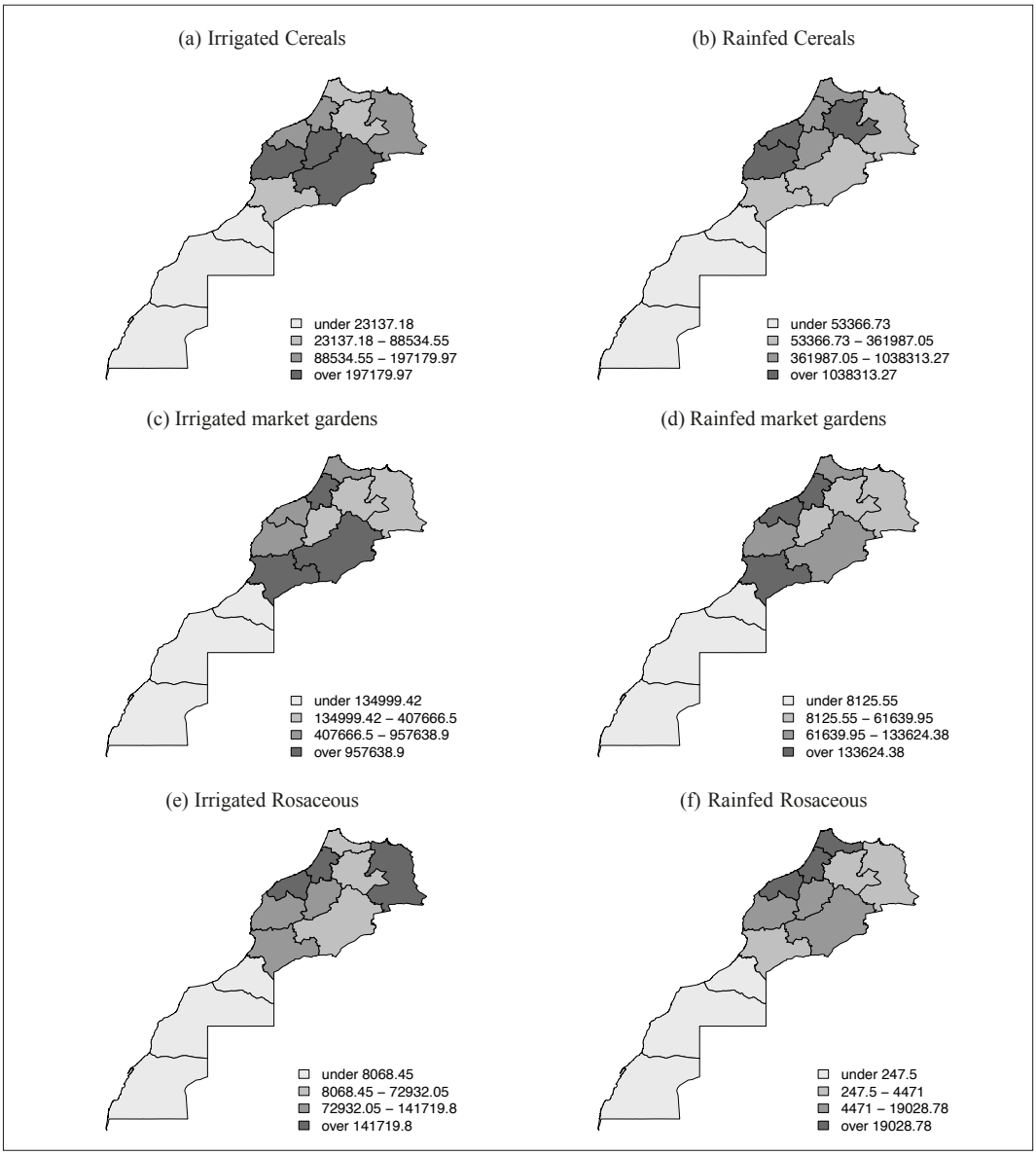


Source: Ministry of Agriculture, 2019.

olives, and almonds), fallow land, fodder crops, market gardens, leguminous, and others (Ministry of Agriculture, 2019). However, this UAA is characterized by the dominance of rain-fed areas (Bour) (up to 80% of the total UAA) and the consequent weight of cereals (nearly 59% of the total UAA, that is, 79% of the UAA in rain-fed areas, as shown in Figure 1).

Analysis of inter-regional variability over the period 1999-2019 shows that production instability is not only temporal but also spatial. Indeed, the distribution by regional zone shows that most crops are spatially concentrated (Figure 2 below). For example, cereals and tree crops are located in the northwest (Tangier-Tetouan-Al-Hoceima, Rabat-Salé-Kenitra, Casablanca-Settat, Marrakech-Safi, Béni Mellal-Khénifra) and northeast (Fez-Meknes and Oriental) regions, re-

Figure 2 - Agricultural production in Morocco: spatial patterns of irrigated and rainfed crops (1999-2019).



spectively. This explains the differentiation in the performance of the agricultural sector according to these regions in terms of their weight in the national AGDP. Indeed, according to report of Ministry of Economy (2019), during the period 2001-2016, the region of Fez-Meknes recorded the largest share in the national agricultural value-added, with an average share of 16.5%, followed by the region of Marrakech-Safi (14.2%), Rabat-Salé-Kénitra (13.4%), and Casablanca-Settat (12%).

4.2. *Data Sources and Measurement*

As previously mentioned, we use regional panel data describing the annual production of three types of crops: Cereals (aggregation for cereal products: wheat, barley, and corn), Market Gardening (aggregation for products: Tomatoes, Potato and Onion), and Rosaceous (aggregation of products: Almond, Apricot, Plum, Apple and Pear) as a function of meteorological variables (Precipitation and Temperature) and agricultural inputs (Total Area of Rain-fed and Irrigated Land, Livestock and Labor) in the twelve Moroccan regions, namely Tangier-Tetouan-Al Hoceima, Oriental, Fez-Meknes, Rabat-Salé-Kénitra, Béni Mellal-Khénifra, Casablanca-Settat, Marrakesh-Safi, Drâa-Tafilalet, Souss-Massa, Guelmim-Oued Noun, Laâyoune-Sakia El Hamra, Dakhla-Oued Ed-Dahab. The time dimension of the panel data covers a period of twenty-one years (1999-2019).

The data concerning economic variables (Production, Labor, Capital) is drawn from the database built with the help of Geographic Information Systems (GIS) existing since the 1990s at the level of the Haut Commissariat au Plan (HCP)[1]. Production is measured in tons. The contribution of capital is represented by livestock (in this context, refers to draught animals) and land inputs. Indeed, the capital requirements of traditional agriculture are low, and Moroccan agriculture relies mainly on animal traction. Therefore, we use the number of donkeys, horses, and mules as an indicator of this livestock input, as it was done in many other studies (Antle, 1983; Barrios *et al*., 2008; Frisvold and Ingram, 1995; Hayami *et al*., 1971; Nguyen, 1979). Land supply is represented by the total area of rain-fed agricultural land measured in hectares. Irrigation can be crucial for production under drought conditions, so it is important to account for changes in the proportion of irrigated land per hectare over time when estimating irrigated crop production function (Ward *et al*., 2014). Labor is also a key determinant of the agricultural production function. We employ the regional agricultural labor data drawn from the HCP database to account for this factor in our production function specifications.

Finally, meteorological data at the regional level, including average monthly temperature and total monthly precipitation, are gridded data extracted from the Global Climate Monitor (GCMon) Web Viewer database. This tool, which is both a data model and a visualization platform, provides access to global climate data (Camarillo-Naranjo *et al*., 2019). The data available are based on the CRU TS3.21 version of the University of East Anglia Climate Research Unit database, covering the period from January 1901 to December 2012, with a spatial resolution of half a degree in latitude and longitude (Harris *et al*., 2014; 2020). From January 2013 until the present, data supplying the GCMon system have come from the Global Precipitation Climatology Centre (GPCC) for precipitation (Fan and Van den Dool, 2008), and the Global Historical Climatology Network-Monthly (GHCN-M) version 3.2.1 for global mean temperature (Ziese *et al*., 2011). The collected monthly weather data were then used to aggregate the annual weather variables (mean temperature and total cumulative precipitation), to account for the effects of weather fluctuations at the specific periods of the year when climate is critical to the growth of rain-fed crops. Indeed, according to Blanc and Reilly (2017) the use of variables from specific periods of the year in the estimates makes it possible to capture discrete parts of the response function. For this reason, and using information on the normal agricultural growth cycle in Morocco by year provided by Balaghi *et al*. (2008),

[1] *Annuaire Statistique des Régions from 1999 to 2019*, available at the library of HCP.

Table 1 - Descriptive statistics.

Statistic	*Notation*	*N*	*Mean*	*St. Dev.*	*Min*	*Max*
Log_Rainfed_Cereals	LogRainf_Cer	210	17.338	3.515	5.132	21.298
Log_Irrigated_Cereals	LogIrrg_Cer	210	15.876	2.650	2.322	19.004
Log_Rainfed_Rosaceous	LogRainf_Ros	210	13.755	2.426	7.622	17.462
Log_Irrigated_Rosaceous	LogIrrg_Ros	210	16.572	2.365	7.868	19.865
Log_Rainfed_Market_Gardening	LogRainf_MarkG	210	14.238	2.486	4.907	18.378
Log_Irrigated_Market_Gardening	LogIrrg_MarkG	210	18.664	1.640	13.694	20.906
Log_Labor	Loglabor	210	18.430	1.123	15.009	19.692
Log_Land	LogLand	210	17.675	2.696	9.155	20.341
Log_Livestock	LogLivestock	210	6.752	1.647	0.848	8.583
Log_Mean_Temperature	LogTmean	210	3.782	0.233	2.911	4.147
Log_Total_precipitation	LogRainf	210	10.194	0.981	7.460	12.563

we calculated the weather variables for the growing season for each of the three crops examined in our case study[2].

However, since irrigation is technically practiced throughout the year, we aggregate the meteorological variables annually (from January to December) without taking into consideration the growing seasons of the irrigated crops. Table 1 presents the descriptive statistics of our economic data.

4.3. *Exploratory Spatial Analysis*

This section examines the spatial dimension of agricultural production and climate variability in Morocco through spatial autocorrelation analysis. Building on the global spatial correlation identified by Moran's I (4.3.1), we utilize the Local Indicator of Spatial Association (LISA) to explore the localized patterns of crop production and meteorological variable clustering (4.3.2).

4.3.1. *Exploring Spatial Dependence: Evidence from Moran's I Statistic*

The spatial dimension of the geographic location of agricultural production and meteorological variables can be further explored using global correlation statistics, such as the Moran's I test, which identifies spatial correlation between Moroccan regions. This test, first introduced by Moran (1948), determines whether regions with similar values for agricultural production and meteorological variables tend to cluster together spatially.

The Moran's I statistic is defined as follows:

$$I_W = \frac{n}{\sum_i \sum_j W_{ij}} \cdot \frac{\sum_i \sum_j W_{ij}(y_i - \overline{y})(y_j - \overline{y})}{\sum_i (y_i - \overline{y})^2} \quad (6)$$

Table 2 presents the results of Moran's I test, its standard deviations (Sd(I)) and p-value, allowing for assessment of the significance of its results for agricultural production and meteorological variables. Moran's I statistic is calculated using the neighborhood matrix W and the values of the variable under study. To analyze the spatial relationships between the data, we employed spatial weight matrices, which represent the neighborhood relationships between data points. Inspired by the work of Le Gallo and Ndiaye (2021), these matrices are commonly used in spatial econometrics and allow for quantifying the influence of neighboring points on a given point. We consid-

[2] According to Balaghi *et al*. (2008), the cropping-practices are adapted to the bimodal rainfall distribution in the country. The first peak in autumn–winter fills the soil moisture reserves and allows the establishment of the crop. The second peak in the spring months is used for dry matter accumulation. Sowing takes place between September and December, depending on the precocity of first precipitations in autumn. Harvest starts around June in the South and continues until July for the Northern regions, as temperatures rise first in the South.

Table 2 - Global spatial correlation test Moran's I.

Variables	*Moran's I statistic*	*Standard deviation*	*p-value*
Rainfed Crops			
Log_Rainfed_Cereals	0.269***	3.385	0.00035
Log_Rainfed_Market_Gardening	0.241**	2.0859	0.01849
Log_Rainfed_Rosaceous	0.318***	1.5486	$6.002e^{-05}$
Irrigated Crops			
Log_Irrigated_Cereals	0.225***	2.9762	0.0014
Log_Irrigated_Market_Gardening	0.257**	2.1866	0.0143
Log_Irrigated_Rosaceous	0.157***	2.3386	0.0096
Meteorological Variables			
Average Precipitation	0.434***	3.296	0.00049
Average Temperature	0.306***	2.4901	0.0063

ered three types of matrices: a Gabriel's neighbor-based adjacency matrix (W_{cont}), a 5-nearest neighbor matrix (W_{nn5}), and an inverse distance matrix ($W_{dinverse}$). Graphical representations of these matrices are provided in Figures 6, 7, and 8 of Appendix A.

Since we are using gridded meteorological data which can lead to spatial correlation resulting in significant impacts between neighboring regions (Auffhammer *et al*., 2013), we only present here the results associated with the $W_{dinverse}$ matrix, as it has the strongest explanatory power and promotes the most intuitive economic interpretation. The Moran's I test reveals a significant positive spatial autocorrelation for all agricultural crops, both rainfed and irrigated. This indicates that agricultural production in Morocco exhibits a strong spatial correlation, with regions of high or low agricultural production tending to cluster together. Furthermore, a significant positive spatial autocorrelation is found for both temperature and precipitation, confirming the spatial variability of Morocco's climate. This correlation can be attributed to various factors, including land quality suitability for specific crops, shared climatic characteristics with neighboring regions, effective farmer organization, and economies of scale.

4.3.2. *Spatial Clustering Analysis: Evidence from LISA*

While Moran's I test effectively identifies global spatial autocorrelation, its limitation lies in its inability to provide insight into the local structure of this correlation. As Anselin (1995) points out, Moran's I test offers a global perspective, neglecting to reveal the intricacies of localized spatial dependencies. To overcome this limitation, we employ the Local Indicator of Spatial Association (LISA) a technique that goes beyond global analysis.

The most commonly used LISA is the local Moran's I, defined as follows:

$$I_i = (y_i - \overline{y}) \sum_j W_{ij}(y_j - \overline{y}) \qquad (7)$$

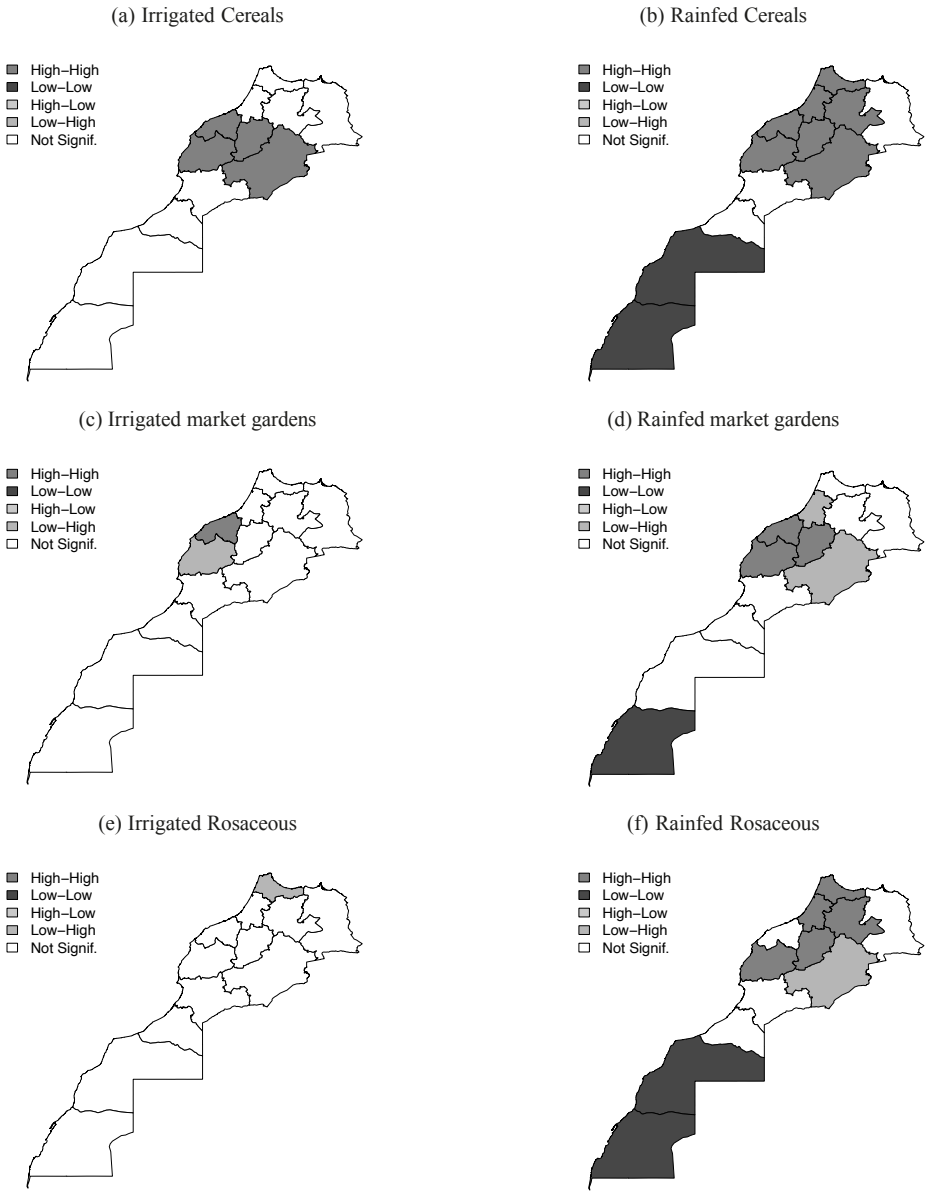
LISA pinpoints significant clusters of similar values surrounding a specific location and also identifies areas of spatial non-stationarity (Anselin, 1995), which deviate from the overall global pattern. In our case study, LISA allows us to discern four distinct scenarios:

- *HH*: a *H*igh production region is surrounded by other *H*igh-production regions
- *LL*: a *L*ow production region is surrounded by other *L*ow-production regions
- *HL*: a *H*igh production region is surrounded by *L*ow-production regions
- *LH*: a *L*ow production region is surrounded by *H*igh-production regions

In the first two cases (*HH* and *LL*), local autocorrelation is positive while in the other cases (*HL* and *LH*), local correlation is negative.

Figure 3 provides spatial clustering patterns corresponding to the LISA index of each agricultural production for the three rain-fed and irrigated crops respectively. The local test, using

Figure 3 - Spatial clustering patterns of irrigated and rainfed crops using LISA in Moroccan regions (1999-2019).



HH, *HL* indicate *H*igh production patterns with *H*igh and *L*ow clustering characteristics; *LL*, *LH* indicate *L*ow production patterns with *L*ow and *H*igh clustering characteristics, respectively. *Not Signif.* indicates no clustering significance.

the LISA index, reveals a positive local spatial autocorrelation for both irrigated and rainfed cereals (Figures 3a and 3b below). This means that regions with high cereal production tend to be surrounded by other regions with high production levels, which corresponds to the *HH* scenario identified by LISA. In other words, we observe a spatial clustering in the northern regions of Morocco, which exhibit high cereal production, in contrast to the southern regions that display a negative

Figure 4 - Spatial patterns of average precipitation and temperature in Morocco (1999-2019).

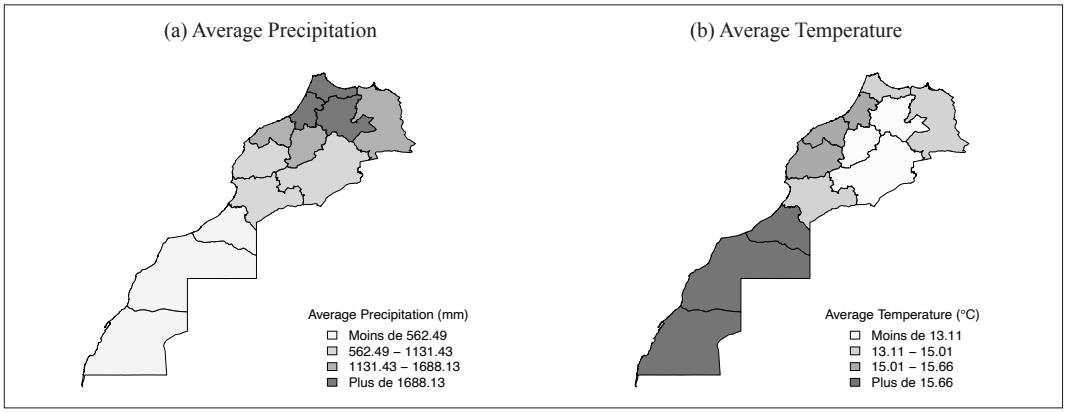
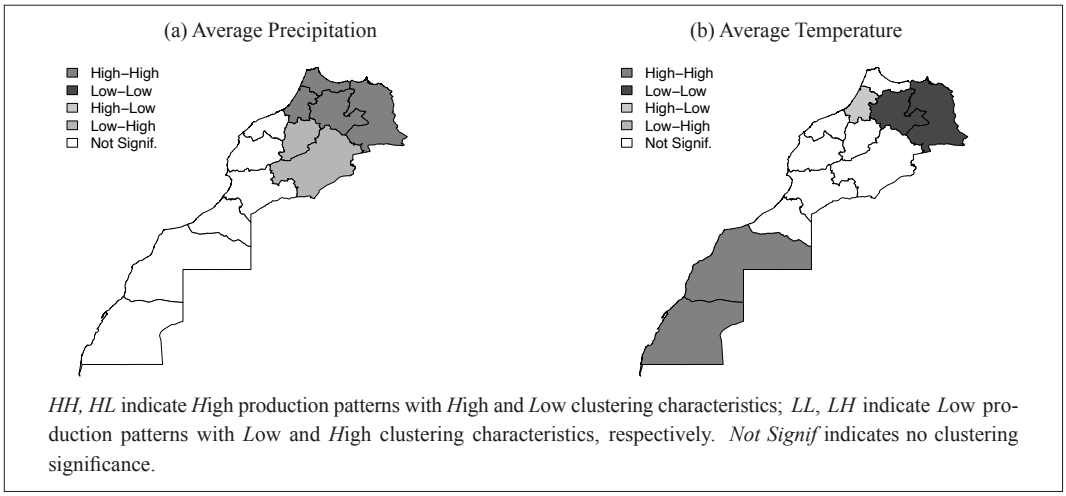


Figure 5 - Spatial Clustering Patterns of average precipitation and temperature using LISA in Moroccan Regions (1999-2019).



HH, HL indicate *H*igh production patterns with *H*igh and *L*ow clustering characteristics; *LL*, *LH* indicate *L*ow production patterns with *L*ow and *H*igh clustering characteristics, respectively. *Not Signif* indicates no clustering significance.

local spatial autocorrelation. The latter indicates a spatial clustering of regions with low cereal production, which tend to be surrounded by other regions with low production. This result confirms the idea that favorable conditions for cereal production, such as water availability, irrigation infrastructure, and suitable agricultural practices, are concentrated in the northern regions of the country.

The same observation is made for market gardening and rosaceous crops (Figures 3c, 3d, 3e and 3f), but with a less marked intensity than for cereals.

This means that there is a significant spatial clustering in the northern regions, where market gardening and rosaceous crops show high production. These regions tend to be surrounded by other regions with high production of the same crops, which corresponds to the *HH* scenario identified by LISA. However, there are also regions with low production of these crops that tend to be surrounded by other regions with high production, which corresponds to the *LH* scenario identified by LISA. If we take, for example, rainfed market gardening (Figure 3d), we find that the regions "Casablanca-Settat, Marrakech-Safi and Béni Mellal-Khénifra" exhibit high production of rainfed market gardening and tend to be surrounded by other regions with high production of rainfed market gardening. In contrast, the

"Drâa-Tafilalet" region is a region with low production of rainfed market gardening, and it tends to be surrounded by other regions with high production of rainfed market gardening.

However, for irrigated rosaceous crops (Figure 3e), the local test reveals a negative spatial autocorrelation. This means that regions with low production of irrigated rosaceous crops are surrounded by regions with high production of irrigated rosaceous crops, which corresponds to the *LH* scenario identified by LISA. This particular spatial dynamic could be explained by the influence of specific restrictive conditions associated with these crops, such as water availability for rainfed market gardening or temperature and light requirements for irrigated rosaceous crops. Moreover, market pressures and competition could also play a role, with low-producing regions potentially facing challenges in market access and profitability, while high-producing regions benefit from organizational advantages and expertise.

The geographic concentration of crops in northern Morocco is primarily driven by a well-defined climatic boundary separating a wetter north from a drier south. Figure 4 above illustrates the spatial clustering patterns corresponding to the LISA index of temperature and precipitation variables, respectively. This climatic boundary is evident in the spatial variability of precipitation, which is more pronounced in the north (Figure 4a). In contrast, the south is characterized by an arid climate (Figure 4b). Spatial analysis confirms this climatic variability. The Moran's I test reveals a significant positive spatial autocorrelation for both temperature and precipitation (Table 2), which is further supported by the local LISA test (Figure 5b and 5a). Regions in the south with high average temperatures tend to be surrounded by other regions with similar high temperatures (*HH* scenario), while the opposite is true for precipitation in the north. This positive local spatial autocorrelation for temperature in the south and precipitation in the north highlights the climatic differences that explain the concentration of crops in the north. Indeed, according to Ezzine *et al*. (2017) the northern part of Morocco is characterized by a sub-humid Mediterranean-type climate, with an average annual rainfall of 1200 mm, which is favorable for agriculture, while, the southern part is characterized by a Saharan (dry) climate, with average annual rainfall of less than 100 mm, which is not suitable for agricultural production. This diversity is due to the combination of several factors, namely its latitudinal location, the influence of the Atlantic Ocean and the Mediterranean Sea, and the influence of elevation through Atlas and Rif mountains (Ezzine *et al*., 2017). The northern regions benefit from several favorable conditions for the development of agricultural production. Indeed, in the Tangier-Tetouan-Al-Hoceima region, for example, the useful agricultural area represents nearly 38% of the total area. Thus this region, thanks to the large hydraulic basin of Loukkous, is endowed with a significant irrigated agricultural perimeter, whose proportion of irrigated land represents 10% of the Tangier-Tetouan region and 6% of the Taza-Al Hoceima-Taounate[3] region. These physical characteristics combined with the Mediterranean-type climate and oceanic influence, with a rainy season that lasts from October to March, are favorable to the production of this type of crops and explain why the northern regions, with high production of such crops, are surrounded by similar region with high production.

5. Estimation Results and Discussions

This section presents the results of estimating the impact of climate variability on agricultural production across 12 Moroccan regions (5.1). We then delve into a comprehensive discussion of these results, exploring their implications and highlighting the limitations of our study (5.2).

5.1. *Interpreting Estimation Results*

This section delves into a detailed interpretation of the estimation results, examining the influence of both climatic and economic factors on agricultural production in Morocco. We begin by discussing the specification tests and model selection

[3] http://www.apdn.ma/index.php?option=com_content&view=article&id=233&Itemid=227&lang=fr.

process employed to ensure the robustness and validity of our findings. Subsequently, we analyze the impact of climatic variables, particularly temperature and precipitation, on the production of both rainfed and irrigated crops, emphasizing the significance of spatial autocorrelation in shaping these effects. We then explore the role of economic variables, including labor, capital, and land area, in influencing agricultural production and reveal any disparities across different crop types

5.1.1. *Specification Tests and Selection of the Appropriate Model*

Following the practical bottom-up approach, we begin our specification with a non-spatial ordinary least squares (OLS) regression model as a reference (Elhorst, 2003). We performed a few specification tests tailored to the spatial panel data shown in Table 3 below. First, we used the classical Lagrange Multiplier (LM) and Robust Lagrange Multiplier (RLM) tests applied on the

Table 3 - Pooled OLS estimation and tests for spatial autocorrelation.

	Dependent variable					
	LogRainf_ Cer (1)	*LogIrrg_Cer* (2)	*LogRainf_ Ros* (3)	*LogIrrg_ Ros* (4)	*LogRainf_ MarkG* (5)	*LogIrrg_ MarkG* (6)
LogLabor	−1.275***	0.059	−0.019	−0.056	−0.689	1.167***
	(0.375)	(0.389)	(0.393)	(0.420)	(0.565)	(0.241)
LogLand	1.054***	0.085	0.364***	0.077	−0.033	0.037
	(0.080)	(0.083)	(0.084)	(0.090)	(0.121)	(0.052)
LogLivestock	1.013***	1.206***	0.201	0.865**	1.117**	−0.065
	(0.306)	(0.317)	(0.320)	(0.342)	(0.460)	(0.196)
LogTmean	−0.928*	−2.355***	3.059***	−4.045***	1.851**	1.240***
	(0.550)	(0.571)	(0.576)	(0.616)	(0.829)	(0.353)
LogRainf	0.231*	−0.291**	0.588***	−0.244*	0.292	0.091
	(0.125)	(0.130)	(0.131)	(0.140)	(0.189)	(0.081)
Constant	16.529***	17.013***	−11.247**	28.192***	10.009	−8.669**
	(5.251)	(5.444)	(5.495)	(5.874)	(7.910)	(3.370)
Observations	210	210	210	210	210	210
R^2	0.835	0.689	0.621	0.545	0.253	0.689
Adjusted R^2	0.831	0.681	0.612	0.534	0.234	0.681
F Statistic (df = 5; 204)	206.876***	90.198***	66.985***	48.842***	13.799***	90.208***
Hausman test:	14.697**	9.608*	749.47***	17.482***	16.064***	14.378**
Spatial test	*Tests for spatial dependence on residuals*					
LM test: lml	0.626	15.219***	6.022**	0.956	3.590**	52.266***
LM test: lme	20.33***	3.962**	7.492***	25.907***	3.485*	2.108
RLM test: Rlml	2.987*	23.3***	14.702***	1.134	10.248***	55.349***
RLM test: Rlme	22.691***	12.044***	16.173***	26.085***	10.143***	5.191**
Spatial Hausman test:	10.847**	12.345**	14.136**	16.274***	19.402***	23.188***

*Note: * significant at 10% level, ** significant at 5% level, *** significant at 1% level.*

error terms (LM_ρ) and spatial lags (LM_δ) to decide between the SEM, SAR, and the non-spatial model (Anselin *et al*., 1996). Generally, these tests reject the hypothesis of no spatial correlation for the error terms and spatial offsets.

Indeed, the classical LME_ρ and $RLME_\rho$ tests showed that the null hypothesis of no spatially auto-correlated error term is strongly rejected at the 1% and 5% significance level while suggesting that the SEM specification is the most appropriate for all the crops studied. Next, the spatial Hausman test (SHT) was used to test the effectiveness of the spatial random effects estimator. The coefficients related to the SHT test were highly significant and showed that the fixed effect model is the most appropriate. Finally, all of these tests suggested that the specification that considers both spatial error autocorrelation and individual heterogeneity in a fixed-effect model (FE-SEM) is the most appropriate for our case study.

5.1.2. *Impact of Climate Variability on Agricultural Production*

The results of the FE-SEM model estimation for rainfed and irrigated crops are presented in Table 4. Moreover, for robustness, the results of the SAR estimator are also presented in Table 5 in Appendix B. Examining the coefficients of the meteorological variables in the FE-SEM model, we observe a more significant impact of meteorological variables on agricultural production in Morocco. Furthermore, the FE-SEM model demonstrates that cereal production is highly sensitive to temperature and precipitation. Indeed, the temperature coefficients exhibit a negative sign on the production of this crop. These coefficients indicate that, ceteris paribus, a 1% change in temperature generates a decrease of 1.149% and 2.469% in rainfed and irrigated production, respectively. The negative sign of the temperature variable coefficients is not surprising and signifies that high temperatures have detrimental effects on cereal production in Morocco. It is noteworthy that this sector still occupies nearly 60% of the total useful agricultural area, of which 90% is cultivated in rainfed areas (Ministry of Economy, 2019). This concentration of cereals, particularly in unfavorable rainfed areas, makes it more vulnerable to climatic hazards, explaining the negative sign of the temperature coefficient. Consequently, this vulnerability will persist.

Regarding precipitation coefficients, they exhibit a positive sign for rainfed production and a negative sign for irrigated production. These

Table 4 - Estimation results of spatial error model (SEM).

	Dependent variables					
	LogRainf_Cer	*LogIrrg_Cer*	*LogRainf_Ros*	*LogIrrg_Ros*	*LogRainf_MarkG*	*LogIrrg_MarkG*
LogLabor	−0.232*	1.330***	−1.030***	2.080***	−0.182	0.591***
	(0.067)	(0.135)	(0.258)	(0.285)	(0.195)	(0.170)
LogLand	1.011***	0.180***	0.339***	−0.119	−0.070	0.044
	(0.068)	(0.069)	(0.077)	(0.082)	(0.104)	(0.050)
LogLivestock	0.257	0.352**	0.728***	−0.359	0.761***	0.2952*
	(0.157)	(0.178)	(0.249)	(0.253)	(0.251)	(0.161)
LogTmean	−1.149**	−2.469***	2.911***	−4.346***	2.505***	1.208*
	(0.487)	(0.535)	(1.063)	(1.081)	(0.764)	(0.671)
LogRainf	0.578***	−0.434***	0.866***	0.064	0.376**	−0.002
	(0.117)	(0.123)	(0.149)	(0.143)	(0.182)	(0.101)
ρ	−0.257***	−0.593***	−0.368***	−0.266***	−0.255***	−0.193**
	(0.092)	(0.093)	(0.089)	(0.062)	(0.091)	(0.092)
Observations	210	210	210	210	210	210

*Note: * significant at 10% level, ** significant at 5% level, *** significant at 1% level.*

coefficients indicate that, ceteris paribus, a 1% change in precipitation generates an increase of 0.578% in rainfed production and a decrease of 0.434% in irrigated production, suggesting low efficiency of irrigation techniques. This inefficiency is partly linked to the issue of water reallocation. While drip irrigation is considered an efficient technology, it does not guarantee water savings at the watershed level, as it can affect return flows and therefore water availability for other users. Climate change, by accentuating the decrease in precipitation and increasing evaporation, risks exacerbating this situation, creating increased competition for water and enhancing the risk of groundwater overexploitation. This overexploitation aggravates inequalities in access to groundwater, as more affluent farmers can continue to irrigate while others are forced to reduce or abandon their production. Furthermore, the lowering of groundwater levels makes drilling more expensive and pumps less efficient, reducing farmers' profitability.

The results for irrigated rosaceous crops are not significantly different concerning climatic variables. For instance, irrigated rosaceous crop production is highly sensitive to temperature, showing a negative coefficient indicating that, ceteris paribus, each 1% increase in temperature causes a decrease of 4.346% in irrigated rosaceous crop production. Conversely, the coefficient for the precipitation variable is not significant. This result highlights that irrigated rosaceous crops are more sensitive to thermal conditions than to precipitation. Temperature directly affects crop growth and development, and a rise in temperatures can lead to water stress, decreased pollination, and an increase in diseases and pests. Moreover, a rise in temperatures causes an increase in plant transpiration as they seek to cool themselves by releasing water as vapor (Molle and Tanouti, 2017). Drip irrigation, while optimizing water input, is not always sufficient to compensate for this increase in transpiration, especially under water stress conditions. The dependence of these crops on irrigation therefore makes them more vulnerable to temperature variations, as water availability is insufficient to offset negative effects, particularly increased transpiration (Molle and Tanouti, 2017).

On the other hand, the FE-SEM model shows that rainfed rosaceous crop production and market gardening (rainfed and irrigated) are less vulnerable to climate change. Indeed, the coefficients of the "temperature" variable exhibit a positive sign for the agricultural production of these crops. The positive sign indicates that, ceteris paribus, each 1% increase in temperature generates an increase of 2.911%, 2.505%, and 1.208% in the agricultural production of rainfed rosaceous crops and market gardening (rainfed and irrigated), respectively. This result can be explained by the fact that the positive effect of the temperature variable coefficient depends on other parameters specific to the crop and its environment, and that higher temperatures during the growing season could have a positive effect on the growth of certain crops. This suggests that these crops thrive in warm weather conditions and are therefore not highly sensitive to global warming.

This result is partially explained by the adaptation of crops and agricultural practices following the GMP. This program has encouraged the adoption of more resistant and profitable crops, such as rosaceous crops and market gardening, and has promoted the use of drip irrigation. Drip irrigation can contribute to crop growth despite higher temperatures by ensuring optimal water supply. Additionally, rainfed rosaceous crops and rainfed market gardening naturally benefit from a certain resilience to the semi-arid climatic conditions of Morocco. However, it is important to highlight that groundwater overexploitation and rising temperatures can eventually negatively affect these crops. It is crucial to continue research and monitor the evolution of these crops in the face of climate variability to anticipate risks and adapt agricultural practices.

5.1.3. *Spatial Error Autocorrelation and Spillover Effects*

The spatial error autocorrelation coefficient, ρ, is negative and highly significant for all agricultural productions, indicating the presence of spillover effects between Moroccan regions. This result supports the argument that unobserved factors are spatially correlated, even after controlling for factors such as weather and agricultural inputs. These unobserved factors include insufficient cohesion of agricultural public policies at the region-

al level, creating disparities. The GMP has had a significant impact on Moroccan agriculture by encouraging drip irrigation and easing access to land. However, this policy, while aiming to modernize and develop agriculture, has generated significant negative effects on water resource management. Take the example of the Gharb region. The GMP has facilitated access to land owned by the state and the privatization of collective lands, attracting investors eager to develop intensive agricultural projects based on drip irrigation. At the same time, generous subsidies offered for drip irrigation have encouraged many farmers to exploit wells without authorization, increasing pressure on groundwater and exacerbating the overexploitation of the Gharb aquifer. This situation highlights a crucial problem of the impact of agricultural policies favorable to one region on neighboring regions. Indeed, the concentration of investments and subsidies in the Gharb has led to increased competition for water resources, negatively affecting neighboring regions such as Loukkos and Doukkala. These regions, already facing problems of groundwater overexploitation, are seeing their situation deteriorate due to the decrease in return flows in aquifers, originating from areas where drip irrigation is practiced intensively.

Furthermore, poor farmer organization can exclude smallholders, who lack resources and have unequal access to markets and modern agricultural adaptation technologies. Certain unsustainable agricultural practices, such as overgrazing and deforestation, contribute to soil erosion and fertility loss. Moreover, excessive use of inputs, such as pesticides and fertilizers, exacerbates these problems. Furthermore, monoculture (cereals) over vast areas reduces plant biodiversity, while excessive irrigation and lack of drainage lead to soil salinization. Recurrent periods of drought put significant pressure on groundwater resources, making Moroccan agriculture more vulnerable to climate change. In other words, spatial error autocorrelation implies the possible presence of measurement errors that tend to propagate across aggregation unit boundaries, omitted variables, or unobserved shocks following a spatial pattern. Moreover, the existence of spatial autocorrelation could be explained by the different data scales and the aggregation process.

5.1.4. *Impact of Economic Variables on Agricultural Production*

Concerning economic variables, capital and labor factors have a statistically significant impact on Moroccan agricultural production. The FE-SEM model shows that regional agricultural production is highly dependent on agricultural labor in Morocco. Indeed, the coefficients of this production factor exhibit a positive sign indicating that, ceteris paribus, each 1% increase in agricultural labor generates an increase of 1.330%, 2.080%, and 0.591% in the production of cereal, rosaceous, and irrigated market gardening, respectively. Unexpectedly, however, labor seems to have a detrimental effect on some rainfed crops. Indeed, ceteris paribus, each 1% increase in agricultural labor generates a decrease of 0.232% and 1.030% in the production of rainfed cereals and rosaceous crops, respectively. This result appears unexpected at first glance.

The unexpected impact of labor on the production of some rainfed crops can be explained by several factors. First, the structure of agricultural employment in Morocco is dominated by self-employed workers and family businesses, often involving unpaid and unskilled labor. This situation is reinforced by the fact that the agricultural sector faces an aging workforce, with a gradual decline in the working-age population in rural areas. Moreover, the harvest of these crops requires specific skills that workers do not always possess, leading to low productivity. Finally, the use of inadequate or poor-quality tools contributes to a decrease in production. It is therefore crucial to invest in worker training and improve the quality of tools used to increase labor productivity in the agricultural sector. The model predicts a significant positive impact for livestock (Draught animals), indicating that, ceteris paribus, each 1% increase in this production factor generates an increase of 0.352%, 0.728%, 0.761%, and 0.295% in the production of irrigated cereals, rainfed rosaceous crops, and rainfed market gardening and irrigated market gardening, respectively. This demonstrates the crucial role of livestock in agriculture, explaining its traditional aspect in Moroccan regions. While for irrigated rosaceous crops, the model predicts a negative but non-significant impact for livestock, indicat-

ing that, ceteris paribus, each 1% increase in this production factor generates a decrease of 0.359% in irrigated rosaceous crop production. Several factors can explain this negative impact. First, the trampling of livestock can compact the soil, reducing water infiltration and increasing runoff. This can create waterlogged conditions around the roots of rosaceous crops, promoting the development of diseases and rot. Moreover, soil compaction can degrade its structure, making rosaceous crops more vulnerable to erosion and water stress. Second, while animal manure provides nutrients to the soil, compaction can limit their availability for rosaceous crops. Excessive manure can also create a nutrient imbalance, increasing competition between rosaceous crops and other plant species, and promoting the development of diseases. Finally, animal manure can contaminate irrigation water, impacting water quality and the health of rosaceous crops.

As for the contribution of the total useful agricultural area of Morocco, it has a positive impact, showing that, ceteris paribus, each 1% increase in this factor implies an increase of 1.011%, 0.180%, and 0.339% in the agricultural production of rainfed cereals, irrigated cereals and rainfed rosaceous crops, respectively. This result is explained by the policies of the GMP, which aimed to stimulate agricultural production by promoting the expansion of cultivated areas. The GMP has facilitated access to land, particularly by encouraging the privatization of collective lands and allowing the purchase of public lands, thus attracting investors eager to develop intensive agricultural projects. Cereals and rosaceous crops, being important crops in Morocco, have benefited from this expansion of cultivated areas. On the other hand, this result can be explained by the use of new technologies, selected seeds, and fertilizers, as well as the cultivation of virgin and fertile land such as forested areas and pastures, in addition to the cultivation of certain species intended for rainfed production in irrigated areas, such as cereals (Oulhaj *et al*., 2013). This expansion is directly linked to the adoption of drip irrigation, and the National Program for Irrigation Water Savings (PNEEI) has played a crucial role in this process. The ambitious goal of converting 550,000 hectares of gravity or sprinkler-irrigated land to drip irrigation in 15 years, accompanied by massive subsidies and technical support, has accelerated the transformation of Moroccan irrigated agriculture.

However, the coefficients for market gardening (rainfed and irrigated) and irrigated rosaceous crops are not significant. This result can be explained by several factors related to the adoption of drip irrigation. First, drip irrigation, while allowing for better water use, does not necessarily translate into a reduction in the amount of water consumed at the field level. Indeed, crop intensification, increased tree density, and the adoption of more water-demanding crops, often associated with this technology, can offset water savings achieved. Second, field evapotranspiration is not always affected by drip irrigation. The reduction of soil evaporation may be limited, and the increase in crop transpiration due to more frequent irrigation may even lead to an overall increase in evapotranspiration. Finally, the expansion of vegetable cultivation towards rainfed areas, where water remains the main limiting factor, can also play a role. Indeed, the area dedicated to early market gardening, an essential component of market gardening, has increased by 42% between 2003-2007 and 2019, reaching 40,000 hectares. Vegetable cultivation is mainly concentrated in the regions of Souss-Massa, Rabat-Salé-Kénitra, Casablanca-Settat, and Tangier-Tetouan-Al Hoceima. Access to water in these regions is often a major obstacle, explaining why an increase in area is not always synonymous with an increase in production.

5.2. *Discussion of Results*

This section delves deeper into the discussion of our study's findings, analyzing the key factors that determine agricultural production in Morocco. We begin by examining the spatial interdependence of agricultural production, highlighting the presence of significant spillover effects between Moroccan regions (5.2.1). Next, we explore the sensitivity of different crops to climate variability (5.2.2). Subsequently, we examine the role of production factors and explore their impacts (5.2.3). Finally, we discuss the limitations of our study and identify avenues for future research (5.2.4).

5.2.1. *Spatial Interdependence and Spillover Effects*

Our findings highlight the presence of strong spatial interdependencies within the Moroccan agricultural sector, suggesting the need to consider spatial spillover effects when analyzing the impact of climate variability on agricultural production in Morocco. Indeed, a geographical concentration of agricultural production in the northern regions, confirmed by positive spatial autocorrelation (Moran's I test) and the use of a FE-SEM model, which accounts for both spatial error autocorrelation and heterogeneity between regions, shows that integrating the spatial dimension into econometric models and considering unobserved factors and regional disparities are crucial for a complete understanding of the Moroccan agricultural sector and for developing more relevant policies. These conclusions are consistent with those obtained by other researchers (Chen *et al*., 2016; Karahasan and Pinar, 2023; Schlenker *et al*., 2006; Vaitkeviciute *et al*., 2019). For example, Chen *et al*. (2016) analyzed the impact of climate variability on agriculture in China using a spatial panel data model on crop yields, planted areas of major crops (corn and soybeans), and meteorological data for the years 2000 to 2009. Chen *et al*. (2016) showed that the presence of spatial correlation between counties can be explained by the existence of several factors, such as agricultural policies, production practices, and local characteristics, that have influenced yields similarly in neighboring counties.

More recently, Karahasan and Pinar (2023) analyzed the impact of climate change on the spatial distribution of agricultural production in Turkey between 2004 and 2019, using fixed-effects panel models while taking spatial aspects into account (SAR and SEM models). Karahasan and Pinar (2023) showed that including spatial effects significantly improves the understanding of agricultural dynamics, highlighting the spatial heterogeneity of the impact between regions. Indeed, their results indicated that climate change has a variable effect depending on the region, with a greater impact in the northern and central areas dominated by agriculture. This finding highlights the inefficiency of "one-size-fits-all" policies in mitigating the negative effects of climate change in topographies exhibiting significant spatial dissimilarities. Thus, they suggested that climate change will significantly threaten the evolution of agricultural activities essential to regional development. Moreover, Karahasan and Pinar (2023) demonstrated that spatial spillover effects and heterogeneity will be crucial for designing climate change policies for rural and agricultural development. Therefore, local model analysis is essential for understanding these regional variations and implementing targeted and effective solutions.

5.2.2. *Sensitivity of Different Crops to Climate Variability*

The FE-SEM model highlights the high sensitivity of rainfed cereal production to temperature variations. These results align with the findings of several studies that shed light on the challenges associated with climate change and water resource management. Simulation studies on the evolution of agricultural yields by Balaghi *et al*. (2016) have indeed shown that climate change will affect wheat and barley, which could experience a projected yield decrease of over 50% in many provinces by 2050. In light of these challenges, the approach employed by the CALESA project (Developing Promising Strategies Using Analogue Sites in Eastern and Southern Africa) proves particularly relevant (Leal Filho and Mannke, 2011). This project, conducted in sub-Saharan Africa, where, like Morocco, nearly 90% of basic food production comes from small rainfed agricultural systems, offers an innovative approach to agricultural adaptation to climate change. Using analogue sites, defined as areas exhibiting the projected future climate conditions, the project has successfully identified promising adaptation strategies for rainfed agriculture in semi-arid and subhumid areas. Ex ante analyses coupled with field research have enabled the evaluation of the effectiveness of these strategies under real conditions, providing tangible solutions for farmers grappling with the challenges of climate change (Leal Filho and Mannke, 2011). The lessons learned from the CALESA project present significant potential for Morocco, particularly in terms of developing adaptation strategies for future climate conditions and strengthening the re-

silience of agricultural systems against droughts and extreme temperatures.

Irrigated cereal and rosaceous crops are extremely vulnerable to climate variability, as they have experienced a significant decrease in production due to variations in temperature and precipitation. According to Abdelmajid *et al*. (2021), this decrease is explained by the increase in groundwater pumping and the risk of aquifer salinization. Additionally, the High Commission for Water, Forests, and the Fight Against Desertification estimates that soil salinization in Morocco affects almost all major irrigated areas. Oulhaj *et al.* (2013) estimate that 22,000 hectares of irrigated land in the provinces of Zagora and Errachidia are affected by salinization, which combines its effects with those of wind erosion. Thus, Fader *et al.* (2016) confirmed that Morocco could face difficulties in mitigating precipitation deficits through irrigation due to the projected decrease in water resources. Moreover, Moutawakkil (2009) highlighted that irrigation presents certain management shortcomings: dangerous exploitation of groundwater, alarming degradation of water and soil resources, a pricing system that does not guarantee the balance of recurring water service costs, and a still low water fee recovery rate. Thus, these results can be explained on the one hand by the under-irrigation of nearly 63% of irrigated areas, mainly those based on the gravity irrigation system that uses large amounts of water, especially since a large part is lost through evaporation, and on the other hand, by the low efficiency of irrigation techniques in nearly 50% of irrigated areas (Ministry of Economy, 2019). Moreover, Schyns and Hoekstra (2014) show that evaporation from storage reservoirs is the second most important form of surface or groundwater consumption in Morocco, after irrigated crop production. Thus, the scarcity of surface or groundwater on a monthly basis is severe in all river basins, and pressure on groundwater resources from abstractions and nitrate pollution is considerable in most basins (Schyns and Hoekstra, 2014). This suggests the rationalization of water resources and the adoption of water-saving irrigation techniques, which is a vital option to accompany the climate variability adaptation efforts undertaken as part of the GPM in Morocco. Indeed, Yuan *et al*. (2022) showed that the use of plastic mulch drip irrigation in the mountain-oasis-desert system of northwestern China has positive climate impacts. This technique enables better water use by reducing evaporation losses and providing targeted irrigation to plants. This leads to increased crop productivity and more efficient use of water resources. Moreover, Schyns and Hoekstra (2014) showed that the most significant potential water savings can be achieved through the partial relocation of crops to basins where they consume less water and through the reduction of the water footprint of crops.

Contrary to cereal production, the FE-SEM model indicates that rainfed rosaceous crops and market gardening (both rainfed and irrigated) are less affected by climate change. These results can be explained by the efforts made by policymakers within the framework of the GPM to contain the negative influence of the cereal sector on agricultural growth. Indeed, according to report of Ministry of Economy (2019), the transformation of the agricultural sector structure originates from the reorientation of agricultural strategies, since the early 2000s, towards better adaptation of agricultural production to the agro-climatic context. This evolution was further consolidated within the framework of the GPM, which reinforced support for crops more resilient to climate hazards, such as market gardening and rosaceous crops. For example, land-use projections for the Gharb indicate a shift from 127,000 hectares of cereals to crops such as olives, citrus fruits, fruits, sugar beets, and fodder, which require more water (ABH-Sebou, 2015). Thus, water conservation policies, to combat water shortages and groundwater overexploitation, have led to a significant increase in the drip irrigation conversion rate, from 10,000 hectares per year to 50,000 hectares per year (El Gueddari and Arrifi, 2009). Indeed, this trend is reinforced by the fact that drip irrigation is often integrated into intensification strategies, leading to an increase in plantation density and a conversion to crops requiring more water. Studies conducted in Tadla (Kuper *et al*., 2012), Souss (BRLi et Agroconcept, 2013), Haouz (Molle and Tanouti, 2017), and Saïss (Kuper *et al*., 2017) have confirmed this link between drip irrigation, intensification, and crop diversification, promoting the expansion of market gardening and fruit trees.

5.2.3. *Economic Variables Analysis's and Their Impact on Moroccan Agriculture*

Regarding economic variables, the FE-SEM model analysis reveals a strong dependence of regional agricultural production in Morocco on agricultural labor, with a positive effect observed for irrigated crops and a negative effect observed for rainfed crops. These results align with the findings of other studies, which highlight the strong dependence of farms on labor. Sraïri *et al*. (2018) distinguished two types of situations: small rainfed farms often favor livestock raising, which requires little land and capital but with limited gross margins, which could hinder the sector's attractiveness for younger generations. Large irrigated farms, on the other hand, can diversify their activities towards cash crops (market gardening, fruit trees), which requires increased reliance on external labor, positively impacting production and profitability. However, this dependence on labor faces an underlying trend: the constant decline in agricultural employment since 1991, from 42.98% in 1991 to 32.36% in 2019, with an acceleration of the decline in recent years (Ministry of Economy, 2019). This situation can be partially explained by the demographic evolution of rural areas. According to Harbouze *et al*. (2019), the agricultural sector represented 72.9% of jobs in rural areas in 2016. The working-age population is expected to remain stable and then decline in rural areas until 2030, while the number of people over 65 will increase, which could weigh on the labor force available for agriculture. Moreover, employment in the Moroccan agricultural sector is dominated by self-employed workers or family businesses, with over 85% of them employing no or few employees. Additionally, unpaid employment, consisting of family helpers, accounts for over 50% of agricultural labor, highlighting the informal nature of work in the agricultural sector and the blurred distinction between the family environment and employment. Finally, the harvesting of certain types of crops requires skills that workers do not typically possess, highlighting the need for appropriate training. Furthermore, the use of inappropriate or poor-quality tools can affect production, highlighting the low labor productivity in certain crops and the need to improve tools and worker skills.

Moreover, our FE-SEM model confirms the significant contribution of the capital represented by livestock (or draught animals) and the useful agricultural area of rainfed and irrigated crops to Moroccan agricultural production. The model highlights the importance of livestock for the production of irrigated cereals, rainfed rosaceous crops, and market gardening in Morocco, but suggests a negative but non-significant impact on irrigated rosaceous crops. These results align with other studies conducted in Morocco, such as those by Elhimdy and Chiche (1988) and Bansal *et al*. (1992), which both evaluated the performance of local animal breeds in single and double hitching. These studies highlight the dependence of the performance of livestock on several factors such as age, genetics, diet, health status, and handling during work (Elhimdy and Chiche, 1988). It is important to note that the results of these studies, as well as our FE-SEM model, suggest that the use of livestock can present challenges. For example, the adaptation of smaller and slower animals to faster and larger animals can lead to stress and reduced efficiency (Bansal *et al*., 1992). This could explain the negative (non-significant) impact observed in our model for irrigated rosaceous crops. Further research could explore the economic and environmental implications of using livestock based on their types and agricultural techniques used, taking into account these key factors that influence their performance.

Regarding the useful agricultural area in Morocco, the FE-SEM model shows a positive impact on the production of cereals and rainfed rosaceous crops but not on market gardening and irrigated rosaceous crops. This result, although seemingly positive, is actually complex and can be explained by several factors. The increase in UAA in Morocco has mainly occurred on marginal lands previously used for livestock or forest (Oulhaj *et al*., 2013), which has contributed to land degradation and a decrease in yields on these lands brought into cultivation (El Jazouli *et al*., 2019; Ghanam, 2003; Harbouze *et al*., 2019; Simonneaux *et al*., 2015). The low productivity of irrigated crops, despite the increase in UAA, is due to poor water management, deficient production techniques, and farm fragmentation (Kusi *et al*., 2023; Oulhaj *et al*., 2013). The ma-

jority of farms located on marginal lands practice subsistence agriculture and are highly vulnerable to drought (Harbouze *et al*., 2019). Despite an increase in UAA, Moroccan agriculture faces significant challenges related to land degradation, low yields, and farm fragmentation, highlighting the need for mitigation strategies focused on land and soil conservation, improving production techniques, and consolidating farms.

As for irrigated crops (market gardening and rosaceous), the productivity per hectare of irrigation is low, and the cubic meter (m^3) of water is poorly valued (40% of the area of large irrigation perimeters is cultivated in cereals). The comparison of the productivity level per hectare remains one of the lowest compared to other countries (Oulhaj *et al*., 2013). In addition to this are deficient production techniques, the non-generalized use of selected seeds, and fertilization and phytosanitary treatments that are not always used optimally. Furthermore, this low productivity is due to the predominance of small farms (nearly 70% of UAA has an area of less than 2.1 hectares), which often coexist with large, modern, more productive, and professionally organized farms. This significant fragmentation is the result of the multiplicity of legal regimes governing agricultural land ownership (customary law, Islamic law, and positive law) and inheritance (Oulhaj *et al*., 2013). For its part, Ghanam (2003) highlights that in Morocco, the desertification process affects vast areas (over 90% of the territory) and is all the more pronounced as the climate is arid and the soils are vulnerable to erosion. Simonneaux *et al*. (2015) showed that even though precipitation is expected to decrease by 10% by the end of the 21st century, the change in temporal distribution would induce an increase in erosion of about 5 to 10%, assuming similar precipitation intensities. El Jazouli *et al*. (2019) showed that the annual soil loss varied from 0 to 400 per pixel, with an average of 58, 66, and 142 t/ha/an in 2003, 2013, and 2017, respectively. It is therefore very important for watershed managers to implement mitigation strategies focused on land and soil conservation, including their maintenance. Recent research by El Bakali *et al*. (2023) highlights the crucial role of financial incentives in promoting sustainable agricultural practices. Their systematic review demonstrated that financial incentives, such as subsidies for inputs and conservation practices, have a significant positive impact on the adoption of conservation agriculture (CA). These incentives contribute to improving crop yields and nutritional quality. Furthermore, Toumi *et al*. (2021) studied the influence of good governance on food security in Morocco. Their study revealed that effective governance in the agricultural sector is crucial to ensure access to legumes. However, challenges related to coordination and communication between stakeholders hinder the full realization of its potential.

5.2.4. *Study Limitations and Perspectives*

The analysis of the impact of climate variability on Moroccan agriculture is limited by a lack of accurate and detailed data. The availability of complete long-term historical data, particularly at the regional level, is restricted. This lack of data has forced us to focus on the production function approach developed by Deschênes and Greenstone (2007), which studies the short-term impact of climate variability rather than the long-term impact of climate change on Moroccan agriculture.

Moreover, data on key factors such as agricultural land prices, growing degree days, agricultural technical progress, fertilizer use, and soil fertility are uneven, limiting our ability to isolate their impacts from exogenous shocks, thus complicating a thorough analysis. Furthermore, future projections of temperature and precipitation rely on climate change scenarios developed at the national level, lacking regional specificity. This lack of detailed local data makes it difficult to simulate the impacts of climate change and plan for effective long-term adaptation in the Moroccan agricultural sector. Future research using data over a longer period to analyze the long-term impacts of climate change (Lobell *et al*., 2011; Nelson *et al*., 2010; Tao *et al*., 2006; Zhao *et al*., 2017) would be valuable to better understand and anticipate the challenges and opportunities that the Moroccan agricultural sector will face in the decades to come.

On the other hand, the use of a spatial econometric model based on a Cobb-Douglas function, which is limited by its rigidity of substitution and its specific form, raises questions about its ability

to capture the complexity of the agro-climatic system. The limitations of the Cobb-Douglas function, notably its restriction in terms of flexibility, lead us to consider exploring more complex functions, such as the CES or Translog, in future research. While it offers a useful analytical framework for quantifying the effects of key variables, the current model does not capture the complexity of the agro-climatic system in its entirety. For instance, our model does not take into account the direct influence of temperature on water availability in the soil, evapotranspiration, plant growth, and sensitivity to diseases, interactions often exacerbated by periods of water deficit. Future research could explore bio-economic models, integrating explicit biological dynamics and a decision-making process stemming from economic theory, as well as a link between these two elements. These models would allow for a better understanding of the complex interactions between water use, agricultural production, and socioeconomic factors (Lokonon *et al*., 2019; Mouysset, 2023).

Finally, given that climate variability adaptation in agriculture is a complex process, it requires a combination of actions at the farm, market, institutional, and technological levels. Regional-level data masks significant variations at the farm level, which limits our analysis of the implementation of effective adaptation strategies, including crop diversification, water conservation, and access to credit and other resources. Jeder *et al*. (2021) showed, using a bottom-up approach, that socio-economic factors such as education level, land ownership, and membership in agricultural development groups influence farmers' perception and adaptation strategies. Future research could explore the bottom-up approach in the study of effective and sustainable adaptation strategies to climate variability, considering the needs and perspectives of farmers for the internal and external environment of their activities.

6. Conclusion

This paper analyzes the impact of climate variability on agricultural production in Morocco between 1999 and 2019 using a production function approach based on spatial panel data. This study is the first of its kind to employ recent and disaggregated data, both at the regional level (12 Moroccan regions) and by major agricultural products (cereals, market-gardening crops, and rosaceous fruits), as well as by production mode (rain-fed and irrigated). To better understand the impacts of climate variability on Moroccan agriculture and its regional variations, preliminary spatial autocorrelation analyses were conducted. This initial step was followed by an in-depth spatial panel data analysis, enabling the identification of specific climate and agricultural effects on irrigated and rain-fed crops for all three agricultural products. This approach allows for capturing the spatial heterogeneity of climate variability impacts on Moroccan agriculture across regions and crop types.

Spatial clustering analysis, encompassing mapping and both global and local Moran's I tests, reveals a concentration of agricultural production and rainfall in the northern regions of Morocco. The Moran's I tests consistently yielded positive and significant results for all agricultural products, indicating a strong positive spatial autocorrelation. This signifies that regions with high agricultural production are spatially clustered together, with neighboring areas also exhibiting high production levels.

Spatial panel data specifications suggest that a model considering both spatial error autocorrelation and individual heterogeneity in a fixed effects framework (FE-SEM) is most appropriate for this case study. Results from our FE-SEM model show at the regional level that Moroccan agriculture is heavily dependent on the direct effects of temperature and precipitation for all goods considered. Notably, these results confirm that the impact of climate variability on agricultural production differs across crops. Cereal production (rain-fed and irrigated) is highly sensitive to climate variability compared to other rosaceous and market gardening (rain-fed and irrigated). Additionally, these findings confirm that the impact of climate variability on irrigated crops differs from that on rain-fed crops. The latter are less vulnerable to climate change, suggesting limited effectiveness of irrigation techniques. This challenges the efforts made in the context of public agricultural policies (GMP) in Morocco towards climate variability adaptation in irrigation.

Furthermore, spatial analysis offers novel insights. It reveals the significance of explicitly accounting for spatial effects between Moroccan regions. The analysis demonstrates the presence of significant spatial heterogeneity, indicating the existence of unobservable factors that are negatively spatially correlated, even after controlling for variables such as weather and agricultural inputs. These unobservable factors, such as technology, agricultural policies, use of similar production practices, existence of dams, organized farmers, and economies of scale, may contribute to spatial correlation.

In other words, spatial error autocorrelation implies the possibility of measurement errors that tend to spread across aggregation unit boundaries, omitted variables, or unobserved shocks following a spatial pattern. Additionally, the existence of spatial autocorrelation might be explained by varying data scales and the aggregation process.

The findings of this paper raise concerns about the sustainability of agricultural production growth in Morocco and question the interdependencies between food availability and the policies adopted within the GMP framework. To mitigate the impact of climate on agriculture, appropriate measures should be implemented, such as implementing water conservation policies by encouraging investments from the public and private sectors targeting support for smallholder farmers, specializing in high-yielding, water-efficient, and drought-resistant crop varieties. Improving workforce skills and capital efficiency through the promotion of agricultural research and development, and implementing appropriate fiscal and environmental policies, as well as developing regional policies to enhance the benefits of dams and groundwater.

References

Abdelmajid S., Mukhtar A., Baig M.B., Reed M.R., 2021. Climate change, agricultural policy and food security in Morocco. In: *Emerging Challenges to Food Production and Security in Asia, Middle East, and Africa: Climate Risks and Resource Scarcity*, pp. 171-196.

ABH-Sebou, 2015. *Etude d'actualisation du plan directeur d'aménagement intégré des ressources en eau du bassin hydraulique de Sebou*, Agence de Bassin Hydraulique du Sebou (ABHS), https: //www.abhsebou.ma/wp-content/uploads/2018/01/Pdaire-sebou-22-10-2015-.doc.

Akesbi N., 2012. Une nouvelle stratégie pour l'agriculture marocaine: Plan Maroc Vert. *New Medit*, 11(2): 12.

Amouzay H., Chakir R., Dabo-Niang S., El Ghini A., 2023. Structural changes in temperature and precipitation in MENA countries. *Earth Systems and Environment*: 1-22.

Anselin L., 1988. Lagrange multiplier test diagnostics for spatial dependence and spatial heterogeneity. *Geographical analysis*, 20(1): 1-17.

Anselin L., 1995. Local indicators of spatial association—LISA. *Geographical analysis*, 27(2): 93-115.

Anselin L., Bera A.K., Florax R., Yoon M.J., 1996. Simple diagnostic tests for spatial dependence. *Regional science and urban economics*, 26(1): 77-104.

Anselin L., Le Gallo J., Jayet H., 2008. Spatial panel econometrics. In: *The econometrics of panel data*, pp. 625-660. Berlin: Springer.

Antle J.M., 1983. Infrastructure and aggregate agricultural productivity: International evidence. *Economic Development and Cultural Change*, 31(3): 609-619.

Auffhammer M., Hsiang S.M., Schlenker W., Sobel A., 2013. Using weather data and climate model output in economic analyses of climate change. *Review of Environmental Economics and Policy*, 7(2): 181-198.

Balaghi R., El Hairech T., Alaouri M., Motaouakil S., Benabdelouahab T., Mounir F., Lahlou M., Arrach R., Abderrakif M., Colmant R., Evangelisti M., Poortinga A., Kuik O., Delobel F., 2016. *Climate change impact assessment using MOSAICC in Morocco*. INRA, Morocco.

Balaghi R., Tychon B., Eerens H., Jlibene M., 2008. Empirical regression models using NDVI, rainfall and temperature data for the early prediction of wheat grain yields in Morocco. *International Journal of Applied Earth Observation and Geoinformation*, 10(4): 438-452.

Bansal R., El-Gharras O., Hamilton J., 1992. Performance of draft animals at work in Morocco: draftability and power output. *Agricultural Mechanization in Asia, Africa and Latin America*, 23(1): 65-70.

Barrios S., Ouattara B., Strobl E., 2008. The impact of climatic change on agricultural production: Is it different for Africa? *Food policy*, 33(4): 287-298.

Belcaid K., El Ghini A., 2019. Measuring the weather variability effects on the agricultural sector in Mo-

rocco. In: *International Conference on Management Science and Engineering Management*, pp. 70-84.

Blanc E., Reilly J., 2017. Approaches to assessing climate change impacts on agriculture: an overview of the debate. *Review of Environmental Economics and Policy*, 11(2): 247-257.

BRLi et Agroconcept, 2013. *Gestion de la demande en eau dans le bassin méditerranéen–exemple du Maroc–cas d'étude du Souss Massa*. AFD et Plan Bleu.

Camarillo-Naranjo J.M., Álvarez-Francoso J.I., Limones-Rodríguez N., Pita-López M.F., Aguilar-Alba M., 2019. The global climate monitor system: from climate data-handling to knowledge dissemination. *International Journal of Digital Earth*, 12(4): 394-414.

Chatzopoulos T., Lippert C., 2016. Endogenous farm-type selection, endogenous irrigation, and spatial effects in Ricardian models of climate change. *European Review of Agricultural Economics*, 43(2): 217-235.

Chen S., Chen X., Xu J., 2016. Impacts of climate change on agriculture: Evidence from China. *Journal of Environmental Economics and Management*, 76: 105-124.

Coulibaly T., Islam M., Managi S., 2020. The impacts of climate change and natural disasters on agriculture in African countries. *Economics of Disasters and Climate Change*, 4: 347-364.

Dell M., Jones B.F., Olken B.A., 2014. What do we learn from the weather? The new climate-economy literature. *Journal of Economic Literature*, 52(3): 740-798.

Deschênes O., Greenstone M., 2007. The economic impacts of climate change: evidence from agricultural output and random fluctuations in weather. *American Economic Review*, 97(1): 354-385.

Desmet K., Rossi-Hansberg E., 2024. *Climate change economics over time and space*. University of Chicago, Becker Friedman Institute for Economics Working Paper, 2024-25.

Driouech F., Déqué M., Sánchez-Gómez E., 2010. Weather regimes - Moroccan precipitation link in a regional climate change simulation. *Global and Planetary Change*, 72(1-2): 1-10.

Driouech F., Stafi H., Khouakhi A., Moutia S., Badi W., ElRhaz K., Chehbouni A., 2021. Recent observed country-wide climate trends in Morocco. *International Journal of Climatology*, 41: E855-E874.

El Bakali I., Ait El Mekki A., Maatala N., Harbouze R., 2023. A systematic review on the impact of incentives on the adoption of conservation agriculture: new guidelines for policymakers and researchers. *International Journal of Agricultural Sustainability*, 21(1): 2290415.

El Gueddari A., Arrifi M., 2009. L'agriculture irriguée au Maroc face à la rareté des ressources en eau. In: *L'Etat des ressources en eau au Maghreb en 2009*, UNESCO, Rabat.

El Jazouli A., Barakat A., Khellouk R., Rais J., El Baghdadi M., 2019. Remote sensing and GIS techniques for prediction of land use land cover change effects on soil erosion in the high basin of the Oum Er Rbia river (Morocco). *Remote Sensing Applications: Society and Environment*, 13: 361-374.

Elhimdy B., Chiche J., 1988. Rentabilité de la traction animale dans les petites exploitations marocaines. In: Starkey P., Faye A. (eds), *La Traction Animale pour le Développement Agricole FAO*, http://www.fao.org/wairdocs/ilri/x5455b/x5455b0o.htm.

Elhorst J.P., 2003. Specification and estimation of spatial panel data models. *International Regional Science Review*, 26(3): 244-268.

Elhorst P., Fisher M., Getis A., 2010. Spatial panel data models. In: *Handbook of applied spatial analysis: Software tools, methods and applications*. Berlin: Springer.

Ezzine H., Bouziane A., Ouazar D., Hasnaoui M.D., 2017. Downscaling of open coarse precipitation data through spatial and statistical analysis, integrating NDVI, NDWI, elevation, and distance from sea. *Advances in Meteorology*, 2017, https://doi.org/10.1155/2017/8124962.

Fader M., Shi S., von Bloh W., Bondeau A., Cramer W., 2016. Mediterranean irrigation under climate change: more efficient irrigation needed to compensate for increases in irrigation water requirements. *Hydrology and Earth System Sciences*, 20(2): 953-973.

Fan Y., Van den Dool H., 2008. A global monthly land surface air temperature analysis for 1948–present. *Journal of Geophysical Research: Atmospheres*, 113(D1).

Filahi S., Tramblay Y., Mouhir L., Diaconescu E.P., 2017. Projected changes in temperature and precipitation indices in Morocco from high-resolution regional climate models. *International Journal of Climatology*, 37(14): 4846-4863.

Frisvold G., Ingram K., 1995. Sources of agricultural productivity growth and stagnation in Sub-Saharan Africa. *Agricultural Economics*, 13(1): 51-61.

Ghanam M., 2003. La désertification au Maroc - Quelle stratégie de lutte? In: *2nd FIG Regional Conference Marrakech*. Copenhagen: FIG, pp. 2-5.

Giannakopoulos C., Le Sager P., Bindi M., Moriondo M., Kostopoulou E., Goodess C., 2009. Climatic changes and associated impacts in the mediterranean resulting from a 2 C global warming. *Global and Planetary Change*, 68(3): 209-224.

Gommes R., El Hairech T., Rosillon D., Balaghi R., Kanamaru H., 2009. *Morocco study on the impact of climate change on the agricultural sector: Impact of climate change on agricultural yields in Morocco*. Rome: FAO. DOI: 10.13140/RG.2.2.30378.80322.

Harbouze R., Pellissier J., Rolland J., Khechimi W., 2019. *Synthesis report on agriculture in Morocco*. ENPARD Mediterranean Initiative Support Project, p. 104.

Harris I., Jones P.D., Osborn T.J., Lister D.H., 2014. Updated high-resolution grids of monthly climatic observations – the CRU TS3.10 Dataset. *International journal of climatology*, 34(3): 623-642.

Harris I., Osborn T.J., Jones P., Lister D., 2020. Version 4 of the CRU TS monthly high-resolution gridded multivariate climate dataset. *Scientific data*, 7(1): 1-18.

Hayami Y., Ruttan V.W., 1971. *Agricultural development: an international perspective*. Baltimore, MD / London: The Johns Hopkins Press.

IPCC, 2022. *Climate change 2022: Impacts, adaptation and vulnerability. Contribution of working group II to the sixth assessment report of the intergovernmental panel on climate change*. Cambridge: Cambridge University Press.

IPCC, 2023. *Climate change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. *Technical report*. Geneva: IPCC, pp. 35-115.

Jeder H., Abdelhamid A., Ahmed S., 2021. Smallholder farmers' perceptions and adaptation strategies to mitigate the effect of climate change in the oases of South-Eastern Tunisia. *New Medit*, 20(5): 3-15

Jones J.W., Antle J.M., Basso B., Boote K.J., Conant R.T., Foster I., Godfray H.C.J., Herrero M., Howitt R.E., Janssen S., Keating B.A., Munoz-Carpena R., Porter C.H., Rosenzweig C., Wheeler T.R., 2017. Toward a new generation of agricultural system data, models, and knowledge products: State of agricultural systems science. *Agricultural systems*, 155: 269-288.

Karahasan B.C., Pinar M., 2023. Climate change and spatial agricultural development in Turkey. *Review of Development Economics*, 27(3): 1699-1720.

Kuper M., Ameur F., Hammani A., 2017. Unraveling the enduring paradox of increased pressure on groundwater through efficient drip irrigation. In: Venot J.P., Kuper M., Zwarteveen M. (eds), *Drip irrigation for agriculture*. Abingdon: Routledge, pp. 85-104.

Kuper M., Hammani A., Chohin A., Garin P., Saaf M., 2012. When groundwater takes over: linking 40 years of agricultural and groundwater dynamics in a large-scale irrigation scheme in Morocco. *Irrigation and drainage*, 61: 45-53.

Kusi K.K., Khattabi A., Mhammdi N., 2023. Analyzing the impact of land use change on ecosystem service value in the main watersheds of Morocco. *Environment, Development and Sustainability*, 25(3): 2688-2715.

Leal Filho W., Mannke F., 2011. Adapting agriculture to climate change by developing promising strategies using analogue locations in Eastern and Southern Africa: introducing the Calesa project. *Experiences of Climate Change Adaptation in Africa*. Berlin: Springer, pp. 247-253.

Le Gallo J., 2002. Econométrie spatiale: l'autocorrélation spatiale dans les modèles de régression linéaire. *Économie & prévision*, 155(4): 139-157.

Le Gallo J., Ndiaye Y., 2021. Environmental expenditure interactions among OECD countries, 1995-2017. *Economic Modelling*, 94: 244-255.

Lobell D.B., Schlenker W., Costa-Roberts J., 2011. Climate trends and global crop production since 1980. *Science*, 333(6042): 616-620.

Lokonon B.O., Egbendewe A.Y., Coulibaly N., Atewamba C., 2019. The potential impact of climate change on agriculture in West Africa: A bio-economic modeling approach. *Climate Change Economics*, 10(04): 1950015.

Mendelsohn R., Nordhaus W.D., Shaw D., 1994. The impact of global warming on agriculture: a Ricardian analysis. *The American Economic Review*, 84(4): 753-771.

Mendelsohn R.O., Dinar A., 2009. *Climate change and agriculture: an economic analysis of global impacts, adaptation and distributional effects*. Cheltenham: Edward Elgar Publishing.

Ministry of Agriculture, Morocco, 2019. *Agriculture in figures 2018* (in French). Technical report. https://www.agriculture.gov.ma/sites/default/files/19-00145-book_agricultures_en_chiffres_def.pdf.

Ministry of Economy, Morocco, 2019. *The Moroccan agricultural sector: Structural trends, challenges and development prospects* (in French). Technical report. https://www.finances.gov.ma/publication/depf/2019/Le%2520secteur%2520agricole%2520marocain.pdf

Molle F., Tanouti O., 2017. Squaring the circle: Agricultural intensification vs. water conservation in Morocco. *Agricultural water management*, 192: 170-179.

Moran P.A., 1948. The interpretation of statistical maps. *Journal of the Royal Statistical Society. Series B (Methodological)*, 10(2): 243-251.

Moutawakkil H., 2009. *Le développement de l'irrigation au Maroc depuis l'indépendance*. PhD thesis. Institut du droit de la paix et du développement, Nice.

Mouysset L., 2023. Modélisation bioéconomique: le cas de l'agriculture française. *L'Economie politique*, 100(4): 49-61.

Nelson G.C., Rosegrant M.W., Palazzo A., Gray I., Ingersoll C., Robertson R., Tokgoz S., Zhu T., Sulser T.B., Ringler C., Msangi S., You L., 2010. *Food security, farming, and climate change to 2050: scenarios, results, policy options*, Research Reports. Washington, D.C.: International Food Policy Research Institute.

Nguyen D., 1979. On agricultural productivity differences among countries. *American Journal of Agricultural Economics*, 61(3): 565-570.

Ortiz-Bobea A., 2016. *The economic impacts of climate change on agriculture: accounting for time-invariant unobservables in the hedonic approach. Technical report*. Working Papers, 250035. Cornell University, Department of Applied Economics and Management.

Ortiz-Bobea A., 2021. Climate, agriculture and food. *ArXiv preprint*, arXiv:2105.12044.

Oulhaj L., De Arce R., El Abbassi I., El Bouhadi A., El Khider A., Medina Moral E., Nihou A., Khellaf A., Lorca A., Mahia R., Mella-Marquez J.M., Tounsi S., 2013. Assessment of Morocco's agricultural strategy (Plan Maroc Vert) using a dynamic general equilibrium model (in French). *FEMISE Research Programme*, 122: 1-110.

Ouraich I., Tyner W.E., 2018. Moroccan agriculture, climate change, and the Moroccan green plan: A CGE analysis. *African Journal of Agricultural and Resource Economics*, 13(311-2019-681): 307-330.

Palatnik R.R., Lourenço Dias Nunes P.A., 2015. Economic valuation of climate change-induced biodiversity impacts on agriculture: results from a macro-economic application to the mediterranean basin. *Journal of Environmental Economics and Policy*, 4(1): 45-63.

Polsky C., 2004. Putting space and time in Ricardian climate change impact studies: Agriculture in the US great plains, 1969-1992. *Annals of the Association of American Geographers*, 94(3): 549-564.

Ponti L., Gutierrez A.P., Ruti P.M., Dell'Aquila A., 2014. Fine-scale ecological and economic assessment of climate change on olive in the mediterranean basin reveals winners and losers. *Proceedings of the National Academy of Sciences*, 111(15): 5598-5603.

Rosenzweig C., Elliott J., Deryng D., Ruane A.C., Müller C., Arneth A., Boote K.J., Folberth C., Glotter M., Khabarov N., Neumann K., Piontek F., Pugh T.A.M., Schmid E., Stehfest E., Yang H., Jones J.W., 2014. Assessing agricultural risks of Climate Change in the 21st Century in a global gridded crop model intercomparison. *Proceedings of the National Academy of Sciences*, 111(9): 3268-3273.

Schilling J., Freier K.P., Hertig E., Scheffran J., 2012. Climate change, vulnerability and adaptation in North Africa with focus on Morocco. *Agriculture, Ecosystems & Environment*, 156: 12-26.

Schlenker W., Hanemann W.M., Fisher A.C., 2006. The impact of global warming on US agriculture: An econometric analysis of optimal growing conditions. *Review of Economics and statistics*, 88(1): 113-125.

Schmidtner E., Dabbert S., Lippert C., 2015. Do different measurements of soil quality influence the results of a Ricardian analysis? A case study on the effects of Climate Change on German Agriculture. *German Journal of Agricultural Economics*, 64(670-2018-1980): 89-106.

Schyns J.F., Hoekstra A.Y., 2014. The added value of water footprint assessment for national water policy: a case study for Morocco. *PLoS One*, 9(6): e99705.

Simonneaux V., Cheggour A., Deschamps C., Mouillot F., Cerdan O., Le Bissonnais Y., 2015. Land use and climate change effects on soil erosion in a semi-arid mountainous watershed (High Atlas, Morocco). *Journal of Arid Environments*, 122: 64-75.

Sraïri M.T., 2021. Repenser le modèle de développement agricole du Maroc pour l'ère post Covid-19. *Cahiers Agricultures*, 30: 17.

Sraïri M.T., Bahri S., Ghabiyel Y., 2018. Work management as a means to adapt to constraints in farming systems: A case study from two regions in Morocco. *Cahiers agricultures*, 27(1): 15007.

Tao F., Yokozawa M., Xu Y., Hayashi Y., Zhang Z., 2006. Climate changes and trends in phenology and yields of field crops in China, 1981-2000. *Agricultural and forest meteorology*, 138(1-4): 82-92.

Toumi L., El Amrani M., El Mekki A.A., Harbouze R., Fadlaoui A., 2021. Perceptions of the links between governance and food security: Case study of the pulses sector in Morocco. *New Medit*, 20(3): 69-84.

Vaitkeviciute J., Chakir R., Van Passel S., 2019. Climate variable choice in Ricardian studies of European agriculture. *Revue économique*, 70(3): 375-401.

Wang J., Mendelsohn R., Dinar A., Huang J., Rozelle S., Zhang L., 2009. The impact of climate change on China's agriculture. *Agricultural Economics*, 40(3): 323-337.

Ward P.S., Florax R.J., Flores-Lagunes A., 2014. Climate change and agricultural productivity in Sub-Saharan Africa: a spatial sample selection model. *European Review of Agricultural Economics*, 41(2): 199-226.

Woillez M.-N., 2019. *Revue de littérature sur le changement climatique au Maroc: observations, projections et impacts*, Papiers de recherche. Paris: AFD, pp. 1-33.

Yuan X., Hamdi R., Luo G., Bai J., Ochege F.U., Kurban A., De Maeyer P., Chen X., Wang J., Termonia P., 2022. The positive climate impacts of drip irrigation underneath plastic mulch on a typical mountain-oasis-desert system in Northwest China. *Agricultural Water Management*, 273: 107919.

Zhao C., Liu B., Piao S., Wang X., Lobell D.B., Huang Y., Huang M., Yao Y., Bassu S., Ciais P., Durand J.-L., Elliott J., Ewert F., Janssens I.A., Li T., Lin E., Liu Q., Martre P., Müller C., Peng S., Peñuelas J., Ruane A.C., Wallach D., Wang T., Wu D., Liu Z., Zhu Y., Zhu Z., Asseng S., 2017. Temperature increase reduces global yields of major crops in four independent estimates. *Proceedings of the National Academy of Sciences*, 114(35): 9326-9331.

Ziese M., Becker A., Finger P., Meyer-Christoffer A., Rudolf B., Schneider U., 2011. *GPCC first guess product at 1.0: Near real-time first guess monthly land-surface precipitation from rain-gauges based on SYNOP data*. Offenbach/Main: Global Precipitation Climatology Centre.

Zouabi O., Peridy N., 2015. Direct and indirect effects of climate on agriculture: an application of a spatial panel data analysis to Tunisia. *Climatic change*, 133(2): 301-320.

Appendix A - Spatial-weight matrix

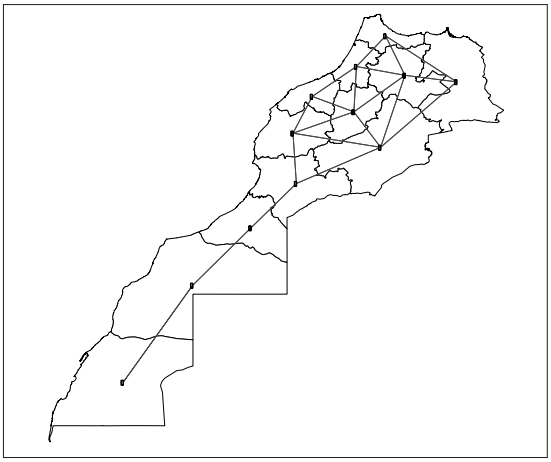


Figure 6 - Gabriel contiguity weight matrix (W_cont)

Figure 7 - Nearest neighbors weight matrix (W_nn5)

Figure 8 - Inverse distance matrix (W_dinverse)

Appendix B - SAR Model's specification and results

Spatial Autoregressive Model (SAR): This model is developed by Anselin *et al*. (2008) and improved by Elhorst *et al*. (2010) to consider directly the spatial dependence of the explained variable on the explanatory variables and the error term for the case of panel data.

$$Y_{it} = \lambda \sum_{j=1}^{N} \omega_{ij} Y_{jt} + X_{it}\beta + \mu_i + \nu_t + \varepsilon_{it}, \quad (8)$$

where Y_{it} is the dependent variable for cross-sectional i at time t (i = 1, ..., N ; t = 1, ..., T). $\sum_{k=1}^{N} \omega_{ik} Y_{kt}$ is the interaction effect of the dependent variable Y_{it} with the dependent variables Y_{it} in neighboring units, where ω_{ik} is the i, jth element of a prespecified non negative $N \times N$ spatial weights matrix W describing the arrangement of the spatial units in the sample, the response parameter of these endogenous interaction effects, and λ: the spatial autoregressive coefficient. X_{it}: $1 \times K$ is the vector of exogenous variables. β is matching $1 \times K$ vector of fixed but unknown parameters. μ_g is individual fixed effect, λ_t is time fixed effect and ε_{it} is vector of the idiosyncratic error term.

Table 5 - Estimation results of spatial autoregressive model (SAR).

	Dependent variables					
	LogRainf_ Cer	*LogIrrg_Cer*	*LogRainf_ Ros*	*LogIrrg_Ros*	*LogRainf_ MarkG*	*LogIrrg_ MarkG*
	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
LogLabor	−1.259***	1.330***	−0.526*	2.080***	−1.628***	1.183***
	(0.317)	(0.135)	(0.393)	(0.285)	(0.405)	(0.236)
LogLand	0.921***	0.180***	0.131*	0.040	−0.033	0.0014
	(0.070)	(0.069)	(0.070)	(0.084)	(0.087)	(0.053)
LogLivestock	1.055***	0.352**	0.615**	1.281***	1.738***	−0.082
	(0.263)	(0.178)	(0.251)	(0.302)	(0.332)	(0.191)
LogTmean	−0.888*	−2.469***	7.746***	−7.650***	2.897***	2.630***
	(0.468)	(0.535)	(1.0009)	(1.257)	(0.602)	(0.775)
LogRainf	0.444***	−0.434***	0.687***	−0.332**	−0.037	0.107
	(0.124)	(0.123)	(0.134)	(0.157)	(0.156)	(0.099)
Constant	19.298***	15.348***	−15.959**	52.456***	36.077***	−11.586***
	(4.313)	(5.152)	(4.757)	(5.872)	(5.614)	(3.681)
λ	−0.191***	0.028	−0.492***	−0.139***	−0.864***	−0.163***
	(0.059)	(0.028)	(0.071)	(0.106)	(0.079)	(0.070)
Observations	210	210	210	210	210	210

*Note: * significant at 10% level, ** significant at 5% level, *** significant at 1% level*

The impact of the 2008 financial crisis on the food-energy-agricultural inputs nexus and implications for economic resilience

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Abstract

We use multivariate copula models to assess the asymmetries in tail dependence between agricultural commodity prices (i.e., cereals and meats) and production input prices (i.e., fertilizers, seeds, animal feed and energy). We use monthly observations between January 2000 and May 2022 and split the time in 2009 to assess the results of the financial crisis. We find upper tail dependence between cereals and fertilizers in the pre-2009 period and upper tail dependence between seeds and fertilizers, and energy and fertilizers post-2009. Furthermore, we find strong and symmetric tail dependence between cereals and seeds in both periods. Our findings suggest that the protective nature of CAP has led to moral hazard effects depriving farmers from the incentives that enhance the sector resilience. Furthermore, agro-chemical companies do not seem to exploit the oligopoly market structure and raise prices arbitrarily. Finally, based on our results, we infer on the economic resilience of the agricultural sector.

Keywords*: Agricultural commodity prices, Input prices, Economic resilience, Price co-movement, Copula models.*

1. Introduction

The food price rally in late 2021 and the subsequent invasion of Russia in Ukraine have renewed interest in the price linkages between production inputs including energy and agricultural markets. Russia is the world leader in the export of fertilizers and a key player in the global energy markets, whereas Ukraine is a major cereals producer and exporter. The specific conflict combined with the adverse effects of climate change jeopardize the food supply of wheat and basic grains (Ibrahim, 2024). In this context, the interrelations between agricultural commodity and input prices such as fertilizers, seeds, animal feed and energy have drawn considerable attention, especially given the concerns for many countries, which dependent on food and imports of crude oil, fertilizers, etc. Nevertheless, it is worth noting that even though nominal grain prices have risen dramatically since the 1960s, in real terms they have actually fallen against oil prices and to a lesser extent against the fertilizer prices (Dorward, 2013), which may pose

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threats relating to the economic resilience of farms and agricultural communities. This paper examines the impact of the 2008 financial crisis on the price dependence relationships between the prices of agricultural commodities (cereals and meats), energy and agricultural inputs (fertilizers, seeds and animal feed) and subsequently discusses the implications on economic resilience for the Greek agricultural sector. The profound effects of the crisis combined with the intrinsic characteristics of the food-energy-agricultural inputs nexus, including the oligopolistic nature of the inputs markets are expected to have borne considerable changes on the Greek agricultural sector and its economic resilience.

The food-energy-agricultural inputs price nexus provides various prospects for empirical research. The energy-intensive nature of agriculture stems from the direct link between energy and agricultural production (Koirala *et al*., 2015). Increasing oil prices incur rises in the agricultural input costs and thus yield rises in the commodity prices. Nevertheless, the intensity of such impacts is affected by various factors, including the relative importance of oil in the cost of production and the market power in the agricultural sector (Koirala *et al*., 2015). Furthermore, energy and agricultural markets are closely connected on the demand side (Reboredo, 2012). Increased oil prices lead to significant raises in the demand for biofuels. This is particularly relevant in periods of increasing biofuel production when the demand for agricultural commodities is exacerbated (Chen *et al*., 2010). Moreover, Chen *et al*. (2010) shows that changes in the prices of corn, soybean, and wheat are affected by increased crude oil prices, especially when increased oil prices have led to increased derived demand for corn and soybean, and to more intense competition for the areas cultivated with other grains. Therefore, several studies show that oil prices are critical in determining the agricultural commodity prices (e.g., FAO, 2008; Mitchell, 2008; OECD, 2008; Piesse and Thirtle, 2009).

Furthermore, agriculture consumes energy indirectly, through the production of fertilizer. Manufacturing inorganic nitrogenous fertilizer is an energy-intensive process, typically requiring significant use of energy from fossil fuels (World Bank Group, 2007) and despite the increasing application of machinery in the agriculture of high-income countries, fertilizer still accounts for almost half of agriculture's demand for energy (Dorward, 2013). Therefore, shocks to fertilizer markets are expected to incur wide economic impacts, which have not been adequately acknowledged. With empirical research so far focusing on direct oil cost-push or demand shocks due to biofuel production, the fertilizer channel is a new element on the food-energy-agricultural inputs nexus, which has been largely overlooked. In this context, competition in the fertilizer industry becomes highly relevant. Gnutzmann and Spiewanowski (2016) point the long history of cartel behavior in the specific industry and relate this behavior to the lack of competition for nitrogen, for mineral reserves such as phosphorus and potash which are geographically concentrated and exploited by export cartels, and for nutrients which are production compliments. Furthermore, we emphasize the importance of seeds and animal feed for agricultural production. Seeds comprise a crucial and expensive factor with the corresponding market being highly concentrated on a global level (USDA, 2023). Animal feed is the largest single cost item for livestock and poultry production, accounting for 60 to 70 percent of the total cost, and what is more, animal producers cannot simply pass cost increases on to consumers, since they act as price takers in competitive markets (Lawerence *et al*., 2008). The respective index involves cereals such as corn, barley, wheat, sorghum, and oats but also includes pasture forage, hay, silage, vitamin and mineral supplements, the prices of which are not captured in the cereals index.

The Greek agricultural sector contributes more than 4.5 percent to the country's GDP (European Commission, 2021) and employs approximately 400,000 people, which is 10 percent of its total employment (European Commission, 2023). The sector comprises a total of 700,000 farms, which are mainly small family holdings, averaging a size of about 7 hectares, while more than 70 percent of these farms occupy less than 5 hectares each (European Commission, 2023). Furthermore, more

than 70 percent of the agricultural area faces natural or other constraints including extreme slopes, low temperatures, dryness of soil, unfavorable soil texture, borderline areas, island regions, which bears significant impacts in the farming process. Rural areas account for 63 percent of the total area and agricultural land amounts to 5.3 million hectares. Regarding agricultural inputs, Greece has very little indigenous oil production and the demand for oil is covered by imports (OECD, 2020). According to Eurostat (2023) oil and petroleum products (excluding biofuels) account for 56 percent of the total direct consumption of energy in the agricultural and forestry sector, and even though this share is considerably lower for the Greek agricultural sector, these factors still remain important for agricultural production. Furthermore, the Greek agricultural sector is heavily dependent on imports of fertilizers, seeds, and animal feed. In 2019, the imports of fertilizers amounted to 34000 tons (WITS, 2019), whereas those of soybean and soybean meals (i.e., the main ingredients in animal feed), raised above 300,000 metric tons (USDA, 2021). In addition, Greece is a net importer of planting seeds, averaging imports of $68 million (USDA, 2015). With fertilizers bearing a cost share of 44 percent in food commodity prices, which far exceeds the share of direct energy (Gnutzmann and Spiewanowski, 2016), their prices are of strategic importance to the producers. Moreover, the market of seeds is highly concentrated with 5 firms dominating the global market (USDA, 2023). Given this oligopolistic market structure, price formation exhibits particular interest, especially since seeds are critical for agricultural production. In this context, we seek to shed light into the interdependencies between agricultural commodity prices and input prices, in the Greek agricultural sector.

Bristow (2010) defines economic resilience as 'the capacity of a system to absorb disturbance and reorganize while undergoing change, so as to still retain essentially the same function, structure and feedbacks' and associates it with the firm's ability to adapt so they maintain an acceptable growth in output, employment and wealth over time (Martin, 2012). It has typically been studied through employment indicators (Martin and Sunley, 2015; Angelopoulos *et al*., 2023), macroeconomic and accounting measures such as gross value added (Sdrolias *et al*., 2022) and gross agricultural output value (Yang *et al*., 2022). Nevertheless, in the context of agriculture, not much attention has been placed explicitly on the cost factors, which are crucial for agricultural production and may challenge the farms and the agricultural sector in general. Even though these costs are implicitly accounted for, these measures include several other factors as well, making them unsuitable for our cause. In this regard, we aim to assess the price interrelations between agricultural inputs (i.e., fertilizers, seeds, energy, and animal feed) and agricultural commodity prices (i.e., cereals and meats), before and after the 2008 financial crisis and subsequently, infer on economic resilience of the Greek agricultural sector.

The interrelations between energy and food prices have traditionally been examined via linear and nonlinear methods. Nazlioglu (2011) employs linear and nonparametric causality methods to examine the causal relationships between world oil and agricultural commodity prices. This study finds that oil and agricultural commodity prices do not influence each other but there are nonlinear feedbacks between them and there exists persistent unidirectional nonlinear causality from oil to corn and soybeans prices. Nazlioglu and Soytas (2011) investigate the short- and long-run interrelationships between world oil prices, exchange rates, and individual agricultural commodity prices in Turkey. This study employs causality and impulse-response analysis, and its findings support neutrality of agricultural commodity markets to both direct and indirect effects of oil price changes. Zhang *et al*. (2010) examine cointegration and multivariate short-run interactions between fuels and agricultural commodities and find no direct long-run and limited direct short-run relations between fuel and agricultural commodity prices. Cheng and Cao (2019) investigate the dynamic relationship between crude oil prices and food price indices applying cointegration, linear Granger causality, threshold vector autoregressive and threshold vector error correction models and find nonlinear causal relationship between the variables, concluding that the adjustment of the food price indices towards

equilibrium is persistent and grows faster than oil prices when a threshold is reached. However, studies employing causality analysis or linear correlation-based methods pose certain limitations. In more detail, the results of causality analyses rely on arbitrarily calibrated price elasticities (Reboredo, 2012). On the other hand, correlation is considered an inadequate dependence measure since it provides no information regarding the dependence structure. Furthermore, linear correlation is not invariant under nonlinear and strictly increasing transformations, which implies that returns may be uncorrelated even though prices are correlated or vice versa (Koirala *et al*., 2015). Therefore, studies applying non-linear methods, including copula-based methods, are needed for the analysis of commodity and resource prices, the dependence structures of which typically exhibit nonlinear traits.

In this context, copula-based studies include Mensi *et al*. (2017) combining wavelets with static and time-varying copulas to analyze the dependence structure between the volatility indices of oil, wheat and corn and finding evidence of asymmetric tail dependence between the cereals and oil in different time horizons. Furthermore, Reboredo (2012) employs both static and time-varying copulas to assess the co-movements between Brent spot prices and global prices for corn, soybean and wheat. This study finds weak oil-food dependence but no extreme market dependence, which indicates that food price spikes are not caused by positive extreme oil price changes. Koirala *et al*. (2015) employs the Clayton and the Clayton–Gumbel copulas to investigate the relationship between the prices of various energy and agricultural commodity futures. They find that agricultural commodity and energy future prices are highly correlated and exhibit positive and significant dependence. This finding is attributed to the connection between energy prices and agricultural production costs, which for increasing energy prices yields decreasing planted acreage and reduced supply of agricultural commodities. Furthermore, this outcome implies that significant utilization of agricultural commodity inputs in the production of energy may lead to greater energy self-sustainability. Finally, in a broader context, Chavas *et al*. (2022) use a quantile autoregressive model to estimate univariate yield distributions for corn and wheat in seven regions of Italy and employ a nonparametric copula model to investigate the co-variability of yield risk across the crops and across the regions. This study finds that yield co-variability decreases between more distant regions, thus providing opportunities for regional diversification to reduce risk in the global food supply.

The present study contributes to the empirical literature towards at least three perspectives. The effects of the 2008 financial crisis have been studied via a wealth of methods and in various contexts (e.g., Kapelko *et al*., 2017; Zhu *et al*., 2021 and Ghazani *et al*., 2023). Nevertheless, the effects of the crisis with regards to agricultural prices and their interconnections with energy and inputs prices have been largely neglected. To this end, this is the first study applying copulas to analyze the changes in the price linkages between agricultural commodities and agricultural input prices, in the aftermath of the crisis. Furthermore, to the best of our knowledge, this is the only study including the price indices of seeds and animal feed in analyzing the food-energy-agricultural inputs price nexus. Finally, relevant analyses regarding the Greek agriculture are limited and we seek to fill this gap. Our findings are of particular interest, given that Greek producers are evidently price takers regarding energy, fertilizers, seeds and to a large extent animal feed. In this respect, the price interplay between food, energy and agricultural inputs is essential for understanding food markets. The rest of the paper is organized as follows: Section 2 presents the methods we apply and discusses the main features of the data we use, Section 3 outlines the empirical results and provides a discussion of our findings, and finally, Section 4 concludes the paper.

2. Materials and methods

2.1. *The marginal models*

Following the semi-parametric approach of Chen and Fan (2006a; 2006b) we first specify a GARCH model which we fit to the price changes, subsequently we convert the standardized residuals of the filtered data into cop-

ula data (i.e., data lying on (0,1)), and finally we estimate the copula models by applying the maximum-likelihood estimator on the copula data. We utilize ARMA(p,q)-GARCH(1,1) and GJR(p,q)-GARCH(1,1) models, and select the most appropriate models based on the usual information criteria (Akaike, Bayes, Shibata, and Hannan-Quinn).

2.2. *Copula models, selection, estimation and testing*

In order to investigate the price interdependencies between the variables, we employ copulas. The general idea underlying a copula is to separate the dependence structure from the marginal distributions. A copula depicts how the marginal distributions are linked in the joint distribution and therefore, copulas are applied to assess dependencies between multivariate marginal distributions and detect price co-movements. A marginal distribution function is associated with each of the components (prices) in a random vector and the copula captures the dependence structure between the individual components.

Vine copulas are a class of models which decompose a multivariate model into a group of bivariate copulas. This decomposition is not unique, but all possible decompositions can be organized as a graphical model (i.e., a collection of nested trees) called the regular vine, where each of the edges corresponds to a pair of random variables conditioned on some others (Nagler *et al*., 2022). A D-vine is a special case of regular vine where each tree is a path, that is, each of the vertices is connected to at most two other vertices. The specific structure is natural when there is a natural ordering of the variables. Another special case of regular vine is the C-vine, where each tree is a star, that is, there is one vertex which is directly connected to all other vertices. The specific structure applies when there is a single variable driving the others.

Each pair-copula can be modeled separately and therefore, regular vines are very flexible in describing complex dependence structures which capture asymmetries and extreme tail dependence. Furthermore, analyzing the price linkages based on bivariate copulas may lead to misleading outcomes, especially in the case of prices which are not directly connected, but for which price co-movements exist given a conditioning market. Aguiar-Conraria and Soares (2014) demonstrate that the co-movement between two prices conditioned on a third price, if modeled directly may be distorted and appear more intense or weaker. Nevertheless, a positive price association between separated markets normally leads to weaker co-movement after conditioning (Diβmann *et al*., 2013; Kellner and Rösch, 2016). Thus, higher numbered trees usually involve the independence copula and become redundant.

For the pair connections of the trees, we consider various static bivariate copula models which can capture diverse patterns of tail dependence, including independence, symmetric, and asymmetric upper or lower tail dependence. More precisely, we apply elliptical (Gaussian and Student's t) and Archimedean bivariate copulas (Clayton, Gumbel, Frank, Joe, Clayton-Gumbel, Joe-Gumbel, Joe-Clayton, and Joe-Frank). This battery of copulas provides sufficient flexibility which allows effectively capturing diverse non-zero lower- and upper-tail dependence structures. Moreover, we consider the rotated Clayton, Gumbel, Joe, Clayton-Gumbel, Joe-Gumbel, Joe-Clayton, and Joe-Frank copulas. A 180 rotated copula corresponds to the respective survival copula, while the 90 and 270 rotated copulas enable modelling negative dependence structures.

To select the most appropriate copula model for each of the pairs of price series we use the Akaike information criterion (AIC). Furthermore, we apply the maximum likelihood estimation method to obtain the parameters of each specified copula model. Finally, we perform the goodness-of-fit tests of Huang and Prokhorov (2014) for the vine copulas we obtain, to confirm the validity of the selected models.

2.3. *Measuring dependence*

We use Kendall's τ to assess the degree of overall dependence. This measure ranges between -1, which indicates perfect dis-concordance, and +1, which indicates perfect concordance. Further-

more, we use the lower- and upper-tail coefficients, taking values in [0,1], to measure tail dependence. If λ_L (λ_U) is positive, then there is lower or left (upper or right) tail dependence, otherwise there is lower (upper) tail independence.

2.4. *Data*

We empirically investigate the tail dependence relationships between agricultural commodity prices, that is cereals (wheat, corn, and barley) and meats (beef and veal, pork, lamb and goat) and input prices (energy, fertilizers, seeds, and animal feed) using monthly data covering the period between January 2000 and May 2022. We utilize agricultural commodity prices instead of consumer or processor prices, given our interest in economic resilience in the agricultural sector and thus, in the farmers' income. The data for cereals, meats, seeds, fertilizers, and animal feed are monthly price indices obtained from the databases of the Hellenic Statistical Authority with base year 2015 (2015=100). As a proxy for the energy prices, we use Europe Brent crude oil prices which are obtained from the official website of the U.S. Energy Information Administration. These are free-on-board (FOB) spot prices reported daily that are averaged on a monthly basis. Moreover, they are initially expressed in US dollars per barrel and are converted in EUR per barrel using the exchange rates obtained from the website of macrotrends. Cereals, meats, fertilizers, seeds, animal feed and oil price returns (r_t) are computed on a continuous compounding basis as $r_t = ln(P_t / P_{t-1})$, where P_t and P_{t-1} are the current and one-period lagged monthly prices. We use monthly observations instead of weekly given the nature of our variables (agricultural commodities exhibit seasonal production and therefore their prices are usually recorded in lower frequencies) and because it is less noisy.

Figure 1 - Development of log-prices for the agricultural commodities and the production inputs.

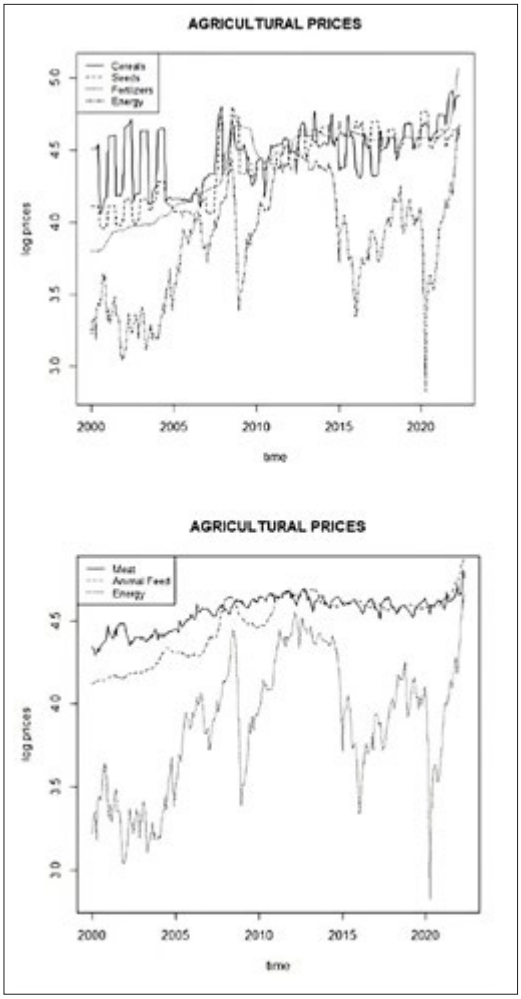

Figure 1 plots the price series under consideration whereas the corresponding descriptive statistics are presented in Table 1.

Table 1 - Descriptive statistics of price returns (raw price shocks).

	cereals	*meats*	*fertilizers*	*seeds*	*animal feed*	*energy*
mean	0.0014	0.0015	0.0048	0.0020	0.0028	0.0054
std. dev.	0.1099	0.0274	0.0184	0.0732	0.0119	0.1056
min	-0.5511	-0.0678	-0.0738	-0.4124	-0.0430	-0.5674
max	0.4348	0.1062	0.1850	0.4641	0.0677	0.4636
observations	268	268	268	268	268	268

Note: Monthly data between 01/2000 and 05/2022.

Table 2 - ADF and Phillips-Perron test results.

	cereals	*meats*	*fertilizers*	*seeds*	*animal feed*	*energy*
Test statistic	-10.9670	-9.9601	-3.1371	-11.3720	-3.9080	-6.5078
Z(alpha)	-235.0800	-332.3400	-189.6700	-244.2700	-105.5900	-178.4200

Note: Null hypothesis: the series has a unit root. Test critical values: 1% level –2.58, 5% level –1.95, and 10% level –1.62.

These figures highlight that it is not uncommon for input price indices to surpass agricultural commodity price indices. Furthermore, energy clearly exhibits larger price variation compared to the indices. This is due to the volatile nature of crude oil prices and to averaging when computing price indices, which tends to reduce large variations.

We examine the stationarity properties of the log-returns applying the augmented Dickey-Fuller (ADF) and the Phillips-Perron unit root test. The respective results are presented in Table 2 and confirm that all the series are stationary on the first differences.

3. Results and discussion

3.1. *Results for the marginal models*

We initially obtain the filtered rates of the price changes. To this end, we fit ARMA(p,q)-GARCH(1,1) and GJR(p,q)-GARCH(1,1) models to each of the price series and select the most appropriate among the different models based on four information criteria (Akaike, Bayes, Shibata, and Hannan-Quinn). The selected models are ARMA(1,0)-GARCH(1,1) for the prices of cereals, meats, fertilizers and seeds, ARMA(2,0)-GARCH(1,1) for the prices of animal feed and ARMA(2,3)-GARCH(1,1) for the prices of energy. We then calculate the empirical distribution functions and obtain the copula data, using the standardized residuals. We do not present the results of the respective models in full detail for the sake of brevity. However, they are available on request.

3.2. *Results for the copula models*

In the first subperiod (2000 to 2008), we find that the D-vine structure best captures the interdependencies between the variables. The only central market is cereals which establishes direct connections with fertilizers and seeds. This implies that the market of cereals receives/transmits strong price signals from/to these markets. The protective nature of the CAP measures in place throughout the respective period could have allowed farmers to determine the prices of cereal considering both the cost-push and the demand-pull effects. On the other hand, the prices of fertilizers and seeds which are both imported, have been determined on the global markets and, to a large extent, irrespective of the domestic demand. Therefore, the price interrelations between cereals and fertilizers/seeds have been stronger, making cereals the central market.

Furthermore, we find that the survival Clayton copula best captures the price linkages between cereals and fertilizers, with Kendall's τ=0.1014. This copula indicates asymmetric upper tail dependence, implying that the prices of cereals and fertilizers boom together but they do not crash together, and that price increases are passed on to a larger extent than price decreases. This finding is consistent with Chowdhury *et al*. (2021) which finds that positive price changes of fertilizers bear larger effects on food (including wheat and corn) prices than negative price changes. To explain this asymmetry, we resort to the EU intervention policies in place throughout the period 2000 to 2008, which seem to have provided some level of protection to the prices of cereals against dropping below certain levels. Therefore, during periods of price surges in the fertilizers markets the prices of cereals increased to accommodate the higher input costs, but during periods of price falls the cereal prices did not match the falls in the fertilizers markets. More particularly, before 2003, support for the production of cereals involved measures such as coupled crop-specific payments, supply control (e.g., set-aside obligation), production refunds for starch processors, intervention buying, and

border measures such as import tariffs, tariff rate quotas for imports designed to protect the internal market from lower-priced world market imports, and export refunds (European Commission, 2012). Moreover, the 2003 Mid Term Review introduced the decoupled Single Payment Scheme, which provided income support regardless of the type or level of production in a specific year (European Commission, 2012). The protective nature of these measures is likely to have prevented the cereal prices from dropping below certain levels during periods of price falls, which in turn resulted in the positive asymmetry we observe between cereals and fertilizers. Furthermore, this asymmetry may be explained as the outcome of the farmers' incentives to use fertilizers. In more detail, in case of high fertilizer prices farmers may hold off from their use in the hope of price decreases. This may result in productivity reductions which in turn, lead to lower productions and thus higher prices. Therefore, we observe increased correlation in the high tail. On the other hand, in case of low fertilizer prices, farmers can use only a certain amount of them without damaging soil health (e.g., altering soil pH, acidification, soil crust, etc.). Therefore, low fertilizer prices do not yield productions beyond, and in response, cereal prices below certain levels. Thus, the correlation in the low tail of prices does not meet the one in the high tail. Finally, this upper tail asymmetry highlights that farms in Greece have not been exposed to potentially low cereal prices, since they have been protected by the respective measures. The agricultural sector has largely relied on the EU support and did not have much incentive to develop appropriate mechanisms to absorb disturbances and reorganize after an external shock. Therefore, economic resilience of the sector cannot be warranted due to moral hazard effects.

Moreover, we find symmetric upper and lower tail dependence for the pair cereals-seeds with the Student-t copula being selected. We observe a considerable degree of price dependence with Kendall's τ=0.2917. This symmetry is unexpected given the high market concentration observed in the specific sector. With six companies (i.e., BASF, Bayer, Dow Chemical, DuPont, Monsanto, and Syngenta) dominating the global markets for seeds and agricultural chemicals and five of them proceeding in mergers and acquisitions in 2015 and 2016 (USDA, 2023), the exercise of some degree of market power followed by the subsequent price asymmetries would be expected. However, OECD (2018) finds no significant correlation between market concentration and seed prices for field crops in European countries, which is consistent with symmetric price transmission and confirms our findings. This strong and symmetric price association entails important implications for the resilience of the farms, which on the one hand, are highly dependent on the few providers of seeds but on the other hand, do not seem to be threatened by the oligopoly of the specific market. More precisely, the efficient price transmission between seeds and cereals implies that agro-chemical companies do not exploit price asymmetries to materialize excessive profits and farmers do not have incentives to maintain seed stocks for future productions. Therefore, the ability of farms to absorb disturbances and reorganize is not jeopardized by the oligopolistic nature of this strategic market.

On the other hand, we find no tail dependence (i.e., the Independence copula) in the pairs seeds-energy, seeds-fertilizers, cereals-energy, fertilizers-energy, meats-energy, animal feed-energy, and meats-animal feed. The independence we observe between energy and cereals supports the neutrality hypothesis, which implies that oil prices do not have a significant effect on agricultural commodity prices and is consistent with Reboredo (2012), Gardebroek and Hernandez (2013), and Fowowe (2016). The results for the first subperiod are summarized in Table 3.

In the second subperiod (2009 to 2022) a C-vine structure is selected with seeds being the central market establishing direct connections to cereals and fertilizers. However, the 90 rotated Gumbel copula is selected for the pair seeds-fertilizers, with Kendall's τ=-0.0774. This copula indicates discordance which is consistent with no tail dependence.

Moreover, the Student-t copula is selected for the pair cereals-seeds, which indicates symmetric upper and lower tail dependence. This dependence is slightly lower than in the first subperiod with Kendall's τ=0.2372, which may

relate to the development of prices differing for cereals and seeds. In more depth, between 1990 and 2020, prices paid for seeds increased by 270 percent, whereas the prices for seeds with genetically modified traits rose by 463 percent, which was substantially higher compared to the increases in the commodity output prices (USDA, 2023). These increases in the seed prices are of particular interest since they reflect productivity gains from cultivating improved crop varieties, which bring forth the return on investments for research and development costs. Even though cereal prices rose as well, their increases were not on par with the increases in seed prices, which may have led to the minor drop in the price dependence between cereals and seeds we observe from the first subperiod to second.

Furthermore, we find some level of upper tail dependence selecting the Joe copula for the pair fertilizers-energy, with Kendall's τ=0.0925. This finding confirms, to a large extent, Khalfaoui *et al*. (2021) who find evidence of price dependence between energy and fertilizers in the high tail, especially in the short and the long term. The fertilizer industry is a prominent energy user and will procure energy even at excessive prices, to ascertain a level of production that meets its demand. In a scenario of high energy prices, the energy-dependent industry of fertilizers, will accommodate a significant surge in the cost of production and in return, will increase the fertilizer prices accordingly (Khalfaoui *et al*., 2021). Thus, we observe increased dependence between energy and fertilizer prices in the high tail. Regarding the lower price tail, it has been emphatically acknowledged that European traders engage in dumping, especially with their Russian and Ukrainian counterparts, which allows the fertilizer prices to reach artificially low levels (Fertilizers Europe, 2013; 2017; 2019; 2021), regardless of the energy prices, and thus provides the grounds for the positive asymmetry we observe. In terms of economic resilience, both these agricultural inputs are covered mainly by imports and therefore, the Greek agricultural sector is vulnerable to price changes of both. This implies that fluctuations of fertilizer or oil prices may threaten economic resilience, without the farmers being able to materialize profits directly from the price interplay between them. On the other hand, engaging in the trade of fertilizers during periods of price crashes could allow farmers to benefit from the low fertilizer prices and prepare for periods of price booms, thus enhancing economic resilience of the sector.

The Frank copula is selected for the pair meats-animal feed, indicating intermediate price dependence with Kendall's τ=0.0884. This price dependence is increased compared to the first subperiod when these prices were independent. The 2008 financial crisis may have played a role in strengthening the price linkages between meats and animal feed through two mechanisms. First, the meat industry agents were expected to overcome the temporarily negative medium-term outlook in the aftermath of the crisis, through focusing on core business activities and cost controls, which enhance efficiency (Lohmann Breeders, 2009). Second, the crisis severely restricted the access to credit and capital markets. Even though credit from banks was still available, banks became more selective in lending or increasing credit, and this resulted in increased costs for borrowing and reduced available credit. Thus, the risk profile of many agents in the meat industry, including farmers was raised. Reduced availability of financing led to difficulties in running or expanding existing operations (Lohmann Breeders, 2009). Therefore, the crisis incentivized farmers to reduce nonvalue adding activities such as storage of animal feed, which reduced their capacity to benefit from price decreases and realize production based on cheaply obtained resources. This in return, led to strengthening the price linkages between meats and animal feed. Furthermore, a symmetric price transmission process is consistent with the notions of economic resilience, since it does not offer opportunities for excessive profits during price booms or crushes, to any of the trading agents. In this respect, farmers are not threatened by booming animal feed prices which essentially are passed on to the meat prices.

Finally, we find no tail dependence (i.e., Independence copula) for the pairs seeds-energy, cereals-fertilizers, cereals-energy, meats-energy, and animal feed-energy. The independence we observe between cereals and energy in both periods is in contrast with the conclusion of Han

Table 3 - Results for the copulas, subperiod 2000-2008.

pair	*Family*	*Parameter(s)*	*SE*	*Kendall's τ*	*Tail dependence*
cereals–fertilizers	Sur. Clayton	0.2258	0.1289	0.1014	$\lambda_U = 0.0464$
cereals–seeds	Student-t	0.4423, 2.001	0.0000, 0.0000	0.2917	$\lambda = 0.3604$
seeds–energy	Independence	-	-	0	-
seeds–fertilizers | cereals	Independence	-	-	0	-
cereals–energy | seeds	Independence	-	-	0	-
fertilizers–energy | cereals, seeds	Independence	-	-	0	-
meats–energy	Independence	-	-	0	-
animal feed–energy	Independence	-	-	0	-
meats–animal feed | energy	Independence	-	-	0	-

Note: Parameters, standard errors, Kendall's τ, and tail dependence coefficients are reported.

Table 4 - Goodness of fit tests for the vine copulas, subperiod 2000-2008.

	AIC	*BIC*	*LL*	*GoF test*	*p-value*
Vine copula	-51.7626	-43.7441	28.8813	0.6555	0.8800

Note: The GoF test for bivariate copulas is introduced by Huang and Prokhorov (2014) and based on the White's information matrix equality.

Table 5 - Results for the copulas, subperiod 2009-2022.

pair	*Family*	*Parameter(s)*	*SE*	*Kendall's τ*	*Tail dependence*
cereals–fertilizers | seeds	Independence	-	-	0	-
cereals–seeds	Student-t	0.3641, 2.001	0.0908, 0.0000	0.2372	$\lambda = 0.3222$
seeds–energy	Independence	-	-	0	-
seeds–fertilizers	90° rot. Gumbel	-1.0839	0.0590	-0.0774	$\lambda = 0.0000$
cereals–energy | seeds	Independence	-	-	0	-
fertilizers–energy | cereals, seeds	Joe	1.1781	0.0919	0.0925	$\lambda_U = 0.1990$
meats–energy	Independence	-	-	0	-
animal feed–energy | meats	Independence	-	-	0	-
meats–animal feed	Frank	0.8035	0.4992	0.0884	$\lambda = 0.0000$

Note: Parameters, standard errors, Kendall's τ, and tail dependence coefficients are reported.

Table 6 - Goodness of fit tests for the vine copulas, subperiod 2009-2022.

	Family	*AIC*	*BIC*	*LL*	*GoF test*	*p-value*
Vine copula		-60.9233	-48.5977	34.4617	1.5359	0.6650
meats–animal feed	Frank	-0.6015	2.4799	1.3007	0.0841	0.1200

Note: The GoF test for bivariate copulas is introduced by Huang and Prokhorov (2014) and based on the White's information matrix equality.

et al. (2015), which finds that the 2008 global financial crisis exerted the most powerful impact on the relationship between agricultural commodities (i.e., wheat, soybean, and corn) and energy prices. We summarize the results for the second subperiod in Table 4.

4. Conclusions

The food–energy–agricultural inputs nexus is of crucial interest and entails various implications for the domestic economies as well as for international trade. It involves several agents along the agricultural supply chains and as such it affects the welfare of large populations. In this regard, the price linkages between agricultural commodities and production inputs, and between production inputs themselves have received considerable attention amongst the research community.

The present research investigates the price dependence relationships between agricultural commodity and agricultural input prices, against the 2008 financial crisis, taking a further view on the implications regarding agricultural economic resilience. To this end, we use static vine copulas and split the time period in 2009, to investigate the effects of the 2008 financial crisis. Our results indicate (i) upper tail dependence in the pair cereals–fertilizers before 2009, (ii) upper tail dependence in the pairs seeds–fertilizers and energy–fertilizers after 2009, and (iii) strong and symmetric tail dependence in the pair cereals–seeds in both periods. Overall, our results suggest that the protective nature of the CAP has shielded Greek farmers from high inputs prices, but at the same time, it has created moral hazard effects depriving them from the incentives to develop appropriate mechanisms which enhance resilience of the sector; the few agro-chemical companies supplying seeds, even though enjoy a predominant position in the food supply chain, they do not seem to exploit this position and engage in price raises irrespective of the farmer income.

Our findings are largely in support of the neutrality hypothesis between energy and cereals, and between energy and meats, implying that oil prices do not significantly affect food prices or in other words, fluctuations in agricultural commodity prices are not driven by oil price movements. This finding is of particular interest to policy makers since it implies that policies seeking to reduce food prices or price variability, do not need to consider the dynamics in the global oil market. Instead, the surges in food prices should be addressed focusing on the forces of supply and demand in the agricultural markets. More particularly, oil price spikes are not shown to be connected to food price spikes, which in turn affect disproportionally the lower incomes since a larger share must be spent on food. Therefore, short-run policies seeking to alleviate the corresponding adverse impacts on the financially challenged, such as food subsidies, should be implemented regardless of extreme oil price shifts. Moreover, food price stabilization policies which aim to control price volatility, including price controls and trade barriers, should differentiate between average oil price movements, which probably bear permanent impacts and extreme oil price shocks, which probably bear no impact on food prices. Furthermore, the independence between energy and agricultural commodity markets entails important implications for risk management, especially regarding the agricultural commodity markets which have gained momentum in recent years. The tail independence shown both before and after the structural break, suggests that risk-averse investors may choose to include assets from both markets to diversify their risk and hedge against it.

Finally, we note that our findings should be further confirmed via different approaches. This study uses exclusively static copula models which is a limitation. The application of time-varying copula models may be more relevant, especially in the case of dynamic price linkages, and as such, it provides a promising strand for prospective research.

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References

Aguiar-Conraria L., Soares M.J., 2014. The continuous wavelet transform: Moving beyond uni- and bivariate analysis, *Journal of Economic Surveys*, 28: 344-375. DOI: 10.1111/joes.12012.

Angelopoulos S., de Silva A., Navon Y., Sinclair S., Yanotti M., 2023. Economic Resilience in a Pandemic: Did COVID-19 Policy Effects Override Industry Diversity Impacts in Australia?, *Economic Papers*, 42: 153-171. DOI: 10.1111/1759-3441.12384.

Bristow G., 2010. Resilient regions: re-'place'ing regional competitiveness. *Cambridge Journal of Regions, Economy and Society*, 3: 153-167. DOI: 10.1093/cjres/rsp030.

Chavas J.-P., Rivieccio G., Di Falco S., De Luca G., Capitano F., 2022. Agricultural diversification, productivity, and food security across time and space. *Agricultural Economics*, 53: 41-58. DOI: 10.1111/agec.12742.

Chen X., Fan Y., 2006a. Estimation of copula-based semiparametric time series models, *Journal of Econometrics*, 130: 307-335. DOI: 10.1016/j.jeconom.2005.03.004.

Chen X., Fan Y., 2006b. Estimation and model selection of semiparametric copula-based multivariate dynamic models under copula misspecification, *Journal of Econometrics*, 135: 125-154. DOI: 10.1016/j.jeconom.2005.07.027.

Chen S., Kuo H., Chen C., 2010. Modeling the relationship between the oil price and global food prices. *Applied Energy*, 87: 2517-2525. DOI: 10.1016/j.apenergy.2010.02.020.

Cheng S., Cao Y., 2019. On the relation between global food and crude oil prices: An empirical investigation in a nonlinear framework. *Energy Economics*, 81: 422-432. DOI: 10.1016/j.eneco.2019.04.007.

Chowdhury M.A.F., Meo M.S., Uddin A., 2021. Asymmetric effect of energy price on commodity price: New evidence from NARDL and time frequency wavelet approaches. *Energy*, 231: 120934. DOI: 10.1016/j.energy.2021.120934.

Diβmann J., Brechmann E.C., Czado C., Kurowicka D., 2013. Selecting and estimating regular vine copulae and application to financial returns. *Computational Statistics and Data Analysis*, 59: 52-69. DOI: 10.1016/j.csda.2012.08.010.

Dorwrad A., 2013. Agricultural labour productivity, food prices and sustainable development impacts and indicators. *Food Policy*, 39: 40-50. DOI: 10.1016/j.foodpol.2012.12.003.

European Commission, 2012. *Evaluation of measures applied under the Common Agricultural Policy to the cereals sector*. Brussels: European Commission, Directorate-General for Agriculture and Rural Development.

European Commission, 2021. *Statistical Factsheet GREECE*. Brussels: European Commission, Directorate-General for Agriculture and Rural Development.

European Commission, 2023. *At a glance: GREECE'S CAP STRATEGIC PLAN*. Brussels: European Commission, Directorate-General for Agriculture and Rural Development.

Eurostat, 2023. *Statistics Explained Agri-environmental indicator - energy use*. Luxembourg: Publications Office of the European Union.

Fertilizers Europe, 2013. *2013 Overview, Closing the Loop*. Brussels: Fertilizers Europe.

Fertilizers Europe, 2017. *2016/17 Overview, Securing the future | Fertilizers and the food chain*. Brussels: Fertilizers Europe.

Fertilizers Europe, 2019. *2018/19 Overview*. Brussels: Fertilizers Europe.

Fertilizers Europe, 2021. *Overview 2020/2021, Green ammonia the workhorse of the EU hydrogen economy*. Brussels: Fertilizers Europe.

Food and Agriculture Organization (FAO), 2008. Soaring food prices: facts, perspectives, impacts and actions required. In: *Proceedings of the High-Level Conference on World Food Security*, Rome, 3-5 June 2008.

Fowowe B., 2016. Do oil prices drive agricultural commodity prices? Evidence from South Africa. *Energy*, 104: 149-157. DOI: 10.1016/j.energy.2016.03.101.

Gardebroek C., Hernandez M.A., 2013. Do energy prices stimulate food price volatility? Examining volatility transmission between US oil, ethanol and corn markets. *Energy Economics*, 40: 119-129. DOI: 10.1016/j.eneco.2013.06.013.

Ghazani M.M., Khosravi R., Caporin M., 2023. Analyzing interconnection among selected commodities in the 2008 global financial crisis and the COVID-19 pandemic. *Resources Policy*, 80: 103157. DOI: 10.1016/j.resourpol.2022.103157.

Gnutzmann H., Spiewanowski P., 2016. *Fertilizer Fuels Food Prices: Identification Through the Oil-Gas*

Spread (September 29, 2016). SSRN: https://ssrn.com/abstract=2808381 or http://dx.doi.org/10.2139/ssrn.2808381.

Götz T.B., Hecq A., Smeekes S., 2015. *Testing for Granger causality in large mixed-frequency VARs*, Discussion Paper n. 45/2015, Deutsche Bundesbank.

Han L., Zhou Y., Yin L., 2015. Exogenous impacts on the links between energy and agricultural commodity markets. *Energy Economics*, 49: 350-358. DOI: 10.1016/j.eneco.2015.02.021.

Huang W., Prokhorov A., 2014. A goodness-of-fit test for copulas. *Econometric Reviews*, 33: 751-771. DOI: 10.1080/07474938.2012.690692.

Ibrahim E.A., 2024. Determinants and Performances of Food Security in the Middle East and North Africa Region Countries. *New Medit*, 23(2): 53-69. DOI: 10.30682/nm2402d.

Kapelko M., Lansink O.A., Stefanou S.E., 2017. The impact of the 2008 financial crisis on dynamic productivity growth of the Spanish food manufacturing industry. An impulse response analysis. *Agricultural Economics*, 48: 561-571. DOI: 10.1111/agec.12357.

Kellner R., Rösch D., 2016. *Financial Market Integration Asymmetry and Contagion*. European Financial Management Association 2016 Annual Meeting, June 29 – July 02, 2016, Basel, Switzerland.

Khalfaoui R., Baumöhl E., Sarwar S., Výrost T., 2021. Connectedness between energy and nonenergy commodity markets: Evidence from quantile coherency networks. *Resources Policy*, 74: 102318. DOI: 10.1016/j.resourpol.2021.102318.

Koirala K.H., Mishra A.K., D'Antoni J.M., Mehlhorn J.E., 2015. Energy prices and agricultural commodity prices: Testing correlation using copulas method. *Energy*, 81: 430-436. DOI: 10.1016/j.energy.2014.12.055.

Lawrence J.D., Mintert J., Anderson J.D., Anderson D.P., 2008. Feed Grains and Livestock: Impacts on Meat Supplies and Prices. *Choices: The Magazine of Food, Farm, and Resource Issues*, 23: 1-5.

Lohmann Breeders, 2009. *Effects of the financial crisis on the international meat industry*. *2009/01* (lohmann-breeders.com).

Martin R., 2012. Regional economic resilience, hysteresis and recessionary shocks. *Journal of Economic Geography*, 12: 1-32. DOI: 10.1093/jeg/lbr019.

Martin R., Sunley P., 2015. On the notion of region economic resilience: Conceptualisation and explanation. *Journal of Economic Geography*, 15: 1-42. DOI: 10.1093/jeg/lbu015.

Mensi W., Tiwari A., Bouri E., Roubaud D., Al-Yahyaee K.H., 2017. The dependence structure across oil, wheat, and corn: A wavelet-based copula approach using implied volatility indexes. *Energy Economics*, 66: 122-139. DOI: 10.1016/j.eneco.2017.06.007.

Mitchell D., 2008. *A note on rising food prices*. World Bank Policy Research Working Paper Series n. 4682. DOI: 10.1596/1813-9450-4682.

Nagler T., Krüger D., Min A., 2022. Stationary vine copula models for multivariate time series. *Journal of Econometrics*, 227: 305-324. DOI: 10.1016/j.jeconom.2021.11.015.

Nazlioglu S., 2011. World oil and agricultural commodity prices: evidence from nonlinear causality. *Energy Policy*, 39: 2935-2943. DOI: 10.1016/j.enpol.2011.03.001.

Nazlioglu S., Soytas U., 2011. World oil prices and agricultural commodity prices: evidence from an emerging market. *Energy Economics*, 33: 488-496. DOI: 10.1016/j.eneco.2010.11.012.

Organization of Economic Cooperation and Development (OECD), 2008. *Rising food Prices: Causes, Consequences and Responses*. OECD Policy Brief 2008. Paris: OECD Publishing.

Organization of Economic Cooperation and Development (OECD), 2018. *Concentration in seed markets: Potential effects and policy responses*. Paris: OECD Publishing.

Piesse J., Thirtle C., 2009. Three bubbles and a panic: an explanatory review of recent food commodity price events, *Food Policy*, 34: 119-129. DOI: 10.1016/j.foodpol.2009.01.001.

Reboredo J.C., 2012. Do food and oil prices co-move? *Energy Policy*, 49: 456-467. DOI: 10.1016/j.enpol.2012.06.035.

Sdrolias L., Semos A., Mattas K., Tsakiridou E., Michailides A., Partalidou M., Tsiotas D., 2022. Assessing the Agricultural Sector's Resilience to the 2008 Economic Crisis: The Case of Greece. *Agriculture*, 12: 174. DOI: 10.3390/agriculture12020174.

U.S. Department of Agriculture, Foreign Agricultural Service, 2015. *Planting Seeds Market in Greece*, IT1594.

U.S. Department of Agriculture, Foreign Agricultural Service, 2021. *Market Fact Sheet: Greece*, GR2021-0009.

U.S. Department of Agriculture, Economic Research Service, 2023. *Concentration and Competition in U.S. Agribusiness*, EIB-256.

World Bank Group, International Finance Corporation, 2007. *Environmental, Health, and Safety*

Guidelines for Nitrogenous Fertilizer Production. Washington, D.C., April 30, 2007.

World Integrated Trade Solutions, 2019. *Greece Fertilizers, mineral or chemical; potassic, potassium sulphate imports by country in 2019*. Accessed: November 10, 2023. https://wits.worldbank.org/trade/comtrade/en/country/GRC/year/2019/tradeflow/Imports/partner/ALL/product/310430.

Yang Q., Zhang P., Ma Z., Liu D., Guo Y., 2022. Agricultural Economic Resilience in the Context of International Food Price Fluctuation—An Empirical Analysis on the Main Grain–Producing Areas in Northeast China. *Sustainability*, 14: 14102. DOI: 10.3390/su142114102.

Zhang Z., Lohr, L., Escalante, C. and Wetzstein, M. (2010). Food versus fuel: what do prices tell us? *Energy Policy*, 38: 445-451. DOI: 10.1016/j.enpol.2009.09.034.

Zhu, B., Lin, R., Deng, Y., Chen, P. and Chevallier, J. (2021). Intersectoral systemic risk spillovers between energy and agriculture under the financial and COVID-19 crises. *Economic Modelling*, 105: 105651. DOI: 10.1016/j.econmod.2021.105651.

Does sustainability fit in the EU-Tunisia trade relations? Evidence from the olive oil sector

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Abstract

Trade agreements between the European Union (EU) and developing countries are often used to promote sustainable development within economic cooperation. The EU-Tunisia trade relations have a long history, starting with the Association Agreement in place and the ongoing negotiations for the new Deep and Comprehensive Free Trade Area (DCFTA) agreement, for further liberalizing the agricultural sector. This study investigates the effects on sustainability of these bilateral relations, with a focus on Tunisian olive oil value chain, considering both the current Free Trade Agreement (FTA) impacts and the future DCFTA agreement expected effects. A two-steps qualitative process consisting of a desk analysis and stakeholders' consultations has been undertaken to report socioeconomic and environmental effects, suggesting policy interventions to be considered within the negotiations framework. Main actions needed encompass an inclusive renovation of Tunisian olive oil sector, a rethinking of exports' tariff quota system to the EU, with special attention to organic olive oil, and water-efficient cultivation systems interventions.

Keywords*: Olive oil, DCFTA Tunisia, Sustainable trade, Tunisia, Stakeholders engagement, Qualitative analysis.*

1. Introduction

Preferential Trade Agreements (PTAs) are designed to promote trade and economic cooperation between participating countries by offering advantages such as reduced tariffs or other trade-related benefits. Having notably increased their prominence over the past few decades, PTAs have progressively started to include provisions that cover a wide range of trade-related policy, including policy areas such as labour rights, environment, investments, intellectual property rights, and migration. These provisions are widely recognized as possible targeted policy tools to step forward in reaching the United Nations Sustainable Development Goals (SDGs) (Dür & Elsig, 2015; Baccini, 2019; Berger *et al*., 2020).

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International trade is seen as a promoter of sensitive sustainability issues also at the EU level, where agreements are used as tools to promote sustainable development, especially with developing countries, through the regulation of their exporting performances to the EU (European Commission, 2006, 2012, and 2015). Indeed, sustainable development provisions have become an essential component of the EU's new generation of Free Trade Agreements (FTAs), which foresee a specific Trade and Sustainable Development (TSD) Chapter. FTAs with developing countries differ mainly in terms of bindingness, enforceability, and transparency (Adriansen and Gonzàlez-Garibay, 2013; Poletti and Sicurelli, 2018; Harrison *et al*., 2019).

Trade agreements between the EU and Tunisia have a long history, starting with the Cooperation Agreement (CA) signed in 1976. This was then replaced by an Association Agreement (AA) focused on the liberalization of trade, particularly industrial goods, regulatory framework harmonization, and enhancement of financial and economic cooperation (Jbili and Enders, 1996), signed by the two parties in 1995, applied from 1996, and ratified in March 1998. This agreement also served as a reference in negotiations with other countries in the EU's Southern Neighbourhood, including Algeria, Egypt, Jordan, Lebanon, and Morocco, among others (Ghesquiere, 2001). Since then, continuous negotiations about liberalizing agricultural trade have been proposed, seeking greater and reciprocal market access. To date, only products like dates and spices benefit from duty-free access, while others, such as olive oil, are subject to preferential access with tariff rate quotas. Those negotiations stopped with the political upheavals in 2010 and were only resumed in 2015 with the proposal of the new Deep and Comprehensive Free Trade Area (DCFTA) agreement (Rudloff and Werenfels, 2018), aiming at further liberalizing the agricultural and other sectors, removing customs barriers, and harmonizing standards, creating new trade and investment opportunities to better integrate the Tunisian economy into the EU market and support the local economic reforms underway (DG Trade, 2024).

Starting from a study developed within the Trade4SD Horizon2020 project[1], this research investigates the effects on sustainability dimensions of the EU-Tunisia bilateral trade relations, with a focus on the Tunisian olive oil value chain. The analysis is carried out through a comparison of the current FTA and the future DCFTA, encompassing also the views of a representative group of stakeholders of the Tunisian olive oil sector. For its analysis, the study follows a qualitative approach that compares the actual outcomes of the current agreement and projections of the future one, while also using the perceptions of local olive oil sector actors to understand their feelings about current factual developments and what they expect from the future agreement under negotiation.

The qualitative approach, despite its clear limits, suits particularly well this type of analysis since it allows to investigate through the opinions of expert stakeholders' collected by face-to-face interviews of the effects of specific trade agreements on a key sector, like olive oil in Tunisia, considering all the main relevant sustainability dimensions. These kinds of approaches have been quite successful in other contexts, mainly because they allow to identify the key actors of a local value chain and reduce, in this way, the number of questionnaires to submit and to elaborate further (Battisti *et al*. 2014; Hennink *et al*., 2017; Townsend, 2021). However, one of the main limits of qualitative approaches is, in fact, their cost and their effectiveness in covering all the sensitive parts of the value chain. Therefore, the best way is to find a reasonable balance between the numerosity of the sample and representativeness, considering that the aim is to reach expert representatives of the productive sector.

[1] The project TRADE4SD - Fostering the positive linkages between trade and sustainable development has received funding from the European Union's Horizon 2020 Research and Innovation programme under grant agreement No. 101000551.

The study is based on two main questions: i) Is the DCFTA expected to be coherent with the effects of the already implemented EU-Tunisian FTA? ii) How are the actual and future effects on non-product dimensions perceived by stakeholders from the agricultural and olive oil sector?

The research first delves into a literature review on DCFTA expected impacts, deepening then the analysis with the comparison of two primary documents: the ex-post evaluation of the FTA impacts published by the European Commission (EC) in 2021 and the Trade Sustainability Impact Assessment (TSIA) produced in 2013 by Ecorys[2], focused on assessing the potential socio-economic and environmental effects of the future DCFTA. This first step is followed by a confrontation of different stakeholders' consultation, comparing the views collected in 2023 within the Trade4SD project activities on the DFCTA possible impacts on non-related products in the olive oil sector (i.e. resource use or workforce conditions) and those collected and underlined in the FTA ex-post evaluation of 2021. The paper is structured into six main sections: a context analysis delving into the Tunisian agricultural sector and EU bilateral trade; a literature review on the impacts of the future DCFTA; a methodology paragraph describing the comparison of both the assessments and the stakeholders' consultations; a results section presenting the primary outcomes coming from the previous desk analysis. Finally, the discussion and conclusions sections are dedicated to a structured analysis of results and formulating policy recommendations given the future negotiations scenario.

For its aims and scope, this research wishes to contribute to the existing literature on the EU-Tunisia trade relations and related socioeconomic and environmental impacts, bringing to the table the visions of some crucial stakeholders of the olive oil sector involved in the political-economic processes related to the agreement's effective implementation path. Also, the comparison between the expected impact of the future DCFTA and the current FTA's effects brings to light whether the expectations of the future agreement have already been partly fulfilled by the agreement in force to date, what difficulties persist and what is missing. The work thus enriches the debate on EU-Tunisia trade relations and may be of particular interest to policymakers and other actors involved in the negotiations to gain a more detailed overview in terms of actions to be pursued in line with the socio-economic and environmental sustainability of the parties involved.

As mentioned, the qualitative approach followed could be seen as limiting the potential of the research, albeit justified by the desire to bring out stakeholders' views on EU-Tunisia trade agreements. Building on these initial results, future analyses could involve quantitative analyses of the sustainability indicators framework, integrating and enhancing the current results, which we consider quite solid and satisfying.

2. Background

The Tunisian agricultural sector faces several socioeconomic and environmental challenges. As reported by Rudloff (2017, 2020), Tunisian agriculture is responsible for 10% of GDP and plays a stabilising role in economic crises by securing the population's food supply. In the past, Tunisia has witnessed violent demonstrations against rising food prices (e.g., bread), which gave the agricultural sector great economic and social significance with direct social stabilization effects.

The last 30 years have seen a distinct fall in the agricultural employment share, from 23% (1991) to 14% (2022), with the fruit and vegetable sector being pivotal in terms of employment due to its labour intensity (ILO, 2024a; EC, 2021). In rural areas, it still represents a major employer for young people (CFYE, 2022), half of which are, however, day labourers without a proper contract (Rudloff, 2020) reflecting the sector's seasonality and precarity in a country with a general youth unemployment rate at almost 38% in 2019 (ILO, 2024b).

[2] Ecorys is an economic research and consulting company based in Europe (https://www.ecorys.com/).

Agricultural productivity seems to be poor for technical and demographic reasons, such as low mechanisation, scarce quality seed and a growing older rural population. The sector growth is limited by a series of market structure characteristics, including export monopolisation by some farms and limited access to market possibilities for traditional small ones. Also, production and marketing infrastructure is reported to need to be improved in some areas, turning into additional criticalities along the supply chains (Rudloff, 2020). In 2023, according to the last World Bank Economic Monitor (2024), Tunisia's economic recovery almost stopped. This was due to rigid financing conditions, slow reform implementation processes and a severe drought highlighting the country's urgency to adapt to climate change, which forced the government to implement irrigation restrictions.

The agricultural sector was, indeed, the main driver of this general slowdown, with a decline of 11% resulting in reduced harvest and significant production losses, like the case of wheat, one of the key elements of the local diet. With import compression and reduced supply in domestic food markets, inflation remains high, especially for food. It is then evident that, in addition to several economic challenges, Tunisian rural areas must deal with the increasing consequences of climate change affecting the agricultural sector, in terms of water-scarcity, vulnerability to droughts and overall rainfall variability (Verner *et al*., 2018). These threats could reflect in the long run into the interruption of some main agricultural products' cropping cycle and in the worsening of Tunisia's food security in terms of quantity and quality of agrifood (Oussar *et al*., 2021). As underlined by the World Bank Group (2023), the agriculture sector, being the main consumer of water plays a pivotal role in improving irrigation efficiency to reduce water demand, also through nature-based solutions and climate-smart practices.

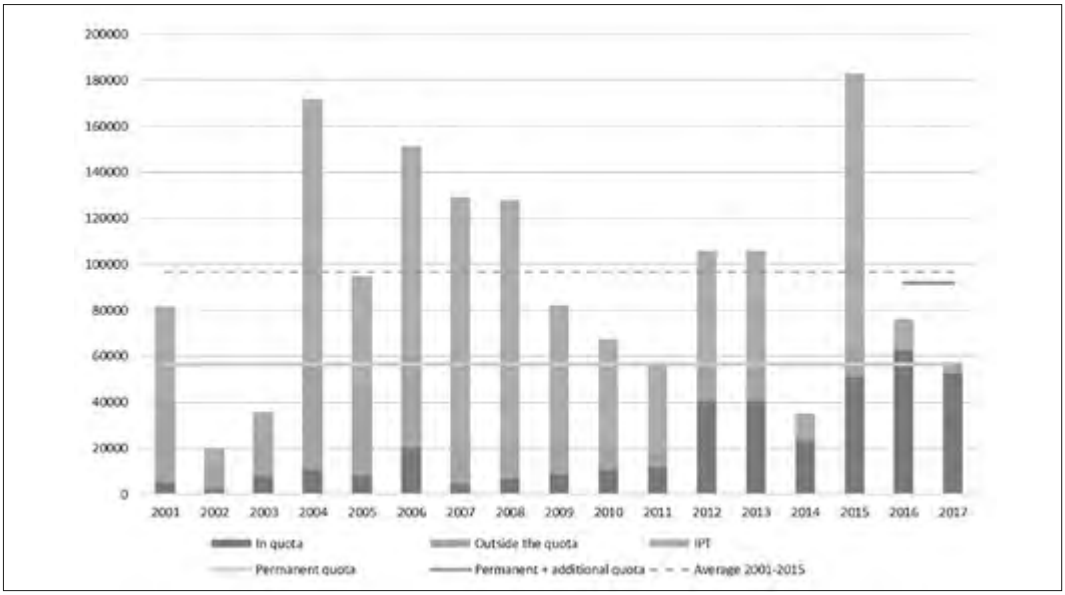
Among the main sectors of Tunisian agriculture, olive oil makes the country the 3rd most important exporter in the world (FAO, 2023), following other Mediterranean countries like Spain and Italy. A study by Kurtoğlu *et al*. (2023) aimed at predicting countries leading olive oil production globally between 2024-2027 shows that Spain, Greece, Turkey, Morocco, and Italy will lead, accounting for 65.96% of the world's production level, followed by other exporting countries, Tunisia included, with 7% estimated production contribution.

The cultivation of olive trees in the country represents 20% of the workforce in the agricultural sector, with olive oil production accounting for 80% of local exported food production, with 2 billion TND (638.844.000 USD)[3] in export income on average per year (CFYE, 2022). Tunisian olive area occupies one-third of the country's total arable land, with increasing expectations over the coming years (USDA, 2023; FAO, 2023). Olive oil exports play a crucial role in Tunisia's trade balance. Over the last decade, Tunisia exported on average 168,000 tons of olive oil, contributing to nearly 40% of the primary sector's export revenue (Jouili, 2023). At the end of April 2024, the National Observatory of Agriculture (ONAGRI) estimates show that olive oil represents 65.7% of the share in total food exports. The average export price reached 27.37 DT/kg (7,40 USD/Kg)[4], recording a growth of 81.0% compared to the previous year.

Olive oil, considered as a "sensitive" Mediterranean product by the EC, stands out as a prime example of intensive trade interactions between the EU and Tunisia (European Commission, 1997). The EU has been by far the largest olive oil importer from Tunisia in the last decade: from April 2022 to March 2023, EU imports from Tunisia amounted to 119,804 tonnes, 77.9% of total extra-UE imports of olive oil (IOC, 2023). Tunisian olive oil enters the EU market through three main export channels, notably Inward Processing Traffic (IPT), most-favoured-nation (MFN) tariff and tariff quota. With the IPT, Tunisian olive oil is used as a cost-effective additive to increase the volume of bulk goods in Eu-

[3] Exchange rate as at 30/12/2022 corresponding to the data publication date.
[4] Exchange rate as at 30/04/2024 corresponding to the data publication date.

Figure 1 - EU imports of virgin olive oil from Tunisia from 2001 to 2017 (tons).



Source: CREA 2019.

ropean olive oil. Since European importers have no obligation to add the specific olive source on labels, the Tunisian origin is lost. This channel is then preferred by importers who can use bulk oil, adding value through their bottling and branding (Grumiller *et al*., 2018a; Raza *et al*., 2022), even though this represents the cause of the low European consumer awareness of Tunisian olive oil quality (Arfaoui *et al*., 2022) which affect market preferences. The MNF, rarely used due to IPT preference, is the channel for exports falling outside the established quota or IPT, with a tariff ranging from 31-32% depending on olive oil quality (Grumiller *et al*., 2018a; GIZ, 2019). The preferential tariff quota governing olive oil exports to the EU has a zero-duty rate for the first 56,700 tons of virgin other than lampante olive oil arriving in the EU. On exported quantities exceeding this limit a tariff of €1.245 per kg applies (Grumiller *et al*., 2018b; CBI, 2024). Only oil produced entirely in Tunisia and from olives grown locally benefits from these tariffs, meaning that Tunisia cannot import Algerian or Libyan olive oil and reexport it to the EU.

Autonomous emergency trade measures have also been introduced by the EU after 2015 to support the local economic slowdown, providing for an additional annual zero-duty tariff quota of 35,000 tons for both 2016 and 2017, provided that the annual quota of 56,700 tons was previously fully allocated. Only 30% of the additional quota was allocated during 2016 (approximately 10,400 tons), whereas in 2017 the temporary quota was not allocated at all. Notably, the allocation of quotas does not necessarily correspond to actual imports. Indeed, in 2016 only 2,557 tons were imported under the additional quota, that is 7.3% of 35,000 tons, and 0% in 2017 (Ben Rouine, 2018a). Considering imports under quotas, those subject to the payment of the duty (outside the quota), and those that occurred in IPT in both years, the total imports of Tunisian virgin olive oil stood at only 76,000 tons and 57,300 tons respectively, a quantity significantly lower than the average imports of the previous 15 years (96,000 tons, period 2001-2015) (Figure 1).

It thus emerges that the additional quota did not increase EU imports, as these are influenced by other factors, such as the level of domestic production both in the EU and Tunisia, which affects imported volumes, and relative prices, which affects the choice of the customs regime utilized (CREA, 2019). Additionally, the EU

Table 1 - Partial list of regulations applicable to olive oil import in the EU.

Regulation's name	*Target*	*Reference*
EU-Tunisia Agreement (Euro-Mediterranean) (1998)	Tariff	L 97/2
Commission Regulation (19/12/2006)	Contaminants	(EC) 1881/2006
Commission Delegated Regulation (18/05/2016), Commission Implementing Regulation (18/05/2016)	"AGRIM certificate" (authorization to import from third countries)	(EU) 2016/1237, (EU) 2016/1237
Commission Delegated Regulation (29/07/2022)	Oil origin	(EU) 2022/2104

Source: Authors' elaboration.

legal provisions are applied to imported goods, including contamination criteria (EC, 2006) related to pesticide residue, microbiological contaminants, and other chemical substances. In this context, EU regulations are essential because of their direct effect over the national rights of members states (Boutayeb, 2020).

Some of the existing EU regulations for olive oil import have been collected to provide an overview of applicable standards. Complying with these rules is a challenge in terms of production, which, on the one hand, encourages Tunisian olive oil exporters to improve product quality but, on the other hand, deals with the technical difficulties and structural capacity of local exporting companies (Table 1).

In line with those identified by Grumiller *et al*. (2018b), various challenges faced by the Tunisian olive oil sector can be found at the upstream and downstream of the supply chain, touching the three sustainability dimensions in different ways. Environmental issues are mainly related to climate change affecting the region with weather and temperature variations which automatically affect water and arable land use (Lavie *et al*., 2023). It is worth noting that almost the entire Tunisian olive grove matures through rainwater and without fertilizers, suggesting the need for developed and innovative irrigation technologies which could efficiently prevent the unpredictability of the harvest (Fernández-Lobato *et al*., 2022; Radhouane, 2018). This kind of difficulty, together with the lack of proper equipment and reliance on adequate agricultural methods, also contributes to low productivity rates and high volatility of olive production, which causes an even stronger dependence on the EU market. Social challenges are particularly pronounced among smallholder farmers, who make up the majority of the workforce but struggle against competition from large monoculture olive farms, which account for over 60% of the total olive cultivation area (Jouili, 2023). Smallholder farmers often face precarious working conditions, limited access to social protections, and inadequate incomes, which are compounded by the unpredictability of olive production and low productivity levels (Rudloff, 2020; Raza *et al*., 2022). Economically, the sector remains highly dependent on exports to the EU market. Tunisian exporting companies struggle to increase export value added because of the predominantly purchase of Tunisian oil in bulk without a proper indication of origin, as set by the EU regulation N. 29/2012, which allows European olive oil manufacturers to label bottles containing Tunisian olive oil simply as "not of European origin" which cause the lack of European consumers' awareness regarding Tunisian olive oil value (Jouili, 2023).

3. Literature review on DCFTA's estimated impacts

Negotiations between the EU and Tunisia for the establishment of the new trade agreement were launched in Tunis on 13th of October 2015. Procedures have been implemented so far (Table 2), and talks are still ongoing to move towards a complete and official agreement, even though the signature is still missing (DG Trade, 2024).

Agricultural trade liberalization is then still far from being achieved, placing tariff liberalization and non-tariff measures (NTMs), sanitary and phytosanitary standards (SPS), as well as technical barriers to trade (TBT) at the centre of the

Table 2 - DCFTA negotiations procedures from 2015 to date.

Year	*Achievement*	*Scope*
2015	Launch of negotiations between EU-Tunisia	Creation of new trade and investment opportunities and better integration of the Tunisian economy into the EU single market.
2016	First round of negotiations	Discussion on asymmetry of liberalization; progressivity of liberalization and relative local economic support; regulatory approximation in the priority areas identified by Tunisia.
2017	Technical round	Further technical discussion carried out in Brussels.
2018	Second and third full rounds of negotiations	Discussions carried out in Tunis and Brussels (May and December).
2019	Fourth round of negotiations	Discussions covered a wide range of issues including agriculture, services, and sustainable development. Tunisia reiterated its request to provide urgent measures in favor of some of its strategic sectors, such as olive oil and textiles, among others.
2021	EU Trade Policy Review	In the new EU Trade Policy Review, the modernization of trade and investment relations with Tunisia are discussed to better adapt them to today's challenges.
2024	Talks	Consultations are still on going in view of a future agreement signature.

Source: Authors' elaboration from DG TRADE (2024 and 2024a).

DCFTA negotiations since the first round (Raza *et al*., 2022). The EU proposal for a TSD Chapter within the DCFTA wishes to ensure that sustainable development commitments are aligned with multilateral governance on these issues by incorporating them into the international consensus.

Numerous studies have then investigated the possible trade liberalization impacts arising from a future DCFTA effective implementation. Some of these are presented hereby, grouped according to the topics covered in terms of economic, social and environmental impacts. For exhaustivity and specificity of analysis, the authors added two further categories found in the analysed literature: one related to the socioeconomic concerns raised by local civil society organizations and groups of interest and another concerning the link between trade and SDGs.

In terms of economic impacts, an overall local growth for Tunisia is predicted by most studies considered by Rudloff (2020), arising mainly from tariff reduction. In these scenarios, the agricultural sectors most benefitted seem being olive oil and fruit and vegetable, while cereals, milk and meat would be those negatively affected. When considering the positive effect of trade liberalization, the role of NTMs in stimulating trade should also be considered, the effects of which are often sidelined in studies because of the difficulty in modelling them. In this regard, only one study (Gasiorek and Mouley, 2019), among those cited in Rudloff's work, explicitly considers the dismantling of NTMs through a partial equilibrium model to picture the separate and aggregate effect of tariffs and NTMs changes. Results highlight that liberalisation based only on tariffs reduction would likely to put more burden on Tunisia with declining outputs, since the EU has already liberalised its tariffs. Whereas, as also stressed by Grumiller *et al*. (2018), potential significant gains would arise for the African country if the DCTFA significantly reduces non-tariff barriers between the two parties, implying adjustment costs that specific structural and adjustment policies should accompany.

Different opinions come from the study of Ben Rouine and Chandoul (2019) according to which in both tariffs and NTMs interventions, the greatest liberalization effort would be borne by Tunisia. Indeed, from the tariff point of view, the EU protects its internal market mostly through internal support policies which keep internal prices artificially low compared to the tariff regime. On the other side, the rapprochement of Tunisian legislation with the community acquis has prohibitive costs. The European SPS system is one of the most complex and rigorous, more stringent than international standards. Tunisia should, therefore, comply with international standards to allow a better diversification of

the market and favour an approach more suited to the real local agricultural sector's conditions.

A CGE model powered by interviews with Tunisian exporters to the EU and agricultural producers has been used by Raza *et al*. (2022) to assess the regulatory approximation under DCFTA, estimating the costs of compliance with the new standards and simulating the effects on the agricultural and food sectors in Tunisia. A full harmonization with EU standards seems to bring a negative impact on local agricultural value added, with greater effects on sectors serving mainly the internal market, even if accompanied by bilateral tariff liberalization. These circumstances could be changed by a strong productivity increase which, at the same time, would also put pressure on other sectors and on natural resources, for example for the absorption of the workforce abandoning agriculture or the greater demand for water in export-oriented production. This aspect also relies on the need to well understand "*the trade-offs between agricultural trade liberalization and the goals demanded by SDG 2*" (Raza *et al*., 2022) and brings us to the other impact categories on environmental and social effects.

In fact, the same authors also underline the need to build a Tunisian negotiation position coherent with a strategic vision of sustainable agricultural development, aiming at achieving SDG 2 objectives of ending hunger, achieving food security and improved nutrition and promoting sustainable agriculture. In these terms, a critical vision is offered by Ayeb (2018) who stress how the already evident food import dependency of Tunisia would be worsened by the DCFTA and the exposition to the European competitors on a freer market, invoking radical reforms to Tunisian agricultural policies based on achieving food independence, reducing rural and urban social marginality and decreasing local environment exposure to climate change consequences.

A combination of positive and negative environmental effects of DCFTA implementation are stressed by Rudloff (2020), reporting ambiguous outcomes in terms of trade-ecology relations. In fact, if an increase in CO_2 emissions, water and plastic consumption and use of pesticides is underlined by the available literature, on the other hand, a loss of profitability could possibly result in the abandonment of crops in ecologically fragile and/or low-yielding areas. This would lead to, for example, a decrease in Tunisian cereal production and a consequent valuable push for the ecosystem, since it represents one of the main factors of soil degradation.

Delving into the social sphere, Lejmi (2020, 2021) stresses the need to better include the protection of socio-economic rights in the DCFTA and, in relation to the SPS harmonisation, underly its possible role as a lever for human capital improvement through the training of farmers, farm workers and qualified personnel, but also a chance to move towards a more digitalized agriculture. The importance of pursuing the creation of structured accompanying policies, underlined by Grumiller *et al*. (2018) in economic terms, is also mentioned in terms of social impact since the adjustment process resulting from trade liberalization produces negative effects for the less competitive agricultural sectors and their workers.

The same authors also give some important insights regarding linkages between trade and sustainable development, a topic examined by Tröster *et al*. (2018) as well. Studies highlight the need to consider the geopolitical specificities of Tunisia and adapt trade policy accordingly. Short-term benefits and safeguarding of socio-territorial cohesion should be central to Tunisian trade liberalization to help the country's political transition and contribute to its economic and democratic consolidation. What is underlined is that the EU currently favours the dialogue approach over hard conditionalities when promoting human rights and labour standards. According to the authors, for economic growth to be truly inclusive and consider the rights of the most vulnerable groups of workers (especially women), greater ownership of the EU institutions in the SD chapter within the DCFTA would be needed, together with greater support for cooperation between the EU and the civil society of the partner country. Another aspect to consider is the promotion of employment that pays decent wages and promotes good working conditions. In this regard, trade policymakers need to assess the impact of trade liberalization on public budgets, since tariff liberalization reduces public income precisely at the time when

additional funds are needed to alleviate the costs of social adjustment in sectors most negatively exposed to structural changes, for example those who have been displaced by the increase in imports. This is possible, again, through specific social and employment policies in partner countries, which often do not exist or do not have adequate resources, like the Tunisian case. Therefore, temporary budgetary support should be provided if needed, as well as domestic resource mobilization promoted.

Tying in with the aspect of civil society inclusion in the dialogue on DCFTA, the current analysis allowed the identification of Tunisian scepticism towards a DCFTA that hinders reaching an agreement considered unbalanced and trapping Tunisia in low value-added activities, according to Rudloff and Werenfels (2018) and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ, 2019). The authors note a lack of knowledge about the agreement itself and its content both in civil society and business, as well as a lack of participation of Tunisian academics in public discussion to assess the possible impacts of the DCFTA. "*Tunisia is not ready for the DCFTA*" is the title of a joint position document signed in May 2018 by a group of NGOs[5] and again "*DCFTA risks reducing Tunisia's political leeway to face its social and economic challenges*" (FTDES *et al*., 2018), suggesting taking time to reflect and evaluate, while recommending several possible adjustments to the negotiation process. Yemmen & Marzouki (2024) also highlight how the DCFTA has raised concerns in Tunisia with some groups feared about the European product competition coming from the liberalization, as well as about the impact on some economic sectors, jobs and state sovereignty.

4. Methodology

Since the agreement is still under negotiation, this study aims at delving deeper into sustainability effects of EU-Tunisia trade relations, understanding if and how the new DCFTA is expected to be coherent with the registered effects of the current agreement, and how stakeholders evaluate its impacts specifically on non-related products in the olive oil sector. The methodology of research is focused on a two-step qualitative analysis.

The first step consists of a desk analysis comparing two main documents: the TSIA produced in 2013 by Ecorys – focused on assessing the potential economic, social and environmental impact of the future DCFTA – and the Ex-post Evaluation of the impact of the current agreement published by the EC in 2021 – focused on assessing trade chapters' main objectives' achievement. The comparison among the main results is the baseline on which this study builds its conclusions on specific policy interventions to be implemented in the DCFTA negotiation framework and key aspects that should be considered within the future agreement.

According to the OECD (2010), the Sustainability Impact Assessment (SIA) is a process for assessing the effects of proposed policies, strategies, plans, or programs before they have been formulated (ex-ante). Considered by the EU as a strong method to evaluate trade negotiations (European Union, 2016), SIA methodology is based on the full integration of the three sustainability aspects, the use of a variety of tools and methodologies to capture qualitative features, and stakeholders' involvement. The TSIA produced in 2013 was based on two methodological elements: quantitative and qualitative analyses for economic, environmental, and social assessments and stakeholder consultations. To assess the impact of the DCFTA, a Computable General Equilibrium (CGE) model was developed based on a tariffs' reduction simulation scenario effects for the agricultural sector (an 80% reduction in tariffs in Tunisia on imports from the EU and a 95% reduction on agricultural tariffs in the EU on imports from Tunisia) as tariffs on industrial goods were previously eliminated under the AA. Moreover, the expected impact of the DCFTA assumes regulatory approximation in sectors such as SPS and

[5] Forum Tunisien pour les droits économiques et sociaux (FTDES) – CNCD-11.11.11 – International Treatment Preparedness Coalition (ITPC) MENA – Euromedrights – Transnational Institute (TNI).

Table 3 - Tunisian stakeholders interviewed in the framework of the Trade4SD project.

Stakeholder typology	*Category*	*N.*
Agricultural holdings	Small-scale farmer	1
	Smallholder producers (Agricultural advisor at the Olive Institute)	1
	Large olive oil producer (Director)	1
Supply chain operators	Public company (ONH) (Chief Executive and Director)	2
	Private retailer (Commercial)	1
	Packtech (CEO)	1
	Olive oil exporter (Business)	1
	Exporters' union (CEPEX)	1
Stakeholders dealing with sustainability issues	International organization (FAO Tunisia)	1
	Irrigation systems expert (Agriculture expert at the Ministry of Agriculture)	1
	Academic researcher (Agronomist)	1
Policymakers	Representative of the Minister's office (Chief of Staff at the Ministry of Agriculture)	1
	Development and production departments (Director General of the Development Department at the Ministry of Agriculture, Director of the Plant Production Department at the Ministry of Agriculture)	2
	Organic production department (Director of the Organic Production Dept at the Ministry of Agriculture)	1
	Total	16

Source: Authors' elaboration.

TBT. The results of the CGE model were complemented by additional quantitative and qualitative social and environmental analyses.

The study conducted in 2021 by the Center for Social and Economic Research (CASE), Ecorys, and the Euro-Mediterranean Forum of Institutes of Economic Sciences (FEMISE) covers the ex-post impact evaluation of the trade chapters of the Euro-Mediterranean Association Agreements (Euro-Med FTAs) with six partners, Tunisia included, to deeply investigate trade performances between those countries and the EU, observing specifically economic, social, and environmental aspects. Various methods have been used to conduct the analysis, from literature review to descriptive statistics, economic modelling and case studies on specific sectors, together with stakeholders' consultations. The second step of the research is based on an evaluation of inputs coming from a group of olive oil sector stakeholders interviewed in 2023 as part of the Trade4SD project activities and the consultations' results collected in the EC document of 2021. To maintain the homogeneity of results, the authors only focus on agricultural stakeholders' inputs coming from the ex-post evaluation as well. Tunisian agricultural stakeholders interviewed by the Trade4SD team have been identified in collaboration with the Tunisian Olive Oil Board (ONH). In-person meetings have been organized with 16 stakeholders (Table 3) during the first months of 2023 (Jan-Feb). Within the interviewed group, the research team has reached the so-called thematic saturation (Hennink *et al*., 2017), a concept developed by Glaser and Strauss (1967) as theoretical saturation (Hennink & Kaiser, 2022), used in qualitative research as an indicator establishing that a sam-

ple is adequate for the studied phenomenon and that data collected have captured the diversity, depth, and nuances of the topics studied, demonstrating content validity (Francis *et al*., 2010). The objective of the survey conducted in Tunisia within Trade4SD was, indeed, to analyse views of stakeholders mainly involved in export activities and the relationship with the EU.

Table 3 provides a detailed list of the stakeholders interviewed, classified by typology, category, and number. Participants were asked about different topics, including olive value chain challenges and organic olive oil evolution, the current agreement and the next DCFTA discussions, trade relations, and sustainability. Because of this study's aim, only inputs related to the last two topics have been considered for comparison with stakeholders' outcomes coming from the ex-post evaluation.

5. Main results from evaluations and stakeholders' views comparisons

This section outlines the main outcomes coming from the compared analysis of the two assessments (Table 4) and the stakeholders' consultations' comparison (Table 5).

Table 4 presents three macro categories, each one collecting the main key findings coming from the FTA ex-post evaluation and the ex-an-

Table 4 - Comparison of main results of DCFTA ex-ante effects and FTA ex-post impacts for Tunisia, divided by sustainability's macro-category.

Macro category	*Specificities*	*2013*	*2021*
Economic Impact	Increase in national income (GDP, Total Welfare)	x	x
	Increase in vegetable oil exports	x	x
	Improvement in citizens' purchasing power	x	x
	Transition from a traditional agriculture-oriented structure to a modern industrialized economy	x	x
	Growth in export diversification		x
	Increase in live animals import from EU		x
	Increase in agricultural products tariffs		x
Environmental Impact	Increase in air pollution in the long run (emissions pollutants)	x	
	Small impact on GHG emissions		x
	Difficulties in assessing waste and water issues (with both positive and negative effects depending on sectors)	x	x
	Increase in land use	x	
	Decrease in land use		x
	Worsening of animal welfare		x
Social Impact	Increase in welfare	x	x
	Negative turn in female employment and gender gap (agricultural sector included)	x	x
	Positive but modest impacts on income and consumer prices	x	x
	Increase in workers purchasing power	x	x
	Decrease in wage distribution	x	x
	Marginal increase in skilled wages compared to low skilled ones	x	x
	No significant impact on social security and social dialogue	x	x
	Reallocation of jobs among sectors	x	x
	Stable employment trends		x
	Increase in access to food		x
	Decline in general poverty	x	
	Increase in employment and labor standards	x	

Source: Authors' elaboration.

te DCFTA expected impact evaluation. The sign "x" in the last two columns of the table indicates if the topic found is covered in both assessments or in one of them only.

Concerning the first macro category, even if some essential aspects have been investigated, both as current effects of the FTA and expected impacts of the future agreement, like the increase in national income in terms of GDP and welfare, the ex-post evaluation presents some inputs not identified in the ex-ante assessment of the new agreement. This suggests some improvements made in these years, for instance, in export diversification growth, but at the same time, some worsening like the increase in live animal imports from the EU and a rise in agricultural products tariffs experienced by Tunisia.

The latter aspect is of particular interest, since after the FTA implementation, Tunisia did not negotiate additional protocols on agricultural products exported to the EU, contrary to what other countries did, so charges imposed have increased from 3.8% in 1996 to 4.1% in 2018, making the African country the one with the highest remaining tariffs on agricultural products. This is crucial to be considered in new agreement negotiations, as the expected gain in national income coming from the future DCFTA is primarily based on the reduction of NTMs in commodities and the decrease in agricultural tariffs. At the same time, third countries importing goods from Southern Mediterranean Countries (SMCs) have lowered tariffs, representing a potential basis for exports reorientation.

Also, EU exports of live animals to SMCs have increased following FTA's implementation, with a +71% for Tunisia. This turns into a drawback in animal welfare, with poor transport and slaughtering conditions on site, the effects of which are also to be found at the environmental level.

The agricultural sector was expected to be the biggest winner of the new agreement, especially with the vegetable oils sector, projected to gain the most significant effect in value added. Working in the same direction as these estimations, the current FTA effects show increased Tunisian vegetable oil exports, with additional benefits in processed food and fishery. Both exports and imports from the EU have expanded, with an exception during the years of crisis. They followed a huge increase in 2015 due to the exceptionality of the olive crop year and the subsequent turning of Tunisia into the major exporter of olive oil worldwide.

Overall, the country emerges as being the most stable in terms of exports compared to the other SMCs assessed, performing well in terms of primary agricultural products, processed agri-food goods and fishery, with a volatile growth registered in all categories and with the horticultural sector acting as the most promising.

In both assessments, the Tunisian economy appears to be transitioning from a traditional agriculture-oriented structure to a modern industrialized paradigm. This paradigm should include an increase in the production and export of processed agricultural goods, which were not yet registered in the analysed period and should, therefore, be of key importance in the current negotiations.

Both the current and future agreements seem to register positive and negative environmental effects simultaneously. First, the long-run forecasted increase in air pollution due to the possible implementation of the DCFTA. Even though the FTA ex-post evaluation confirms this progress, population growth and economic-energy development are identified as the main drivers of it, whereas the contribution of the FTA in this sense is considered slight. In fact, its role is tough to be calculated, also because both reductions and increases of pollutants depend on the type and entity of sectors which have been impacted the most by the agreement in these years.

The new DCFTA is also expected to cause an increase in land use intensity, whereas the current effects on land and biodiversity pressures seem register a decrease due to the contraction faced by most of primary sectors, an analogous situation to what happens also in Morocco and Egypt.

The general economic activity improvement in Tunisia could imply more household waste production. As it happens for the emissions calculations, the net effect of the future DCFTA on waste production is challenging to estimate, considering the several driving forces at play.

The same happens when assessing the effects of the current agreement on waste and water scarcity, about which stakeholders also have mixed

opinions. Indeed, what emerges is a commonly positive idea of the current agreement's effects on the environment, despite some negative impacts, mainly due to the increase in production and development of some sectors. Nonetheless, the interactions with the EU spark a series of technological and policy improvements that could positively change the local picture.

Deepening the social dimension, on average, the effects of the current agreement seem to have matched the expected positive and negative impacts of the future DCFTA. Findings make clear the bond that social aspects have with economic ones, bringing out issues that can easily be addressed to the economic dimension as well.

Despite an increase in welfare of about 1.5% (corresponding to 600 million EUR or more than 679 million USD[6]), a reported decline of around 0.3% of consumer prices, and an increase in workers' purchasing power, female employment and the gender gap seem to have worsened after the Arab Spring years, also in the agricultural sector.

Although remarkably similar, high-skilled wages in the country seem to have increased marginally more compared to low-skilled ones, which has implied a worsening in wage distribution.

The effect of the current agreement on employment and labour conditions is expected to be small. In fact, total employment remained constant over the period analysed, even though job reallocations occurred among sectors. This was also forecasted in case of a DCFTA implementation, with expected reallocation of workers between sectors and related difficulties for vulnerable groups. The issue of cross-sectoral reallocation is a key point to be monitored and addressed.

The current and future agreements do not seem to have specific effects on social dialogue and social protection. Concerning poverty, instead, while a general reduction through the increase in income levels is expected after the DCFTA implementation, no evidence regarding the link with the agreement in place is registered to date. Regarding human rights, the overall effect of the DCFTA in Tunisia is expected to be small, but positive.

Agricultural and olive oil sector stakeholders' views have been gathered to complement the theoretical considerations with direct opinions, allowing the identification of issues and priorities to be addressed and giving more clarity to the study. Table 5 summarizes the main stakeholders' outcomes in terms of bilateral trade relationships and perceived impacts of the current FTA and the future DCFTA. It is worth noting that the stakeholders directly interviewed in 2023 represent actors closely involved with economic and political activities related to the ongoing negotiations on the new agreement not yet in force, thus not including other actors in the olive oil supply chain – such as the labour force – who will encounter specific impacts once the agreement will enter into force. As done in Table 4, the sign "x" in the last two columns of the table indicates if that opinion is found both in Trade4SD interviews and in the FTA ex-post assessments, or only in one of them.

Concerning the EU-Tunisia trade relationships, Trade4SD interviews find correspondence with almost all the issues raised by stakeholders from the FTA ex-post evaluation.

Major impediments to European market access for Tunisian olive oil refer to quota governance and distribution of import licenses among European importers (notably Italian and Spanish), identifying the EU as the partner applying the most constraining NTMs. What additionally emerges from Trade4SD interviews is that export volumes vary according to climatic fluctuations in both Europe and Tunisia, as well as several other factors that conditionate the olive oil sector's development. Examples are the fluctuations in prices and quantities demanded on the Italian and Spanish markets, since Tunisian oil has long been regarded as a mean to adjust quantities produced in Europe. To expand market horizons also for bottled olive oil, some young Tunisian entrepreneurs are developing new markets which demand high quality, and which are positioned on the high-end.

Agricultural stakeholders generally agree on the EU's importance as a major and strategic part-

[6] Exchange rate as at 31/12/2021 corresponding to the publication year of the document.

Table 5 - Tunisian agricultural stakeholders' engagement results coming from the analysis of the ex-post evaluation of 2021 and the interviews conducted in TRADE4SD project framework in 2023.

Main stakeholders' results collected through desk analysis and interviews	*2021*	*2023*
Quota governance and distribution of import licenses are considered major impediments to EU market access for Tunisian olive oil.	x	x
Export volumes vary according to climatic fluctuations in Europe and Tunisia.		x
The olive oil sector is conditioned by several factors, including fluctuations in prices and quantities demanded from the EU side.		x
Young entrepreneurs are developing new markets for bottled oil.		x
The EU market is considered a major and strategic one, representing a potential element for ecological transition.	x	x
Tunisian oil is not fully recognized by consumers because it is not mentioned on the labels of the sold olive oil bottles.		x
Environmental concerns on water scarcity and desertification, with the request of adopting new water-efficient irrigation methods.		x
Need to improve agronomic strategies encouraging the adoption of crop adaptability techniques.		x
Production intensification is seen as the main liberalization risk, for resources use and small producers' marginalization.		x
Skepticism among farmers about DCFTA and feeling that the agricultural sector has not fully benefitted from the FTA.	x	x
Stakeholders are unsure about environmental impact of the increased agricultural production.		x
DCFTA should contain measures supporting a sustainable transition and climate change adaptation techniques.	x	x
Need to enlarge the export market, which may represent an opportunity for modernizing production techniques.		x
Need an expansion of quota and/or the introduction of a specific quota for organic olive oil; the EU market demand can be a driver for investment in this sense.	x	x
Policymakers pointed out that often EU control, permission, certifications, importation licenses and administrative procedures are heavy and time-consuming obstacles to EU market access.	x	x
Awareness about the DCFTA's potential for sustainability investments and minimization of environmental impact which reflects the views on the current FTA contributions on the same topic.	x	x
Competitiveness based on compliance with voluntary sustainability standards and regulations; the most problematic NTMs in place for agricultural sector are Sanitary and Phytosanitary (SPS) standards.	x	x
Valorization of sustainability efforts, in particular certified organic production systems, is needed together with national efforts in supporting organic and quality labels.	x	x

Source: Authors' elaboration.

ner for Tunisia, and this relation could represent a potential vector for a needed ecological transition. Despite the exported volumes, the lack of a fully recognition among European stakeholders of Tunisian oil due to the missing information on oil origin in labels remain an issue.

Environmental concerns deriving from a possible DCFTA implementation emerge particularly with water scarcity and desertification, according to the interviewed stakeholders, who advocate for new water-efficient irrigation methods and the improvement of agronomic strategies to offset the loss of productivity and possible changes in fruit and oil quality, at the same time encouraging the adoption of techniques able to enhance crop adaptability. Starting from the fact that some stakeholders believe that the agricultural sector has not fully benefitted from the current FTA because of the strict standards imposed by the EU, not perfectly fitting within the local agricultural context,

production intensification coming from a DCFTA implementation is seen as negatively affecting natural resources use and small-holders farmers' market position. The skepticism of farmers about the effects of DCFTA is accompanied by the idea that supportive measures will be needed once the agreement is adopted.

Other measures needed from stakeholders' point of view relate to climate change adaptation techniques for the olive oil value chain. According to the ex-post assessment opinions, Tunisian farmers lack the resources to invest in developed equipment that would allow increased productivity and fair competition with European counterparts. The expansion of the export market seems to also be an opportunity for the modernization of production techniques.

Other inputs have been collected in the interview in relation to the need for an expansion of the quota and/or the introduction of a specific quota for organic olive oil. This aspect also emerged from the ex-post evaluation consultations, where a stakeholder observed the investment in organic olive oil because of the European market demand.

Policymakers pointed out that all the procedures including controls, permissions, certifications, licenses and other administrative procedures are reported as heavy obstacles to market access. In fact, health and safety certifications enabling exports to the EU are conceived as time and money consuming for local businesses. The most problematic NTMs remain the Sanitary and Phytosanitary standards for the agricultural sector.

Some regrets emerge from companies about the commercial relations with European importers, which do not allow to value sustainability efforts in production, particularly for organic production systems. This aspect is reflected in the ex-post evaluation consultations, which underline that quality and organicity of Tunisian olive oil needs to be better supported at state level in terms of policies and labels.

There is also awareness about the significant opportunity for sustainability enhancements and investments to improve production and minimize environmental impact that DCFTA could offer, for instance reducing the impact of waste and finding reuse solutions or optimizing the use of irrigation water. This feeling is also stressed by independent experts on the current FTA effects who assumed that its environmental impact has been mostly positive, because of the improved local management systems and modifications in operational strategies.

Concerning waste, mixed views are collected: some stating an increase due to more activity and transport, others identify some reductions due to environmental and efficiency performance.

6. Discussion

Tunisian-EU liberalization of agricultural trade presents issues which are not limited to the inadequate upgrading of the sector in general but lie above all in the almost total asymmetry (natural and structural) between the two competing agricultural economies. Although some significant steps forward have been made thanks to the current FTA, the proposed DCFTA could offer greater opportunities for integrating sustainable development considerations thanks to its broad regulatory scope of many economic sectors, agriculture included. In this process, the participation of all stakeholders, civil society included, is pivotal to ensure a comprehensive inclusion of not only economic but also social and environmental needs to be addressed.

For the olive oil sector, as suggested both by literature and stakeholders, the major risk of liberalization lies in the needs to intensify specific production processes, leading to two main issues: a strong and growing pressure on already compromised natural resources, like water, and the marginalization of small farmers and producers, who already face problems due to the competition from major exporting companies and lack of proper technical and financial means.

Based on the desk study and stakeholders' consultation analysis, some policy interventions or sector strategies covering all three sustainability dimensions are needed in the Tunisian olive oil sector. These should be considered in the framework of the ongoing negotiations for the establishment of the new DCFTA.

Looking at the economic dimension, it is evident that the current tariff quota system, together with the preference on other channels, especially

IPT, is affecting the potential of the olive oil sector, hindering production exports and value-added benefits. Even though the EU remains the main destination for olive oil exports, as resulted both from literature and interviews, one of the major challenges arises with the predominantly purchase of Tunisian olive oil in bulk and then blended with European oils. This severely limits Tunisia's ability to add value and creates consumers' ignorance about the origin of the olive oil they use, mixed with the European originating one.

Moreover, as Grumiller *et al*. (2018a) pointed out, a part of the bottles used for packaging are imported for quality maintenance reasons, burdening producers' costs. This is also underlined in Trade4SD interviews, where young producers who are trying to upgrade production and increase the share of branded products face difficulties and advocate for support. The elimination of quota could then enhance an increase of both bulk exports and bottled oil exports to the EU, ensuring an increase in value-added also from this market and not only from exports to third or emerging countries importing Tunisian oil. Furthermore, the increase in domestic consumption of olive oil should be an aspect not to be ignored.

As stressed by Ouertani and Dhraief (2022), the domestic use of olive oil in Tunisia is much lower than the average in the other major producing countries like Italy or Greece, and this is due to the historical attitude of Tunisia to focus on olive oil promotion primarily on foreign markets. At the same time other vegetable oils are imported and locally refined, packed and then sold on the market at a lower price compared to the olive one, which remains purchased mainly in bulk based on family reserves or directly from olive mills. Promoting domestic sell of bottled oil could serve as a lever for building a solid domestic formal olive oil trade, boosting quality assurance, meeting local consumers' needs in terms of taste and food safety, increasing citizens fair access to high-quality olive oil and local distribution companies added value, thus reducing the reliance on imported vegetable oils.

It is worth remembering that, as underlined by Fernández-Lobato *et al*. (2022) Tunisian olive plants are cultivated with reduced inputs use, without irrigation, and with only small quantity of fertilizers, most of which are organic and used in extensive cultivation. Thus, as also stressed by stakeholders, the organic quality of Tunisian agricultural products is high and should receive a more robust support at State level as well as in the envisaged DCFTA, focusing on ensuring compliance with required standards throughout the entire value chain.

For these reasons, three main economic policy recommendations have been developed:

1. Deep reform of the tariff quota system for olive oil exports to the EU, with special attention to Tunisian organic oil, for increasing the overall volume of exports and enhancing the proportion of higher-value and processed export products.
2. Promotion of national marketing and branding strategies for bottled oil exports and domestic selling as a lever for building a solid formal olive oil trade, boosting quality assurance, meeting local consumers' needs in terms of taste and food safety, increasing citizens fair access to high-quality olive oil and local distribution companies added value, thus reducing the reliance on imported vegetable oils.
3. Strengthened efforts in promoting the organicity and quality of Tunisian agricultural products through certification schemes, to drive olive oil exports and meeting the rising demand and attention among European consumers for organic products.

From an environmental perspective, as stressed in the previous sections, the impacts of climate change in Tunisia mainly concern arable lands and water resources, with a rising incidence of drought.

Water scarcity, in particular, is a critical issue that threatens the long-term sustainability of agriculture in Tunisia. The country's water resources are being depleted at an alarming rate, with the country already classified as experiencing absolute water scarcity and groundwater levels continuing to decline due to over-extraction (Chebil *et al*., 2019). These challenges affect farming activities in terms of profitability.

Several strategies and actions have been implemented in the country to deal with water

scarcity, such as precise and alternative irrigation techniques (DGPA, 2020; UNDP, 2022), sustainable high-density planting methods (Larbi *et al*., 2017), wastewater treatment systems (MA, 2018; FAO, 2015), as well as farmers' participation in water resource governance (Bied-Charreton *et al*., 2006; Ballet *et al*., 2009). The National Water Program (MA, 2022), which encompasses desalination plants powered by solar energy, dam construction, water reservoirs, and urban water collection, is a step in this direction. However, additional efforts are needed to promote water-efficient cultivation systems and ensure the inclusion of all farmers in the value chains (Chebil *et al*., 2019), as emphasized by stakeholder consultations and interview results. Addressing these aspects within the framework of the new DCFTA would contribute to overcoming farmers' scepticism about its effects at the farm and local market levels.

In this regard, three environmental policy actions have been elaborated:

1. Global transformation of the Tunisian agricultural and food trade model should be encouraged, leveraging both larger and smallholder farmers through specific public policies in support of locally sustainable agricultural development.
2. Focused interventions on water-efficient cultivation systems dedicated to farms of all sizes.
3. Nationally supported measures enabling olive oil value chain stakeholders to manage the sustainable transition required for the sector with the appropriate financial, technical, and marketing-related resources.

The social dimension is deeply intertwined with both the economic and environmental challenges faced by Tunisia's agricultural sector, particularly the olive oil supply chain. The transformation of this sector has occurred within a sociopolitical context marked by instability and ongoing processes of democratic consolidation (Grumiller *et al*., 2018a). As Tunisia continues its path toward democracy, it is crucial to recognize the vulnerabilities of rural communities, which often bear the brunt of these economic and environmental shifts. As highlighted in the interviews, small producers struggle with limited resources and market access, leaving them ill-equipped to manage the ecological transition necessary for sustainable farming practices. Stakeholders emphasized that any reform must promote not only economic growth but also territorial and social cohesion, with specific attention to rural areas and small producers who lack the means for managing a sustainable food system transition. This requires policies that bridge the rural-urban divide, ensuring that rural areas benefit from improved infrastructure, education and market access (Grumiller *et al*., 2018a). Furthermore, empowering smallholders through capacity-building initiatives, access to financial resources and technical training would enable them to engage fully in ecological and technological advancements to cope with the effects of climate change (Ballet *et al*., 2009).

Thus, three social policy recommendations have been drafted:

1. Promotion of a national stable economic growth, based on territorial and social unity.
2. Counteract of spatial inequalities in terms of production and food security, with a bottom-up approach, inclusive of all farmers and producers' needs, avoiding risks of marginalization.
3. Olive oil sector's transformation into an inclusive segment, driven both by exports and domestic production, with an equitable benefits' sharing.

7. Conclusions

The topic of sustainability in trade relationships is dominating the international debate for fairer links among areas and countries. A broader renewed multilateral approach is advocated, since environmental and social aspects of sustainability cannot be solved on a unilateral or bilateral basis. Indeed, only through the diffusion of fairer and more inclusive commercial rules, attentive to the diversity of local agri-food systems, domestic economies and social systems, we could avoid the upheaval of the socio-economic and environmental unbalances with which many territories coexist today (Ferroni, 2024; World Economic Forum, 2021; Gallagher

and Kozul-Wright, 2019). Stakeholders perceive them as being further undermined by uneven international trade relations, which remain in place to maintain economic and political interests, often at the expense of the local dimension of production.

From the analysis conducted in this study, several challenges can be easily traced back to all three areas of sustainability. Economic, environmental and social issues of the Tunisian agri-food system and, in particular, of the agricultural sector, must necessarily be taken into consideration so that a future bilateral trade agreement defined as "deep and comprehensive" can lead to tangible benefits for both the parties involved. The current DCFTA negotiations should be then seen as the great opportunity to promote the EU's commitment in establishing trade relations based on multilateral needs and interests, to enhance the European market access for Tunisian olive oil and to comprehensively upgrade the local olive oil sector.

In this context, the EU's role could be pivotal in areas where cooperation can provide the greatest benefits to the local olive oil industry. By meeting the needs raised by the value chain stakeholders, the EU could contribute to decreasing the disparities that generate the current asymmetry of the two sector economies.

Sustainable and affordable agricultural practices working on the efficient use of water, the reuse of wastes and appropriate cultivation methods could be promoted also by conducting field studies and context research envisaging the direct collaboration of smallholder farmers and local value chain stakeholders. This would serve as leverage both for farmers, who would be active participants in the process of changing their sector and local economy, and for local government, which would have additional information at its disposal to enable the shaping of need-based sectoral policies. These terms also include all the efforts in terms of economic and technical support needed by farmers to cope with the ecological transition required to face the ongoing climate issues that are challenging the Mediterranean and North African regions.

The transformation of the local olive oil sector into an inclusive and structured one could be also supported by fostering the coordination of farmers into groups or cooperatives. Farmer-based organizations could serve as opportunities for fostering interests at both local and national political levels, bringing to attention the challenges of the sector and especially the great opportunities that high-quality local production can seize. Establishing connections among various stakeholders in the value chain could bring positive impacts not only on productivity and quality standards of olive oil, but also in terms of brand promotion and strengthening of the identity of Tunisian oil. Because of its importance to the national economy, boosting the sector would generate spillover effects on the country's overall economy, taking Tunisia a step closer to the SDGs alignment and contributing to reaching a symmetrical participation in bilateral trade with the EU.

Considering a framework of sustainability indicators and studying the causality between trade agreements' effects and the three dimensions of sustainability, this study could open further developments and perspectives, which could include quantitative analyses of the impacts of EU-Tunisia trade agreements on the olive oil sector, but also a broader involvement of sector's stakeholders through interviews or questionnaires aimed at investigating the views of female and male workers, for instance, not included in the current analysis for the aforementioned reasons. By employing appropriate methodologies that combine quantitative and qualitative data analysis (such as text mining and sentiment analysis), the perceptions of local actors involved in the reference supply chain could be utilized to validate what has been quantitatively analysed.

References

Adriansen J., Gonzàlez-Garibay M., 2013. The illusion of choice: the European Union and the trade-labor linkage. *Journal of Contemporary European Research*, 9: 542-549.

Arfaoui M., Erraach Y., Boudiche S., 2022. The performance of the Tunisian olive oil exports within the new distribution of world demand. *New Medit*, 21(2): 17-30. https://doi.org/10.30682/nm2202b.

Ayeb H., 2018. *Sortir de l'ALECA et de l'ensemble du système alimentaire mondial : Pour une nouvelle*

politique agricole et alimentaire souveraine qui rompt définitivement avec la dépendance alimentaire et les marchés internationaux. https://osaemarsad.org/2018/12/31/sortir-de-l-aleca-pour-une-nouvelle-politique-agricole-et-alimentairesouveraine/.

Baccini L., 2019. The economics and politics of preferential trade agreements. *Annual Review of Political Science*, 22(1): 75-92.

Ballet J., Kouamékan J., Koffi M., Boniface K., 2009. Co-management of natural resources in developing countries: The importance of context. *Économie international*, 120: 53-76.

Battisti M., Jurado T., Perry M., 2014. Understanding small-firm reactions to free trade agreements: Qualitative evidence from New Zealand, *Journal of Small Business and Enterprise Development*, 21(2): 327-344. https://doi.org/10.1108/JSBED-10-2013-0151.

Ben Rouine C., 2018. *Bilan du soutien européen temporaire aux exportations d'huile d'olive tunisienne*, Tunisian Observatory of Economy, Briefing Paper n. 5, Tunis.

Ben Rouine C., Chandoul J., 2019. *ALECA et agriculture: Au-delà des barrières tarifaires*. Report on behalf of Rosa Luxemburg Stiftung and the Tunisian Union of Agriculture and Fisheries. Tunis: RLS North Africa.

Bied-Charreton M., Makkaoui R., Petit O., Requier-Desjardins M., 2006. La gouvernance des ressources en eau dans les pays en développement : enjeux nationaux et globaux. *Mondes en développement*, 34: 3-135.

Centre for the Promotion of Imports from developing countries (CBI), 2024. *Entering the European market for olive oil* (last accessed: 23/05/2024).

Challenge Fund for Youth Employment (2022). *Tunisia Scoping Report*. https://fundforyouthemployment.nl/wp-content/uploads/2022/02/Scoping-Report-Tunisia-2022-Challenge-Fund-for-Youth-Employment.pdf.

Chebil A., Frija A., Makhlouf M., Thabet C., Jebari S., 2019. Effects of water scarcity on the performances of the agricultural sector and adaptation strategies in Tunisia. In: Kulshreshta S.N. (ed.), *Agricultural Economics - Current Issues*. DOI: 10.5772/intechopen.83568.

CREA, 2019. *Annuario dell'agricoltura italiana 2017*, vol. LXXI. Roma: CREA - Consiglio per la Ricerca in Agricoltura e l'Analisi dell'Economia Agraria, Centro di ricerca Politiche e Bio-economia, pp. 191-192.

DG Trade, 2024. *Tunisia. EU trade relations with Tunisia. Facts, figures and latest developments*. https://policy.trade.ec.europa.eu/eu-trade-relationships-country-and-region/countries-and-regions/tunisia_en (last accessed: 23/05/2024).

DG Trade, 2024a. *EU-Tunisia Deep and Comprehensive Free Trade Area: Documents*. https://policy.trade.ec.europa.eu/eu-trade-relationships-country-and-region/countries-and-regions/tunisia/eu-tunisia-dcfta-documents_en.

DGPA, 2020. *Ministère de l'Agriculture et des Ressources Hydrauliques de la Tunisie - DGPA (Direction Générale de la Production Agricole) - Biobase, base de données documentaire en AB*. https://abiodoc.docressources.fr/index.php?lvl=publisher_see&id=2268.

Dür A., Elsig M., 2015. *Trade Cooperations: The Purpose, Design and Effects of Preferential Trade Agreements*. Cambridge: Cambridge University Press, pp. 1-22. https://doi.org/10.1017/CBO9781316018453.001.

ECORYS, 2013. *Trade Sustainability Impact Assessment in support of negotiations of a DCFTA between the EU and Tunisia – Final Report*. Rotterdam.

ECORYS, CASE, FEMISE, 2021. *Ex-post Evaluation of the impact of trade chapters of the Euro-Mediterranean Association Agreements with six partners: Country Report Tunisia*. Final Report.

European Commission, 1997. *Report from the Commission to the Council: Mediterranean concessions impact study*, Bruxelles.

European Commission, 2006. *Global Europe: competing in the World.* COM (2006) 567 final, 4 October.

European Commission, 2012. *Trade, growth and development: tailoring trade and investment policy*. COM (2015) 497, 14 October.

European Commission, 2015. *Trade for all. Towards a more responsible trade and investment policy*. COM (2015) 497/4, 14 October.

European Commission, 2021. *Ex-post evaluation of the impact of trade chapters of the Euro-Mediterranean Association Agreements with six partners – Country report Tunisia*. Directorate-General for Trade, Final report, Publications Office of the European Union. https://op.europa.eu/en/publication-detail/-/publication/13421b9f-cc51-11ed-a05c-01aa75ed71a1/language-en.

European Union, 2016. *Handbook for trade sustainability impact assessment*. 2nd ed., Luxembourg.

FAO, 2015. *Tunisie : Analyse de la filière oléicole*. FAO Investment Center, Rome. https://openknowledge.fao.org/server/api/core/bitstreams/f4cebefc-6282-4626-9b72-3951f8a710f3/content.

FAO, 2023. *Turning Tunisia's magnificent olives into*

liquid gold. https://www.fao.org/newsroom/stories/article-simple/Turning-Tunisia-s-magnificent-olives-into-liquid-gold/en.

Fernández-Lobato L., López-Sánchez Y., Baccar R., Fendri M., Vera D., 2022. Life cycle assessment of the most representative virgin olive oil production systems in Tunisia. *Sustainable Production and Consumption*, 32: 908-923.

Ferroni F., 2024. Il dialogo strategico sul futuro dei sistemi agroalimentari nell'Unione europea tra sostenibilità economica, ambientale e sociale. *AE 1/2024 – La giusta transizione per un settore agroalimentare sostenibile*: 59-68.

Francis J.J., Johnston M., Robertson C., Glidewell L., Entwistle V., Eccles M.P., Grimshaw J.M., 2010. What is an adequate sample size? Operationalising data saturation for theory-based interview studies. *Psychology and health*, 25(10): 1229-1245.

FTDES, CNCD-11.11.11, *ITCP Mena, Euromedrights, TNI, 2018. EU-Tunisia DCFTA*. 1 May 2018. https://ftdes.net/en/note-politique-aleca-tunisie/.

Gallagher K.P., Kozul-Wright R., 2019. *A New Multilateralism for Shared Prosperity: Geneva Principles for a Global Green New Deal*, UNCTAD/Boston University, April.

Gasiorek M., Mouley S., 2019. *Analyzing the impact of an EU-Tunisia DCFTA on Tunisian trade and production*, FEMISE Research Papers, Report FEM43-16.

Ghesquiere H., 2001. The Impact of European Union Association Agreements on Mediterranean Countries. In: Iqbal Z. (ed.), *Macroeconomic Issues and Policies in the Middle East and North Africa*. Washington: International Monetary Fund.

GIZ, 2019. *Liberalising agricultural trade between the EU and Tunisia. Analysis of trade relations and recommendations for the negotiation of a new trade agreement*. Sector project "Agricultural Trade, Agribusiness, Agricultural Finance", Policy Brief n. 5, GIZ, Bonn.

Glaser B., Strauss A., 1967. *The Discovery of Grounded Theory: Strategies for Qualitative Research*. Mill Valley, CA: Sociology Press.

Grumiller J., Grohs H., Raza W., Staritz C., Tröster B., 2018b. *Strategies for sustainable upgrading in global value chains: the Tunisian olive oil sector*, ÖFSE Research Report 26, Vienna.

Grumiller J., Raza W.G., Staritz C., Tröster B., Von Arnim R., Grohs H., 2018a. *The economic and social effects of the EU Free Trade Agreement (DCFTA) with Tunisia* (n. 9/2018). Research Report.

Harrison J., Barbu M., Campling L., Richardson B., Smith A., 2019. Governing Labour Standards, through Free Trade Agreements: Limits of the European Union's Trade and Sustainable Development Chapters. *Journal of Common Market Studies*, 57(2): 132.

Hennink M., Kaiser B.N., 2022. Sample sizes for saturation in qualitative research: A systematic review of empirical tests. *Social science & medicine*, 292: 114523. https://www3.weforum.org/docs/WEF_International_Trade_and_Economic_Justice_GFC_2021.pdf.

Hennink M.M., Kaiser B.N., Marconi V.C., 2017. Code saturation versus meaning saturation: how many interviews are enough? *Qualitative health research*, 27(4): 591-608.

ILO, 2024. *ILOSTAT Database, "Unemployment, Youth Total (% of Total Labor Force Ages 15–24) (Modeled ILO Estimate) – Tunisia"* (Last accessed: 16/05/2024) https://data.worldbank.org/indicator/SL.UEM.1524.NE.ZS?locations=TN.

International Olive Council (IOC), 2023. *IMPORT FIGURES OF OLIVE OIL: EXTRA-EU(27)*. https://www.internationaloliveoil.org/wp-content/uploads/2023/07/IOC-Import-figures-EU.html#fn1 last accessed 20/05/2024.

Jbili A., Enders K., 1996. The Association Agreement Between Tunisia and the European Union. *Finance & Development*, September, pp. 18-20.

Jouili M., 2023. *Olive Oil and Water: Moving towards sustainable agricultural trade between the EU and Tunisia*, Issue Brief n.1, Amsterdam.

Kurtoğlu S., Uzundumlu A.S., Gövez E., 2024. Olive Oil Production Forecasts for a Macro Perspective during 2024-2027. *Applied Fruit Science*: 1-12.

Larbi A., Msallem M., Sai M.B., 2017. *L'intensification des oliviers en Tunisie: les avantages, les problemes et les perspectives*, Olive Tree Institute (IO), Tunisia.

Lavie E., Ould Ahmed P., Cadène P., Chiab I., Kypreos V., 2023. Challenging global changes in a post-revolutionary context: the case of irrigated olive growing in central Tunisia. *Geographica Helvetica*, 78(3): 417-428.

Lejmi L., 2020. *L'accord de libre-échange complet et approfondi (ALECA) et la sécurisation del'espace euro-méditerranéen: le cas de la Tunisie*. HAL Open Science. dumas-03441003.

Lejmi M., 2021. *EU-Tunisia Deep and Complete Free Trade Agreement (DCFTA) Analysing Standards Harmonisation Challenges, and Opportunities*.

MA, 2018. Ministère de l'Agriculture, des Ressources Hydrauliques et de la Pêche, Bureau de la Planification et des Equilibres Hydrauliques. *Rapport National du Secteur de l'Eau*. http://www.onagri.nat.tn/uploads/Etudes/Revue_2020_final.pdf.

MA, 2022. Ministère de l'Agriculture, des Ressources Hydrauliques et de la Pêche, Bureau de la Planification et des Equilibres Hydrauliques. *Rapport National du Secteur de l'Eau*. Elaboration du Plan Directeur National de Réutilisation des Eaux Usées Traitées en Tunisie – WATER REUSE 2050: prospective de la filière à l'horizon 2050. https://onagrihome.files.wordpress.com/2022/07/2.-rapport-phase-2-prospectives.pdf.

ONAGRI, 2024. *La balance commerciale alimentaire à fin avril 2024*. http://www.onagri.nat.tn/uploads/balance/BCA-04-24-Fr.pdf.

Ouertani E., Dhraief M.Z., 2022. Factors Determining where to Buy Olive Oil on the Tunisian Local Market: The Importance of Quality Attributes Perception. *Agriculture and Food Sciences Research*, 9(1): 22-31.

Ouessar M., Sghaier A., Frija A., Sghaier M., Baig M.B., 2021. Impacts of Climate Change on Agriculture and Food Security in Tunisia: Challenges, Existing Policies, and Way Forward. In: Behnassi M., Barjees Baig M., El Haiba M., Reed M.R. (eds), *Emerging Challenges to Food Production and Security in Asia, Middle East, and Africa*. Cham: Springer, https://doi.org/10.1007/978-3-030-72987-5_3.

Poletti A., Sicurelli D., 2018. *The Political Economy of Normative Trade Power Europe*. Basingstoke: Palgrave Macmillan.

Radhouane P.L., 2018. Why don't adapt Tunisian agriculture to climate change? *International Journal of Science, Environment and Technology*, 7(5): 1542-1562.

Raza W.G., Tröster B., von Arnim R., Chandoul J., Ben Rouine C., 2022. *Regulatory approximation under ALECA: Assessing the economic and social effects on the Tunisian agricultural sector*. Research Report, n. 15/2022, Austrian Foundation for Development Research (ÖFSE), Vienna.

Rudloff B., 2017. *Die Saat geht nicht auf: EU-Handels-und-Agrarpolitik können strukturelle Fluchtursachen nicht beseitigen, sondern allenfalls abfedern*. SWP-Aktuell 5/2017. Berlin: Stiftung Wissenschaft und Politik, January 2017, 4.

Rudloff B., 2020. *A Stable Countryside for a Stable Country? The Effects of a DCFTA with the EU on Tunisian Agriculture*. SWP Research Paper 2, January, Berlin.

Rudloff B., Werenfels I., 2018. *EU-Tunisia DCFTA: Good Intentions Not Enough*. SWP Comment n. 49, November, Berlin.

Townsend B., 2021. Defending access to medicines in regional trade agreements: lessons from the Regional Comprehensive Economic Partnership – a qualitative study of policy actors' views. *Globalization and Health*, 17(78): https://doi.org/10.1186/s12992-021-00721-4.

Tröster B, Raza W., Grohs H., Grumiller J., Staritz C., von Arnim R., 2018. *The EU-Tunisia Deep and Comprehensive Free Trade Area (DCFTA): macroeconomic impacts and pro-developmental policy responses*. Policy Note, n. 28/2018, Austrian Foundation for Development Research (ÖFSE), Vienna.

UNDP, 2022. *UNDP popularizes Tunisian underground irrigation technology in the Aral Sea region*. https://www.undp.org/uzbekistan/press-releases/undp-popularizes-tunisian-underground-irrigation-technology-aral-sea-region.

U.S. Department of Agriculture, 2023. *Tunisia: Oilseeds and Products Annual*. https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Oilseeds%20and%20Products%20Annual_Tunis_Tunisia_TS2023-0002.pdf.

Verner D., Treguer D., Redwood J., Christensen J., McDonnell R., Elbert C., Konishi Y., 2018. *Climate variability, drought, and drought management in Tunisia's agricultural sector*. Washington, D.C.: World Bank.

World Bank Group, 2023. *Tunisia Country Climate and Development Report*. CCDR Series. Washington, D.C.: World Bank Group. http://hdl.handle.net/10986/40658.

World Bank Group, 2024. *Tunisia Economic Monitor - Renewed energy to the Economy: Spring 2024*. Washington, D.C.: World Bank Group. http://documents.worldbank.org/curated/en/099740005072417820/IDU1e54c94ee11c2e14f95189e1133746e880b3e.

World Economic Forum, 2021. *International Trade and Economic Justice: A Revised Approach*. Community Paper, September 2021.

Yemmen J., Marzouki M.M., 2024. The Challenges of Free Trade with the European Union for Tunisia. *Journal of International Cooperation and Development*, 7(1): 13. https://doi.org/10.36941/jicd-2024-0002.

Enhancing olive oil communication through blockchain agri-food traceability

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Abstract

A large part of society remains unaware of agri-food blockchain traceability's value as an additional certification for ensuring the authenticity, safety and quality of several food products through their life cycle processes. Consequently, communication can help consumers by informing them about blockchain advantages orienting their trust, acceptance and purchase intentions. Communication of blockchain traceability can also help the agri-food sectors to differentiate their food products in their supply chain and consumer markets by mitigating the existing information asymmetry. Identifying the blockchain attributes communicated by olive oil organizations' websites, this study aims to analyze specific profiles of these agri-food operators who adopt this technology. Through a fuzzy set Qualitative Comparative Analysis (fsQCA) we analyze the blockchain attributes in order to determine the business drivers that influence the extent to which food traceability communication is associated with the corresponding strategic and business profile of olive oil organizations. Being that olive oil is one of the most counterfeited Mediterranean foods in global trade with a recent boost in global demand, our findings can help orient the management of the olive oil sector towards setting up a business and communication strategy with adoption of blockchain traceability system, thus capitalizing the added value of its certification. Filling a lack of literature in olive oil blockchain communication, this study offers an extended framework of blockchain attributes that can be applied to other agri-food sectors, thus opening up a new line of research.

Keywords*: Blockchain, Traceability, Communication, Websites, Olive oil, FsQCA.*

1. Introduction

Olive oil is one of the most counterfeited foods in global trade (Alkhudary *et al*., 2022). Repeated cases of fraud regarding the origin of olive oil by misleading and false labeling claims (Gentile *et al*., 2020; Rifna *et al*., 2022), adulteration and misconduct, or incidents in compliance with safety and hygiene regulations have generated five global consequences: lack of consumer trust (Rainero and Modarelli, 2021), reduction in consumption (Meerza and Gustafson, 2019), transmission of diseases in the population with social costs (Di Girolamo *et al*., 2015), reputational damage and losses in the agri-food sector and supply chains (Yan *et al*., 2020). Even if there

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are multiple sources of information, consumers are often scared of food knowledge and wary of certified-labeled foods without understanding their concept (Borda *et al*., 2021). Moreover, consumers are unable to control the transparency of food-labeling information (Zhang, 2023).

From the offer side, olive oil organizations are facing the following global challenges (Informe Annual de Conjuntura del Sector Oleícola 2022, Caja Rural Jaén - España): super-intensive plantations that assure low prices altering the markets' competition; the environmental impact in terms of sustainability, extended to social and economic issues; asymmetrical information in the global trade supply chains; a more administrative complexity due the increasing data requirements imposed by several controls from multiples nationals and international public bodies and certification authorities; healthier lifestyle habits of consumers with an increasingly demand of organic food products; large request of more information and transparency about food origin, quality and safety from supply chain operators and society; misinformation on the Internet media that devalues the healthy olive oil value.

Therefore, in this context agri-food traceability has become one of the most strategic societal concerns and challenges worldwide, particularly for olive oil (Tseng *et al*., 2022) and the adoption of blockchain TS in the area of agri-food traceability can solve the previously indicated problems (European Commission, 2021; Castañeda and Fejo, 2023; Chiaraluce *et al*., 2024). This innovation allows consumers, farmers, supply chain operators and public authorities to connect directly in real time and to monitor food and information regarding its life cycle process in a public, transparent, and auditable digital register, eliminating the need for third-party certification and avoiding the risk of fraud, counterfeiting and negligent behavior (Tiscini *et al*., 2020).

However, most global consumers remain unaware of the concept of food Blockchain Traceability System (Blockchain TS hereinafter) and its digital tools for accessing traceability information (FMCG-GURUS, 2020). On the offer side, 58% of agri-food companies worldwide declare marketing and commercial objectives as their main priorities in the adoption of a blockchain Traceability System (TS) (Aparicio-Ruiz *et al*., 2022; Politecnico di Milano, 2023). Only two surveys of European olive oil producers and operators have revealed different results regarding the adoption of innovative TS and related objectives (Guido *et al*., 2020; Corallo *et al*., 2020). Effective communication is crucial to addressing global information asymmetry and promoting blockchain traceability in the olive oil sector (Muñiz-Gonzáles and Muñiz de la Torre, 2018). This helps to convey the blockchain's unique value to consumers, thereby improving their understanding, acceptance, and purchasing decisions (Cozzio *et al*., 2023).

In the context of blockchain communication, the website is an essential tool to consider. Websites play a crucial role in bridging the information gap between organizations and consumers, particularly in the context of emerging technologies (Chaffey and Ellis-Chadwick, 2019). By serving as centralized platforms for information, they enable organizations to control the narrative surrounding their technologies, ensuring that accurate and relevant information reaches potential users (Kumar and Reinartz, 2016; Shahid *et al*., 2020). This controlled environment is especially important for technologies that require consumer trust and understanding, such as artificial intelligence and blockchain (Zarbà *et al*., 2024). Focusing on communication through websites allows for a nuanced analysis of how organizations strategically position themselves in relation to these innovations, providing valuable insights into their marketing approaches and priorities (Kingsnorth, 2022). This multifaceted perspective underscores the importance of website analysis in understanding the dynamics of communication surrounding blockchain in the agri-food sector, offering essential insights for fostering adoption and trust in these technologies (Ferreira da Silva and Moro, 2021).

In this study we have focused the blockchain communication on websites of agri-food organizations to consumers due to the current lack of literature (WOS and Scopus, 2016-2024) and fragmented and scarce communication on different web channels (FB, YouTube, Instagram, TikTok and others) (Ancín *et al*., 2022). Sec-

ondly, most of the agri-food organizations market their products as traced through blockchain on the e-commerce webpage as on a traditional retail channel (Zen *et al*., 2017). In this dimension the website page can help the consumers to understand how to use blockchain tools (QR code, batch code, applications, etc.) and explain to them the value of blockchain traceability adoption, supporting the differentiation marketing strategy to promote and sell these foods whatever the sale channel is (Borsellino *et al*., 2018; Violino *et al*., 2019; Reitano *et al*., 2024). To address this gap, our study explores the following questions: Which profile variables and key business factors of olive oil organizations influence their website communication regarding blockchain traceability systems? To answer this, we first consolidated the communication attributes from the existing literature and then applied fuzzy set qualitative comparative analysis (fsQCA) to organizations identified as using this technology. Consequently, this study identifies the profiles of olive oil organizations to understand whether blockchain technology (TS) is adopted solely to reduce costs in the supply chain and agri-food processes, or whether it is also used to gain a competitive advantage in the consumer market with appropriate strategies (e.g. to trace by blockchain TS organic Extra Virgin Olive Oil (EVOO hereinafter) or premium – PDO – olive oils).

This research is particularly relevant in today's market, where transparency and traceability are essential to building consumer trust (Dionysis *et al*., 2022). By identifying the profile variables and key business factors that influence website communication, we provide insights that can help organizations tailor their messaging in order to better engage consumers. Additionally, this study offers a framework of blockchain TS attributes for evaluating the effectiveness of communication strategies, which is crucial for companies looking to differentiate themselves in a competitive agri-food landscape. Ultimately, our findings contribute to the broader discourse on how digital communication can enhance the adoption of innovative technologies in the sector.

The remainder of this paper is organized as follows. After the introduction, we present the contextual framework, detailing the propositions of the study. The material and methods section outlines the technical aspects of our research. Subsequently, we present the results and conclude the study with a discussion of the findings and their limitations.

2. Theoretical background

2.1. *Agri-food traceability concept and challenges*

The concept of agri-food traceability encompasses the ability to record and control five key historical dimensions: identifying the animal, agricultural, or food product and its corresponding owner; ensuring safety at each stage of the process to prevent contamination or disease risks for both the population and animals; guaranteeing product quality for stable business relations; and preventing adulteration, fraud, and theft (Martínez, 2022). Technically, the identification of a unit method known as the Traceable Resource Unit (TRU) (Moe, 1998) has been extensively discussed in the literature to elucidate the traceability concept, involving three factors: the object of measurement and a mechanism for identifying, documenting, and recording agricultural food attributes. In the olive oil sector, EU traceability regulations and much of the international legislation are grounded in policies and standards established by the International Olive Council (IOC).

Currently, agri-food traceability presents a significant global challenge, particularly in sectors such as olive oil, meat, fish, and wine, because these foods are the most unsafe and counterfeited in the global supply chains with a significant % of uncertainty and not declared origin (Yan *et al*., 2020). To prevent these concerns there are a wide range of agri-food certification authorities from public regulations (e.g., PDO - Protect Designation of Origin or PGI -Protect Geographical Indication of European Union, EC Reg. 510/2006), private bodies (e.g., ISO), and other international food council bodies (e.g., IOC for olive oils), and others. This poses various questions within global agri-food supply chains, including compatibility issues with standards and

legal requirements, data inconsistency, trustworthiness concerns, security vulnerabilities, diminished effectiveness, interoperability, scalability issues, and increased certification costs (Hassoun *et al*., 2020; KPMG, 2022).

Consequently, public authorities have difficulty controlling the food origin, safety, and quality traceability from different countries (von Ruth *et al*., 2018; Rocchi *et al*., 2020). On the other hand, the limitations placed on labelling by current regulations limit consumers' ability to verify the authenticity of food information provided by external intermediaries or central authorities using traditional third-party certification systems, reducing food risk perception (Montecchi *et al*., 2019). To maintain transparency information and trust through the value chain operators, consumers and central certification authorities the adoption of blockchain technology for agri-food traceability can resolve these issues by enabling tracking of the origin, its history in transformation and logistic processes, ensuring the quality of food product (Yele *et al*., 2024).

2.2. *Blockchain traceability system in the agri-food sector*

Blockchain responds to visionary research and human aspirations to communicate and conduct transactions without intermediaries and central authorities (Tang *et al*., 2019).

Technically, blockchain is a technology composed of both digital and physical components, serving as an open-source dataset or a digital, shared, distributed, and decentralized network of ledger systems (blocks) (Ben Ayed *et al*., 2022; Gligor *et al.*, 2022). It facilitates various transactions, including assets, money, intellectual property, contracts and data management (Clohessy and Acton, 2019). Developed to tackle historical algorithmic challenges in digital environments, blockchain operates within peer-to-peer web-based systems, enabling the real-time recording and verification of each transaction. This system maintains an immutable and reliable database without relying on central authority (Dujak and Sajter, 2019). Every participant in the network bears the responsibility of disseminating accurate information (Chen *et al*., 2018).

Because of the attributes of blockchain, including transparency, data integrity, and immutability, coupled with the absence of central controls or intermediaries, this technology was initially proposed for integration into the agri-food supply chain in 2016 (Demestichas *et al*., 2020; Tessitore *et al*., 2021; Politecnico di Milano, 2023). Blockchain technology applied to agri-food sector, by a new traceability certification system, can revolutionize and contribute to solving and contrasting the problems of fraud and adulteration, misconduct in the production and distribution processes, and recalls for damaged stocks that negatively influence the operators of the supply chain and customers´ trust and their relationship with the product (Sestino *et al*., 2022; Martínez-Castañeda and Fejioo, 2023; Chiaraluce *et al*., 2024). Consumers who buy food products with this traceability certification will know that they are not only consuming a product that complies with food safety and quality regulations, but that the farmers and mills are operating with good farming and production practices in line with the SDGs (Sgroi, 2022). Consequently, this innovation responds to society's considerable interest in obtaining more transparent traceability information, reducing the perception of food risk (Montecchi *et al*., 2019) and encouraging a new customer relationship (Rainero and Modarelli, 2021) in order to reassure consumers and protect them from possible counterfeits and fraud (Bandinelli *et al*., 2023).

One of the key topics associated with blockchain TS is its potential to promote sustainability (Friedman and Ormiston, 2022). In particular, the growing demand for organic products has highlighted the need for more transparent and reliable systems that ensure the authenticity of these products. In a globalized market, where organic products are sold on a large scale, consumers require assurances that what they are purchasing truly meets the environmental and health standards that define such products (Sahoo *et al*., 2024). In this context, blockchain technology emerges as a crucial tool for ensuring traceability and compliance with the standards established by organic certifications

On the other hand, blockchain TS provides a significant boost to Protected Designations of Origin (PDOs), which serve as a certification

mechanism ensuring that certain products originate from a specific geographic region and adhere to traditional production methods characteristic of that area (Scuderi *et al*., 2019; Vasileiou *et al*., 2024). This type of certification is commonly associated with food products and holds immense value for both producers and consumers, as it is closely linked to cultural identity and product quality. Blockchain offers an innovative solution to enhance consumer confidence by guaranteeing the authenticity and provenance of these products (Tran *et al*., 2024).

Furthermore, a considerable increase in food and agricultural products including traceability is expected in the coming years, as stated by all public and private international sources (FAO, OECD and others). In the supply chain, in the agri-food industry, blockchain traceability applications are providing new models for improvement and automation (Kramer *et al*., 2021). This allows easy and direct identification and generation of the certificate of origin of organic foodstuffs in international maritime transports and all stages of processing and distribution (Bettin-Díaz *et al*., 2018) In this line, some studies point out how traceability can increase the intrinsic value of the product (quality and profitability), establishing a new relationship of trust with the consumer (Lezoche *et al*., 2020; Boschi *et al*., 2021; Yadav *et al*., 2022). For these reasons blockchain TS redefines the trust paradigms into operators of agri-food supply chain and in consumer markets developing new business models (Galanakis *et al*., 2021).

Presently, eighty-five percent of the existing blockchain platforms are deployed for traceability solutions, with 40% dedicated to the agri-food sector (KPMG, 2022). According to the data of the WOS platform, approximately 2,673 studies on blockchain traceability systems applied to the agri-food sector have been published between 2015 and 2024. Computer technology and various supply chain applications have been the most researched topics, comprising 65% of all studies, owing to the versatility of blockchain traceability systems with different configurations (Köhler and Pizzol, 2020). This keen interest stems from researchers, companies, and organizations seeking novel alternatives and opportunities offered by blockchain TS across various agri-food sectors.

As the costs of management control, information systems, waste, and food recalls continue to increase, compliance with regulations and standards for traditional agri-food traceability has become increasingly complex throughout the supply chain (Bumblauskas *et al*., 2020). Consequently, agri-food and olive oil companies seek to minimize intermediary costs and certifications by transitioning to a new business model based on trust relationships (Zhang, 2023). Blockchain traceability systems have gained traction in the agri-food supply chain owing to their ability to provide full transparency in food products and processes, reduce information asymmetry (Sestino *et al*., 2022) and ensuring data privacy and safety for operators and consumers (Ghose, 2009), as well as facilitating regulatory oversight (Martínez-Castañeda and Fejioo, 2023).

2.3. *Blockchain traceability system in the olive oil sector*

As stated by WOS and Scopus data, there are only 20 publications on olive oil blockchain traceability, with a broader range of 231 studies in related areas. Most studies on the olive oil sector have focused on technical aspects (Marchesi *et al*., 2021; Bistarelli *et al*., 2022) and in the supply chain management (Caro *et al*., 2018; Guido *et al*., 2020; Fricka *et al*., 2023) with limited research exploring marketing dimensions (Bonetti *et al*., 2023; Treiblmaier and Petrozhitskaya, 2023).

In general terms, the blockchain traceability certification system applied to the olive oil sector allows the following advantages: 1) It disseminates good practices in the cultivation and extraction processes of EVOO by identifying technical quality standards, and consequently of the product (Stranieri *et al*., 2021); 2) It favors environmental sustainability and the circular economy, with good practices that respect and preserve the environment (Dal Mas *et al*., 2023); 3) It achieves cost savings throughout the value chain by reducing areas of risk and inefficiency (Caro *et al*., 2018); 4) It qualifies the differential value of indigenous EVOO, premium and organic pro-

duction, with fair and appropriate trade (Elfkih *et al*., 2021; Chiaraluce *et al*., 2024); 5) It favors the adhesion of distribution agents in the platform, who also benefit compared to large supermarkets (Antonucci *et al*., 2019; Shahid *et al*., 2020).

From a market perspective, blockchain TS can contribute to building loyalty among current consumers and conquers new consumer groups: 'Millennials', organic, online shoppers, and others (Bonetti *et al*., 2023). In this context, the blockchain has developed as a changeover value in the existing social, economic and governance models, (Zutshi *et al*., 2021) as well as in the sustainability area (Dal Mas *et al*., 2022), moving from the traditional controlled value-chain orientation to a network orientation based on participation, interaction and a trusting relationship with customers (Sahut *et al*., 2019).

Considering that olive groves are one of the most important plantations throughout the EU and in other emerging countries, the correct implementation of an adequate traceability system in the olive oil field that respects the environment contributes to soil sustainability and to counteracting greenhouse gases and optimizing the water regime (Tripoli *et al*., 2018; Ben Ayed *et al*., 2022). It is an aligned green forest that if properly cared for would lead to the conservation of biodiversity at soil and landscape scale. In addition, research has shown that olive groves act as a sink for CO2, one of the main greenhouse gases (Kamilaris *et al*., 2019; Lezoche *et al*., 2020).

3. Propositions

There is a lack of studies on the communication and marketing of blockchain traceability websites in the olive oil and agri-food sectors. The scarcity of studies in these areas also concerns olive oils and foods traced by traditional third-party certifications (Rossi, 2017; Mascio *et al*., 2024). These studies confirm the relevance of European PDOs and PGIs olive oil certification against frauds and safety concerns and a favorable consumers purchase orientation. However, there are some interesting points that can be applied to this emerging technology in olive oil website communication. Websites are among the most common online references for brands and image companies and are among one of the first contact channels for consumers and Internet users (Garaus *et al*., 2022). This medium allows a strong online position to be achieved by combining the informative, community, relational, and transactional functions associated with social media and e-commerce (Galati *et al*., 2016).

In the olive oil sector with traditional third-party certification, only a low percentage of online organizations exploited the opportunities offered by Web 2.0 (Fransi *et al*., 2020; Fernandez-Uclés *et al*., 2023). These website functions facilitate purchase orientation and the purchase process of olive oil consumers on e-commerce pages (Borsellino *et al*., 2018; Elfkih *et al*., 2021). Considering the consumer interaction, participation, involvement, and brand experience provided by blockchain TS, website communication functions can also develop Strategic Experiential Modules (SEM) for brand-land olive oil (Iaia *et al*., 2018).

However, the literature reveals a limited number of studies analyzing agri-food blockchain topics within the realm of business strategy and communication dimensions for agri-food organizations (Bonetti *et al*., 2023; Treiblmaier and Petrozhitskaya, 2023). Using a configurational approach (Fiss, 2011), we aim to identify the combinations of organizational characteristics related to blockchain traceability systems associated with increased information dissemination on an organization's website.

A quality website helps reinforce consumer trust (De Vries *et al*., 2022) and transfers the perceived value of a product to the market (Muñiz-Gonzales and Muñiz De La Torre, 2018; Landeta-Echeberría, 2021). According to Resources and Capabilities Theory (Barney and Mackey, 2005), intangible resources such as having a website with useful and abundant information can lead to a competitive advantage. A successful commercial strategy in the online channel is to be present on different platforms with a close relationship with the consumer; this is known as inbound marketing (Patrutiu-Baltes, 2016). Having a website reinforced by social networks, chats, blogs, or other types of platforms facilitates information and communication with consumers, and increases trust (Zeng

et al., 2017). Companies with a stronger focus on online channels tend to offer more information through these platforms, which enhances their relationships with consumers and fosters customer loyalty (Fernández-Uclés *et al*., 2023).

Similarly, agri-food companies operating online are expected to provide a significant amount of information, as digital platforms reduce transaction costs and consumers increasingly rely on this information to make informed purchasing decisions (Caiazza and Bigliardi, 2020). According to Kaplan and Haenlein (2010), as organizations expand their presence across diverse digital platforms, they create more opportunities to share not only product-related information but also details about emerging technologies. In this context, organizations with a stronger online presence are expected to offer more comprehensive communication about both their products and technological innovations, including advancements in blockchain. Based on this, the following proposition can be made:

Proposition 1. *Organizations with a more prominent presence across diverse online platforms are expected to provide greater communication about blockchain (TS).*

Although digital technologies have increased tools for improving their commercial position in the market, company size remains a relevant attribute associated with greater performance and impact in this medium (Kiang and Chi, 2001). There is a clear consensus that small companies benefit from operating in an online environment, but large organizations still have a greater capacity for investment, both human and technological, to strengthen their positioning on the internet (Wang, 2020; Fernández-Uclés *et al*., 2023). However, in the agri-food sector, small organizations are increasingly active in providing transparency and data, and larger companies have more possibilities and lower costs for managing the collection, processing, and communication of information (Bernal-Jurado *et al*., 2018). With this in mind, we make the following assertions:

Proposition 2. *Increased communication on blockchain TS is linked to the size of the company.*

Technological development positively influences the competitive, differential, advantageous, and structural aspects of the sector in which it operates. Consequently, the communication and marketing areas in the adoption of innovative technology are central to the market strategy of organizations, especially in a digitization context (Kotler *et al*., 2016), which produces strong digital interaction with consumers and society (Marlene, 2019). Consistent with Hobbs *et al*. (2005), consumers show a strong interest in food traceability when the perceived transferred added value is associated with this communication content (Rainero and Modarelli, 2021). Communication in blockchain technology can also contribute to solving information asymmetry with consumers through QR or batch codes on food packaging or olive oil labeling (Mohammed *et al*., 2023). This information is provided to consumers to improve their trust, perceptions of quality, and purchase intentions (Liu *et al*., 2022; Treiblmaier and Garaus, 2022). This makes it necessary to implement blockchain TS, because key strategic communications and information commitments on digital platforms are relevant (Huijbregts-Jaén, 2021). However, it is expected that, in this process of technological integration, as this innovation develops the communication and information provided by the company to the consumer will be strengthened. Thus, we propose the following hypothesis:

Proposition 3. *Further communication on blockchain TS is determined by the degree of technological development within a company.*

Consumers of organic products need more information to purchase this type of product, partly because of a lack of knowledge about its characteristics and compensation for its higher price (Marozzo *et al*., 2023). Vega-Zamora *et al*. (2016) demonstrates that consumers have more positive attitudes and purchase intentions toward organic olive oil in the presence of adequate communication. In the case of olive oil, with cheaper substitute products, its marketing benefits from online communication, which opens doors to international markets and provides a greater amount of information about the

company, products, and production (Carzedda *et al*., 2021). Thus, organizations offer organic products that present a greater amount of information on digital platforms (Fernández-Uclés *et al*., 2020). The above arguments lead us to propose the following hypothesis:

Proposition 4. *The increased communication about blockchain TS is explained by the offer of organic products to the company.*

As with the organic attribute, the Protected Designation of Origin (PDO) has been widely used in the agri-food sector as a differentiation strategy, adding value to certified products by highlighting their quality and authenticity (Lajara *et al*., 2022). This label influences consumer satisfaction, loyalty, and purchase intentions, underscoring the importance of effectively communicating these attributes through digital channels (Violino *et al*., 2019). Proper communication of information about PDO products strengthens companies' reputations and builds consumer trust, making digital communication a key tool for commercial success (Scuderi *et al*., 2019). In this context, particularly for products with a PDO, where there is an expectation for greater transparency and detailed information about product traceability (Fotopoulos and Krystallis, 2003), the communication regarding blockchain is expected to be more extensive.

Proposition 5. *Increased communication on blockchain is associated with the presence of products with a designation of origin.*

4. Material and methods

4.1. *Population*

We compiled a comprehensive list of international olive oil companies that have developed blockchain traceability technology, or are in the process of doing so, identifying a total of 38 companies. This figure aligns with data from prominent Blockchain Distributed Ledger Technology Working Groups, including those in Italy, which hold particular significance in the olive sector. Table 1 captures the information from these companies.

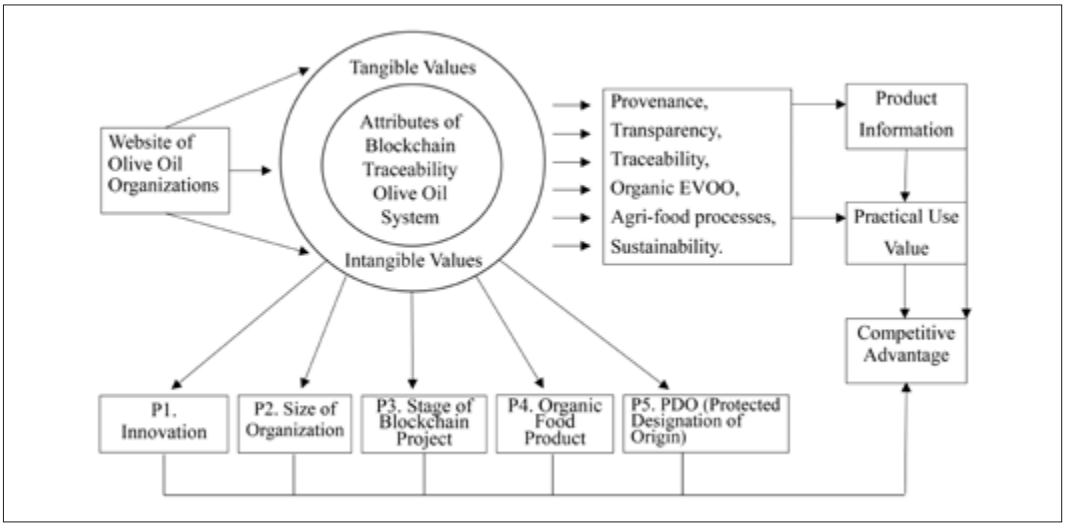
The data were gathered through an exhaustive review of the information available on leading Internet search engines, such as Google, reports from esteemed university centers, digital blockchain observatories (e.g., Politecnico di Milano, University of Federico II of Napoli, and Wageningen University), and scientific and popular articles in the specialized press dedicated to innovation and olive oil. Upon reviewing the liter-

Table 1 - Descriptive statistics of the olive oil organizations analyzed.

Profile of olive oil organizations	*Italy*	*Spain*	*E.U.*	*Non E.U.*
Country of origin	25	8	33	5
Other private certifications	19	7	26	4
Social media blockchain TS communication	24	9	33	5
Olive oils sold through e-commerce	2	1	3	2
Sustainability	10	3	13	2
Integration by other digital technologies 4.0.	7	2	9	2
Company profile: private	24	4	28	5
Company profile: cooperative	0	2	2	0
Company profile: consortium	1	2	3	0
Producer	20	6	26	2
Distributor	4	0	4	3
Consortium, European P.D.O. (Protected Designation of Origin) and G.I. (Geographical Indication) bodies	1	2	3	0

Source: own compilation.

Figure 1 - Blockchain traceability attributes framework.



Source: own compilation.

ature on the agri-food and olive oil sectors, we identified several attributes of blockchain TS I, along with their respective justifications (references and concepts). Figure 1 synthesizes information from the research study by referencing initial propositions.

4.2. *Method*

Qualitative comparative analysis (QCA), based on Boolean algebra, uses verbal, conceptual, and mathematical language to make it a simultaneously qualitative and quantitative approach, combining the main advantages of both (Ragin, 2014). Specifically, QCA allows a systematic analysis of a set of cases in order to determine causal patterns between a set of conditions and a given outcome in the form of necessity and sufficiency relationships (Schneider and Wagemann, 2010). Unlike conventional (symmetric) statistical approaches such as multiple regression and structural equation modeling, QCA has greater explanatory power and can be used on its own to provide rich insights into the relationships of interest (Gligor and Bozkurt, 2020). This is because QCA assumes that asymmetry, equifinality, and causal complexity may exist, mitigating some of the limitations of multiple regressions (Ragin, 2006).

QCA is a highly objective technique for deriving predictive conclusions, assuming the application of the complexity theory to scientific research (Kumar *et al*., 2022). QCA provides one or more antecedent combinations sufficient for the attainment of a particular outcome, such as X1*–X2*X3, which is sufficient for an outcome (Y). Using the symbology of this technique (X1*~X2*X3→Y) and X1, X2 and X3 are antecedents; Y, the result; * is the union, and ~ is the absence or negation, in this case the opposite value to X2 (1- X2).

The development of fuzzy sets (fsQCA) is one of the most widely used QCA variants, because it resolves one of the main drawbacks and criticisms of the initial csQCA approach, its strictly dichotomous approach (Sehring *et al*., 2013). It is a valid and reliable method that has the advantage of being developed for small samples or population settings, unlike other traditional quantitative methods (Pappas and Woodside, 2021), (Rihoux and Ragin, 2008).

4.3. *Outcome and conditions*

The outcome of this research represents the amount of information that organizations provide about the traceability of products linked to blockchain and traceability. Reviewing the liter-

Table 2 - Variables used in the fsQCA.

Outcome	*Description*	*Type of variable*
Blockchain TS communicated	Number of attributes reported in the digital environment linked to blockchain TS.	Continuous
Antecedents	Description	Type of variable
Innov	Digital platforms on which the company operates	Categorical*
Size	Company size according to EU Legislation	Categorical**
Stage of Project	Level of development of blockchain TS	Categorical***
Organic olive oil	The company markets organic products	Dichotomous****
PDO	The company offers products with designation of origin	Dichotomous****

Notes: Continuous variables were calibrated using fsQCA 4.1 software, according to the recommended thresholds. Although the literature recommends avoiding automatic calibration, it is most appropriate when there are no previous references to the variable (Pappas and Woodside, 2021).
** Categorical variable with four levels according to the number of digital platforms on which the company operates (website, blog, social media and mobile app).*
*** Categorical variable with four levels according to the size of the organization: micro, small, medium and large enterprises. Calibrated from Rihoux and Ragin, (2008).*
**** Categorical variable with three levels according to the status of development of the blockchain dlt technology (Companies that have announced the implementation of this technology, companies that are currently developing it and companies that have this traceability system already running).*
***** Dichotomous variables indicate the presence of the condition with a value of 1 and 0 its absence.*
Source: own compilation.

ature, we identified several blockchain attributes of olive oil on the different digital platforms of the companies analyzed. This outcome measures the amount of traceability information linked to traceability attributes and values according to the corresponding literature and to the laws of food safety, quality, and origin requirements valued by the consumer. The main value attributes cited in the literature are transparency and consumer trust (Reieb *et al*., 2020; Rana *et al*., 2021), safety, origin authentication, quality, sustainability and supply chain efficiency (Thompson and Rust, 2023).

Five conditions have been established that allow us to delimit the profile of an organization that performs more complete communication about attributes by integrating blockchain traceability into the olive sector. Table 2 lists all the variables considered in this study.

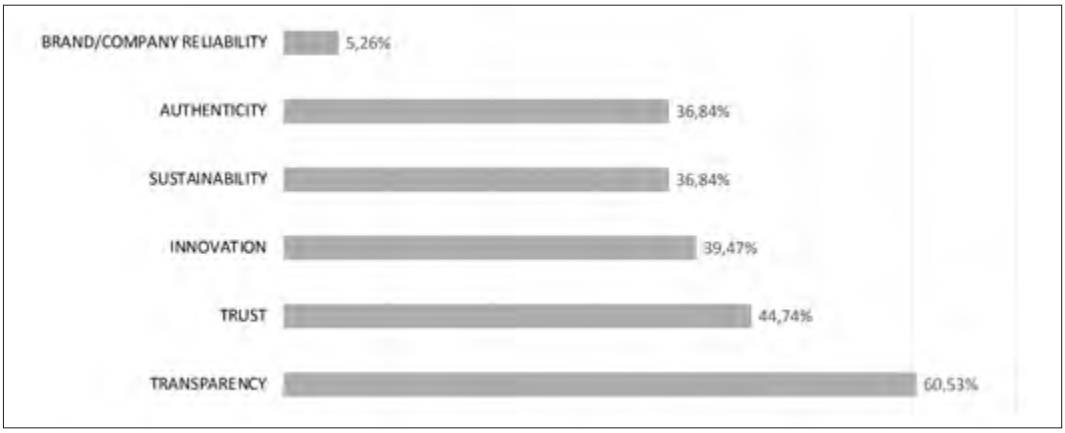
5. Results

In an initial approach to the study's results, the averages of the values and attributes communicated on the websites of the companies analyzed are presented (Figure 2). These attributes, serving as the foundation for the study's outcomes, indicate that the current total quantity of website communication, provided by 81.8% of olive organizations, falls short of encompassing even 50% of the blockchain TS attributes.

Regarding fsQCA, necessity tests were performed in which the necessary conditions were detected if they exceeded the consistency threshold of 0.9 (Pappas and Woodside, 2021). Simultaneously, we conducted the same analysis for non-occurrence of the detected phenomenon. It should be noted that the fsQCA technique is not symmetrical, and it is convenient to study which combinations (or configurations) of factors lead to a low level of reported information. An assessment of the triviality of conditions was also conducted using the Relevance of Necessity (RoN) indicator (Schneider and Wagemann, 2010). The literature advises checking for RoN values below 0.5, because they are the cause of concern. In none of the cases was the consistency equal to or above the recommended limit of 0.9, and no coverage was too low (<0.5) (Ragin, 2006) (Table 3).

The next part of the study required the use of fsQCA software 4.1. The truth table is calculated by considering these variables. The main findings of this analysis are presented in Table 4, which shows the various combinations that lead

Figure 2 - The most communicated attributes of blockchain TS.



Source: own compilation.

Table 3 - Analysis of necessary conditions.

	Blockchain communicated		*~ blockchain communicated*		*RoN*
	Consistency	*Coverage*	*Consistency*	*Coverage*	
Innov	0.7390	0.5935	0.7006	0.7475	0,6816
~innov	0.6857	0.6329	0.6190	0.7591	
Size	0.6183	0.7387	0.2454	0.3895	0,8381
~size	0.4890	0.3279	0.8353	0.7440	
Progress	0.6863	0.5333	0.4871	0.5029	0,6333
~progress	0.3603	0.3459	0.5480	0.6988	
Eco	0.6134	0.5561	0.3685	0.4439	0,7145
~eco	0.3866	0.3155	0.6315	0.6845	
Pdo	0.3977	0.4056	0.4387	0.5944	0,6982
~Pdo	0.6023	0.4468	0.5613	0.5532	

Source: own compilation.

Table 4 - Analysis of sufficiency results.

Configurations	*1*	*2*	*3*	*4*	*5*
Innov	●		⊗	⊗	⊗
Size		•	●	●	●
Progress	●	•	•		•
Eco	●	•		⊗	⊗
Pdo		⊗	⊗	⊗	
Raw coverage	0.3879	0.2022	0.1942	0.1795	0.1127
Unique coverage	0.2469	0.0196	0.0000	0.1078	0.0411
Consistency	0.9738	0.8616	0.9031	0.8772	0.9154
Model coverage	0.6697				
Model consistency	0.9093				

Source: own compilation.

to greater communication regarding traceability of a company's products. Specifically, four solutions were identified and presented in order from highest to lowest gross coverage. Using the usual terminology in this type of study, black circles (●) denote the presence of a condition, while crossed-out circles (⊗) indicate its absence. A blank indicates that the condition is irrelevant. The distinction between central and peripheral conditions is denoted by large and small circles, respectively (Fiss, 2011). The following table includes the set-theoretic consistency values for each configuration and the overall model solution.

The results show that, considering the proposed variables, different combinations lead to a greater amount of information on the traceability of the products offered by the company. Table II includes the set-theoretic consistency values for each configuration, as well as the global solution of the model. The global solution exceeds the recommended threshold of 0.80 (Pappas and Woodside, 2021). The global model obtained from this analysis reflected a total coverage of 0.6697. Thus, in 66.97% of the olive oil organizations analyzed, this set of causal configurations explains the amount of information. The core conditions of the model obtained are two: innov*progress*eco and size*~innov. The first configuration, with a gross coverage of 0.3879, establishes that the combination of innovation, state of progress, and offering organic products explains 38.79% of the cases with a greater amount of information. The corresponding consistency shows that 97.38% of the cases presented results of interest.

6. Discussion

Analyzing the communication of blockchain TS attributes in the olive oil sector, this study tries to identify the profile of olive oil organizations that adopt this certification technology and to understand the key drivers that move the business strategy. To achieve this objective, we have focused on the website communication channel for the following reasons: expands two foundations of the value of blockchain traceability transparency: visibility and disclosure (Duan *et al*., 2017; Köhler and Pizzol, 2020); explains to consumers how to use blockchain labelling tools (QR or batch code) to obtain a value information about the olive oil food product and processes (Violino *et al*., 2019; Liu *et al*., 2022); helps consumers to develop their decision-making abilities, engagement, and physical product experience (Iaia *et al*., 2018); build a direct trust-customer relationship with an olive oil brand company improving a competitive advantage (Singh and Sharma, 2022; Bonetti *et al*., 2023). Moreover, this blockchain TS attributes communication analysis allows us to understand if the adoption of this traceability technology is only a cost-saving on processes objective in their supply chain (Zheng *et al*., 2023) or hides an effective market strategy responding to global consumers' concerns about sustainability, trust and health (Dal Mas *et al*., 2022; Treiblmaier and Garaus, 2023; Giganti *et al*., 2024). Regarding the profile of olive oil organizations that trace their food products by blockchain TS we have found the following dimensions and corresponding strategies.

The size of the company influences the level of blockchain TS communication on the websites of olive oil organizations. Companies with larger dimensions can absorb rising communication costs because their operational and organizational structures can communicate more on the websites to thus achieve commercial and marketing objectives focused on consumers (Caiazza *et al*., 2020; Sgroi, 2022). This relevance has been confirmed in other traditional traceability certification systems used in the olive oil sector (Fernández-Uclés *et al*., 2023). Through the digital communication of blockchain technology the biggest companies of olive oil sector can develop a corporate and territorial competitiveness allowing a greater efficiency in management of agri-food supply chain (Antonucci *et al*., 2019; Zhao *et al*., 2019).

The blockchain technology project progress status at the announcement, ongoing development, and operation stages in the adoption of agri-food blockchain TS are also related to the level of blockchain TS communication on the websites of olive oil organizations. On the other hand, olive oil organizations that have completed the blockchain TS project are more sensitive

to communicate their results into a Corporate Social Responsibility (CSR) website content (Rainero and Modarelli, 2021) and to a consumer values and attributes when differentiating their brands and products traced by this technology to achieve a competitive advantage (Gazzola *et al*., 2023).

Organic olive oil is another relevant variable that impacts blockchain TS website communication and plays a significant role in the business strategy of olive oil sector. Producers of organic olive oil are highly oriented toward using Internet channels to promote and sell their products, maximize their economic performance, and obtain positive interest, acceptance, and purchase orientation from consumers (Carzedda *et al*., 2021; Pérez-Pérez and Gracia, 2023). This study confirms that olive oil organizations, especially those from Italy and Spain, trace their organic olive oils by blockchain TS adding an additional certification value to their premium olive oil productions (EVOO and or PDO) The corresponding website communication content aims to achieve the following business objectives: to reinforce the value labelling information of a previously organic traceability certification from European Union (Polenzani *et al*., 2020; van Hilten *et al*., 2020); to assure more familiarity with blockchain TS labelling tools (QR and batch code) and its usefulness to consumers (Georgescu *et al*., 2022); increasing a willingness to pay a premium price offering an extensive range of information about quality, safety and origin of organic olive oils because consumers of organic olive oil need more information than consumers of conventional olive oil products and need to be assured of the higher price of organic olive oils (Borsellino *et al*., 2019; Fernández-Uclés *et al*., 2020; Brusset *et al*., 2024). Organic olive oil communication is also associated with the social environmental sustainability concern. Consumers show a favorable purchase intention for olive oil organizations that certify their sustainability in the cultivating and mill processes by blockchain TS (Violino *et al*., 2019; Fernandes *et al*., 2022; Zhang, 2023).

Even if PDO and PGI offer to the agri-food and olive oil organizations a distinctive protection of origin, quality and practices of local production methods in the global supply chain trade on meet repeated cases of fraudulent activities that can damage the reliability of these entities and sectors (Scuderi *et al*., 2019; Vasileiou *et al*., 2024). In our study we have observed that several organizations that trace olive oil (especially the organic EVOO) via blockchain TSs are PDO and PGI entities, and this variable greatly influences the level of website communication because it has a positive impact on the consumer preferences (Violino *et al*., 2019; Contini *et al*., 2023). Consequently, this communication reinforces the value that PDO and GI olive oil offer to consumers: additional certification through blockchain regarding origin, safety, quality, and process compliance (Aparicio-Ruiz *et al*., 2022). Blockchain TS communication could be also a further asset for small-to-middle-size local organizations that belong to PDO and PGI olive oils entities in the consumer market, increasing company reliability to achieve a differential competitive advantage (Sanjuán-Lopez and Resano-Ezcaray, 2020).

7. Conclusions

The aim of this study has been to conduct an exploratory investigation of olive oil organizations that have implemented the new 4.0 digital blockchain traceability system (TS) and evaluate its impact on online communication using this innovative technology. This study addresses a gap in the literature and contributes to the consolidation of knowledge concerning blockchain within organizational profiles and communication attributes in the olive oil sector. Specifically, it investigates how the profile variables of olive oil organizations influence blockchain TS communication, and examines how and to what extent olive oil organizations communicate the values and benefits of blockchain on their websites. This analysis has aimed to determine the corresponding correlations and key business factors that impact the consumer market.

The results of this study reveal that communication of olive oils traced through blockchain TS is not perceived as a priority in olive oil organizations, contradicting their declarations, where the commercial objective was the main goal

in the adoption of blockchain technology. Our findings identify two different profiles of olive oil organizations: those with a larger dimension and those with an advanced blockchain TS project. These organizations are present on several digital platforms selling organic olive oils, and belong to a PDO organization that enforces the authenticity of the origin and quality of olive oil with a focus on sustainability. To be effective, the blockchain TS communication of organic olive oil should consider and be aligned with different consumer profiles in different countries and continents, such as "organic seekers," expanding web content to other groups, such as "organic indifferent," "quality and origin lovers," and "local consumers."

The organic food strategy in olive oil profile organizations is a key factor in explaining the adoption of blockchain as a strategy product and agri-food production process. This evidence indicates a clear strategic choice by olive oil companies to coherently develop this market channel with sustainability trends and consumers' expectations in order to achieve a competitive advantage.

However, current website content communication remains inadequate for mitigating the information asymmetry in the olive oil market traced by blockchain. The lack of clear and concise information explaining blockchain concepts and tools to consumers and online users impedes their perception and acceptance of this innovation, thereby limiting their purchase intentions and sustained usage. This communication gap hinders consumer awareness and familiarity with the newly-labeled blockchain TS tools. Additionally, the absence of differentiation, both visually and in content, as well as in price and sustainability attributes, between olive oils traced by blockchain TS and those traced by other certification systems sold via e-commerce channels, may negate the potential competitive advantages generated by blockchain TS adoption, particularly for premium olive oil categories.

Furthermore, our study highlights that this communication gap extends to professional clients and supply chain operators, potentially impacting olive oil-producing countries and organizations focused on bulk production, such as Spain and other emerging countries, where business clients represent a significant market value in global trade.

7.1. *Practical implications*

This study offers a complementary and enriching perspective for interpreting data from agri-food organizations that adopt blockchain traceability systems. Specifically, website communication about blockchain traceability systems (TS) for olive oil organizations can be extended in three dimensions:

First, supply chain operators can mitigate information asymmetry in global trade.

Second, transparency is a key factor in developing consumer trust.

Finally, a social dimension aligned with the Principles of Digital Development promoted by international entities (e.g., UNICEF, FAO, WHO, and the World Bank) and foundations (e.g., the Bill and Melinda Gates Foundation) can be integrated, contributing to the development of a local sustainability production, better farmer inclusion, shared values, health disease prevention, and development goals. For these reasons, some governments have invested extensively in agri-food blockchains as consumers are increasingly concerned about their health and product quality.

This study also addresses the management of olive oil organizations to support their website communication strategies in the blockchain TS area. These findings provide valuable information for managers emphasizing blockchain adoption to enhance consumer issues and requirements and help them establish a competitive advantage. Our work encourages organizations to align their blockchain agri-food traceability objectives with their communication strategies, especially for the European Protected Designation of Origin (PDO) and Geographical Indication (GI) or consortium associations in other countries.

From a business perspective, the study's findings highlight the strategic role that effective blockchain communication can play in helping agri-food operators differentiate their products within both the supply chain and the broader

market. Clear communication about blockchain traceability can mitigate information asymmetry, a persistent issue in food markets, particularly for products prone to fraud, such as olive oil. Ultimately, the study provides a valuable framework for agri-food businesses to assess the effectiveness of their communication strategies. This solution will also enable the use of key performance indicators (KPIs) in commercial, marketing, and digital web metrics to benchmark other olive oil categories.

The results of this study underscore its usefulness and need for significant investments in IT technical areas, organizational processes in the supply chain, and consumer communication. The framework of values and attributes identified in this study can be used to implement the information that the blockchain distributed ledger technology (DLT) platform needs to trace in the cultivation and mill production processes, integrating machinery and sensors.

7.2. *Limitations and future directions*

Although our findings address this study's research question, certain limitations should be acknowledged. First, the blockchain traceability system examined is specific to the olive oil sector rather than the entire agri-food sector. Due the difficulty of accessing the entire agri-food blockchain data, the focus was on analyzing the olive oil sector for its economic significance in several emerging countries, its recognized value food impact on health and nutrition for consumers, and the sustainable productions offering ecological premium olive oils coherently to the market trends and society concerns. Second, the study sample is confined to the offer side, analyzing the profiles of olive oil organizations rather than consumer behavior in order to understand the objectives and strategies behind the adoption of blockchain traceability systems.

As an exploratory study, our results were derived from a literature review and data compiled from various sources. This was necessitated by the lack of a pre-existing common model to serve as a guideline for this nascent research area. These limitations highlight areas for future research, particularly the need to examine consumer behavior to better understand market interactions in blockchain-based agri-food traceability.

Future research should include an analysis of the organizational profiles and website communication indices of agri-food organizations that have adopted blockchain technology. This finding can be used to compare the impacts and relationships between the supply and market sides. Further studies should develop and test comprehensive models in order to facilitate a holistic understanding of blockchain adoption in the agri-food sector.

References

Ahmed W.A.H., MacCarthy B.L., Treiblmaier H., 2022. Why, where and how are organizations using blockchain in their supply chains? Motivations, application areas and contingency factors. *International Journal of Operations & Production Management*, 42(12): 1995-2028. https://doi.org/10.1108/IJOPM-12-2021-0805.

Alkhundary R., Brusset X., Naseraldin H., Féniès P., 2022. Enhancing the competitive advantage via: an olive oil case study. *IFAC - Papers On Line*, 55(2): 469-464. https://doi.org/10.1016/j.ifacol.2022.04.238.

Ancín M., Pindado E., Sánche M., 2022. New trends in the global transformation of the agri-food sector: An exploratory study based on Twitter. *Agricultural System*, 203: 103520. https://doi.org/10.1016/j.agsy.2022.103520.

Antonucci F., Figorilli S., Costa C., Pallottino F., Raso L., Menesatti P., 2019. A review on blockchain applications in the agri-food sector. *Journal of the Science of Food and Agriculture*, 99(14): 6129-6138. https://doi.org/10.1002/jsfa.9912.

Aparicio-Ruiz R., Tena N., García-Gonzáles D.L., 2022. An International Survey on Olive Oils Quality and Traceability: Opinions from the Involved Actors. *Foods*, 11(7): 1045.

Barney J.B., Mackey T.B., 2005. Testing Resource-Based Theory. In: Ketchen D.J., Bergh D.D. (eds), *Research Methodology in Strategy and Management* (vol. 2, pp. 1-13). Bingley: Emerald Group Publishing Limited, https://doi.org/10.1016/S1479-8387(05)02001-1.

Ben Ayed R., Hanana M., Ercisli S., Karunakaran R., Rebai A., Moreau F., 2022. Integration of innovative technologies in the agri-food sector: the fundamentals and practical case of DNA-based traceabil-

ity of olives from fruit to oil. *Plants*, 11(9): 1230. https://doi.org/10.3390/plants11091230.

Bernal-Jurado E., Mozas-Morales A., Fernández-Uclés D., Medina-Viruel M.J., 2018. Evaluation of Corporate Websites and Their Influence on the Performance of Olive Oil Companies. *Sustainability*, 10(4): 1274. https://doi.org/10.3390/su10041274.

Bernal-Jurado E., Mozas-Morales A., Fernández-Uclés D., Medina-Viruel M.J., 2019. Agri-food companies in the social media: a comparison of organic and no-organic firms. *Economic Research*, 32(1): 321-334. https://doi.org/10.1080/1331677X.2018.1547203.

Bettín-Díaz R., Rojas A.E., Mejía-Moncayo C., 2018. Methodological Approach to the Definition of a Blockchain System for the Food Industry Supply Chain Traceability. In: Gervasi O. *et al.*, *Computational Science and Its Applications – ICCSA 2018*. ICCSA 2018. Lecture Notes in Computer Science, vol. 10961. Cham: Springer. https://doi.org/10.1007/978-3-319-95165-2.

Bistarelli S., Faloci F., Mori P., Taticchi C., 2022. *Olive Oil as Case Study for the Chain Platform. DLT 2022* (June 20). 4th Distributed Ledger Technology Workshop [Conference presentation]. Rome: CEUR-WS.org. https://docs.soliditylang.org/en/v0.8.6/.

Bonetti E., Bartoli C., Mattiacci A., 2023. Applying blockchain to quality food products: a marketing perspective. *British Food*, ahead-of-print, https://doi.org/10.1108/BFJ-12-2022-1085.

Borda D., Mihalache O.A., Dumitraşcu L., Gafiţianu D., Nicolau A.I., 2021. Romanian consumers' food safety knowledge, awareness on certified labelled food and trust in information sources. *Food Control*, 120: 107544. https://doi.org/10.1016/j.foodcont.2020.107544.

Borsellino V., Zinnanti C., Migliore G., Di Franco C.P., Schimmenti E., 2018. An exploratory analysis of website quality in the agri-food sector: The case of extra virgin olive. *Quality - Access to Success*, 19(165): 132-138. http://hdl.handle.net/10447/297530.

Brusset X., Kinra A., Naseraldin H., Alkhudary R., 2024. Increasing willingness to pay in the food supply chain: a blockchain-oriented trust approach. *International Journal of Production Research*, 62(24): 1-22. https://doi.org/10.1080/00207543.2024.2352763.

Bumblauskas D., Mann A., Dugan B., Rittmer J.A., 2020. Blockchain use case in food distribution: Do you know where your food has been? *International Journal Information Management*, 52: 102008. https://doi.org/10.1016/j.ijinfomgt.2019.09.004.

Caiazza R., Bigliardi B., 2020. Web marketing in agri-food industry: Challenges and opportunities. *Trends in Food Science & Technology*, 103: 12-19. https://doi.org/10.1016/j.tifs.2020.04.024.

Caja Rural Jaén, España, 2022. Análisis de la demanda. In: *Informe Anual de Coyuntura del Sector Oleícola*, 1ª ed., octubre 2022, cap. 3, pp. 79-126. Jaén: EDITA, Caja Rural de Jaén. https://www.catedraaceitesdejaen.com/download/informe-coyuntura-2022/.

Caro M.P., Ali M.S., Vecchio M., Giaffreda R., Blockchain-based traceability in Agri-Food supply chain management: A practical implementation. In: *2018 IoT Vertical and Topical Summit on Agriculture - Tuscany (IOT Tuscany)*. IEEE Italia, pp. 1-4, DOI: 10.1109/IOT-TUSCANY.2018.8373021.

Carzedda M., Gallenti G., Troiano S., Cosmina M., Marangon F., De Luca P., Nassivera F., 2021. Consumer preferences for origin and organic attributes of extra virgin olive oil: A choice experiment in the Italian market. *Foods*, 10(5): 994. https://doi.org/10.3390/foods10050994.

Casadei E., Valli E., Panni F., Donarski J., Farrús Gubern J., Lucci P., Conte L., Lacoste F., Maquet A., Brereton P., Bendini A., Gallina Toschi T., 2021. Emerging trends in olive oil fraud and possible countermeasures. *Food Control*, 124: 107902. https://doi.org/10.1016/j.foodcont.2021.107902

Chaffey D., Ellis-Chadwick F., 2019. *Digital Marketing: Strategy, Implementation, and Practice*. London: Pearson Education.

Chen G., Xu B., Lu M., Chen N.S., 2018. Exploring blockchain technology and its potential applications for education. *Smart Learning Environments*, 5: 1. https://doi.org/10.1186/s40561-017-0050-x.

Chiaraluce G., Bentivoglio D., Finco A., Fiore M., Contò F., Galati A., 2024. Exploring the role of blockchain technology in modern high-value food supply chains: Global trends and future research directions. *Agricultural and Food Economics*, 12: 6. https://doi.org/10.1186/s40100-024-00301-1.

Clohessy T., Acton T., 2019. Investigating the influence of organizational factors on blockchain adoption: An innovation theory perspective. *Industrial Management & Data Systems*, 119(7): 1457-1491. https://doi.org/10.1108/IMDS-08-2018-0365.

Contini C., Boncinelli F., Piracci G., 2023. Can blockchain technology strengthen consumer preferences for credence attributes? *Agricultural and Food Economics*, 11: 27. https://doi.org/10.1186/s40100-023-00270-x.

Corallo A., Latino M.E., Menegol M., Striani F., 2020. The awareness assessment of the Italian agri-food industry regarding food traceability systems. *Trends in Food & Science Technology*, 101: 28-37. https://doi.org/10.1016/j.tifs.2020.04.022.

Cozzio C., Viglia G., Lemarie L., Cerutti S., 2023. Toward an integration of blockchain technology in the food supply chain. *Journal of Business Research*, 162: 113909. https://doi.org/10.1016/j.jbusres.2023.113909.

Dal Mas F., Massaro M., Ndou V., Raguseo E., 2023. Blockchain technologies for sustainability in the agri-food sector: A literature review of academic research and business perspectives. *Technological Forecasting and Social Change*, 187: 122155. https://doi.org/10.1016/j.techfore.2022.122155.

De Vries A., Gallersdörfer U., Klaaßen L., Stoll C., 2022. Revisiting Bitcoin's carbon footprint. *Joule, CellPress*, 6(3): 498-502. https://doi.org/10.1016/j.joule.2022.02.005.

Demestichas K., Peppes N., Alexakis T., Adamopoulou E., 2020. Blockchain in agriculture traceability systems: A review. *Applied Sciences*, 10(12): 4113. https://doi.org/10.3390/app10124113.

Di Girolamo F., Masotti A., Lante I., Scapaticci M., Calvano C.D., Zambonin C., Muraca M., Putignani L., 2015. Simple and Effective Mass Spectrometric Approach to Identify the Adulteration of the Mediterranean Diet Component Extra-Virgin Olive Oil with Corn Oil. *International Journal of Molecular Sciences*, 16(9): 20896-20912. https://doi.org/10.3390/ijms160920896.

Dionysis S., Chesney T. McAuley D., 2022. Examining the influential factors of consumer purchase intentions for blockchain traceable coffee using the theory of planned behaviour. *British Food Journal*, 124(12): 4304-4322. https://doi.org/10.1108/BFJ-05-2021-0541.

Duan Y., Miao M., Wang R., Fu Z., Xu M., 2017. A framework for the successful implementation of food traceability systems in China. *The Information Society*, 33(4): 226-242. https://doi.org/10.1080/01972243.2017.1318325.

Dujak D., Sajter D., 2019. Blockchain Applications in Supply Chain. In: Kawa A., Maryniak A. (eds), *Smart Supply Network. EcoProduction*. Cham: Springer, pp. 21-26. https://doi.org/10.1007/978-3-319-91668-2_2.

Elfkih S., Fernández Uclés D., Mozas Moral A., Bernal Jurado E., Medina Viruel M.J., 2021. ICT as a development factor in the Tunisian olive oil sector. *New Medit*, 20(4): 3-14. https://doi.org/10.30682/nm2104a.

European Commission, 2021. *Farm to Fork Strategy*. https://ec.europa.eu/food/horizontal-topics/farm-fork-strategy_en.

Fernandes M.A., Cruz E.F., Da Cruz A.R., 2022. Smart contract and web DApp for traceability in the olive oil production chain. In *2022, the 17th Iberian Conference on Information Systems and Technologies (CISTI)*. Madrid: IEEE, pp. 1-6. https://doi.org/10.23919/CISTI54924.2022.9820169.

Fernández-Uclés D., Bernal-Jurado E., Mozas-Morales A., Medina-Viruel M.J., 2020. The importance of website for organic agri-food producers. *Economic Research*, 33(1): 2867-2880. https://doi.org/10.1080/1331677X.2019.1694426.

Fernández-Uclés D., Mozas-Moral A., Bernal-Jurado E., 2023. Online reputation of agri-food companies and determining factors: an empirical investigation. *Review Managerial Science*, 18: 363-384. https://doi.org/10.1007/s11846-023-00639-8.

Ferreira da Silva C., Moro S., 2021. Blockchain technology as an enabler of consumer trust: A text mining literature analysis. *Telematics and Informatics*, 60: 101593. https://doi.org/10.1016/j.tele.2021.101593.

Fersht V., Zhang M., Spink J., 2019. Blockchain in the food industry at the United Nations ESCAP project, *Pacific Information Superhighway*. https://www.researchgate.net/publication/330158719_Blockchain_in_the_food_industry_at_the_United_Nations_ESCAP_project_Pacific_Information_Superhighway.

Fiss P.C., 2011. Building better causal theories: A fuzzy set approach to typologies in organization research. *Academy of Management Journal*, 54(2): 393-420. http://www.jstor.org/stable/23045087.

FMGC-GURUS, 2020. *Blockchain, Trust & Transparency*, March 2020. TOP TRENDS 2020. St. Albans: M&R Insight Ldt. https://fmcggurus.com/top-trends-2020/.

Fotopoulos C., Krystallis A., 2003. Quality labels as a marketing advantage: The case of the "PDO Zagora" apples in the Greek market. *European Journal of marketing*, 37(10): 1350-1374. https://doi.org/10.1016/j.techfore.2021.121403.

Fransi C.E., Montegut-Salla Y., Ferrer-Rosell B., Daries N., 2020. Rural cooperatives in the digital age: an analysis of the Internet presence and degree of maturity of agri-food cooperatives' e-commerce. *Journal of Rural Studies*, 74: 55-66. https://doi.org/10.1016/j.jrurstud.2019.11.011.

Friedman N., Ormiston J., 2022. Blockchain as a sustainability-oriented innovation? Opportunities for and resistance to Blockchain technology

as a driver of sustainability in global food supply chains. *Technological Forecasting and Social Change*, 175: 121403. https://doi.org/10.1016/j.techfore.2021.121403.

Frikha T., Ktari J., Hamam H., 2022. Blockchain Olive Oil Supply Chain. In: *International Conference on Risks and Security of Internet and Systems*, Cham: Springer Nature, pp. 101-113. https://doi.org/10.1007/978-3-031-31108-6_8.

Frikha T., Ktari J., Hamam H., 2023. Blockchain Olive Oil Supply Chain. In: Kallel S., Jmaiel M., Zulkernine M., Hadj Kacem A., Cuppens F., Cuppens N. (eds), *Risks and Security of Internet and Systems. CRiSIS 2022*. Lecture Notes in Computer Science, vol. 13857. Cham: Springer. https://doi.org/10.1007/978-3-031-31108-6_8.

Galanakis C.M., Rizou M., Aldawoud T.M.S., Ucak I., Rowan N.J., 2021. Innovations and technology disruptions in the food sector within the COVID-19 pandemic and post-lockdown era. *Trends in Food Science & Technology*, 110: 193-200. https://doi.org/10.1016/j.tifs.2021.02.002.

Galati A., Crescimanno M., Tinervia S., Siggia D., 2016. Website quality and internal business factors: An empirical investigation in the Italian wine industry. *International Journal of Wine Business Research*, 28(4): 308-326. https://doi.org/10.1108/IJWBR-08-2015-0026.

Garaus M., Wolfsteiner E., Florack A., 2022. When Food Co-Branding Backfires: The Over Expectation Effect. *Foods*, 11(14): 2136. https://doi.org/10.3390/foods11142136.

Gazzola P., Pavione E., Barge A., Fassio F., 2023. Using the Transparency of Supply Chain Powered by Blockchain to Improve Sustainability Relationships with Stakeholders in the Food Sector: The Case Study of Lavazza. *Sustainability*, 15: 7884. https://doi.org/10.3390/su15107884.

Gentile E., Loi A., Berisio S., Parisi P., Gentile M., Bruni M., Montanari F., Christodoulou M., Bisonni M., Puzniak J., García Azcárate T., Folkeson Lillo C., Ebert V., Gerwing E., Elles A., Luitaud C., Joya R., Hamann K.T., Mendívil S., M. De Román S., 2020. *Study on the implementation of conformity checks in the olive oil sector throughout the European Union*. European Commission: Directorate-General for Agriculture and Rural Development, Publications Office, 2020. https://doi.org/10.27 62/274137.

Georgescu B., Onete B.C., Pleșea D.A., Chița S.D., Sava Ș., 2022. Consumer Attitude Toward the Use of Blockchain Technology. Study on the Implementation of the "Green Deal" Strategy for Organic Foods. *Amfiteatru Economic*, 24(60): 379-394. https://doi.org/10.24818/EA/2022/60/379.

Ghose A., 2009. Internet exchanges for used goods: An empirical analysis of trade patterns and adverse selection. *MIS Quarterly*, 33(2): 263-291. https://doi.org/10.2307/20650292.

Giganti P., Borrello M., Falcone P.M., Cembalo L., 2024. The impact of blockchain technology on enhancing sustainability in the agri-food sector: A scoping review. *Journal of Cleaner Production*, 456: 142379. https://doi.org/10.1016/j.jclepro.2024.142379.

Gligor D., Bozkurt S., 2020. FsQCA versus regression: The context of customer engagement. *Journal of Retailing and Consumer Service*, 52: 101929. https://doi.org/10.1016/j.jretconser.2019.101929.

Guido R., Mirabelli G., Palermo E., Solina V., 2020. A framework for food traceability: case study - Italian extra-virgin olive oil supply chain. *International Journal of Industrial Engineering and Management*, 11(1): 50-60. http://doi.org/10.24867/IJIEM-2020-1-252.

Hassoun A., Kamiloglu S., Garcia-Garcia G., Parra-López C., Trollman H., Jagtap S., Aadil R.M., Esatbeyoglu T., 2023. Implementation of relevant fourth industrial revolution innovations across the supply chain of fruits and vegetables: A short update on Traceability 4.0. *Food Chemistry*, 409: 135303. https://doi.org/10.1016/j.foodchem.2022.135303.

Hobbs J., Bailey D., Dickinson D., Haghiri M., 2005. Traceability in the Canadian Red Meat Sector: Do Consumers Care? *Canadian Journal of Agricultural Economics*, 53(1): 47-65. DOI: 10.1111/j.1744-7976.2005.00412.x; https://doi.org/10.3390/foods11071045; https://ec.europa.eu/food/horizontal-topics/farm-fork-strategy_en European Commission, 2021.

Huijbregts Jaén P., 2021. Aplicaciones de la tecnología blockchain en marketing. *Revista de Marketing y Publicidad*, 3: 103-132. https://doi.org/10.51302/marketing.2021.706.

Iaia L., Fait M., Maizza A., Cavallo F., Scorrano P., 2018. *How Italian agri-food products communicate their authenticity? The brand land link investigated on the web*. [Conference presentation] 11th Annual Conference of the Euromed Academy of Business, Research advancements in national and global business theory and practice. La Valletta: Euromed Press, pp. 650-652. https://hdl.handle.net/2318/1892452.

Kaplan A.M., Haenlein M., 2010. Users of the world, unite! The challenges and opportunities of social media. *Business Horizons*, 53(1): 59-68. http://dx.doi.org/10.1016/j.bushor.2009.09.003.

Kiang M.Y., Chi R.T., 2001. A Framework for analyzing the potential benefits of Internet marketing. *Journal Electronic Commerce Research*, 2(4): 157-163. https://api.semanticscholar.org/CorpusID:15806406.

Kingsnorth S., 2022. *Digital marketing strategy: an integrated approach to online marketing*. Sections: 2-3. London: Kogan Page Publishers. EAN: 9781398605978.

Köhler S., Pizzol M., 2020. Technology assessment of blockchain-based technologies in the food supply chain. *Journal of Cleaner Production*, 269: 122193. https://doi.org/10.1016/j.jclepro.2020.122193.

Kotler P., Kartajaya H., Setiawan I., 2016. New Frameworks for Marketing in the Digital Economy - The New Customer Path. In: *Marketing 4.0: Moving from Traditional to Digital*. New York: J. Wiley & Sons, Part II, 5. https://www.wiley.com/en-ie/Marketing+4+0%3A+Moving+from+Traditional+to+Digital-p-9781119341208.

Kramer M.P., Bitsch L., Hanf J., 2021. Blockchain and Its Impacts on Agri-Food Supply Chain Network Management. *Sustainability*, 13(4): 2168. https://doi.org/10.3390/su13042168.

Kumar V., Reinartz W., 2016. Creating enduring customer value. *Journal of marketing*, 80(6): 36-68. http://dx.doi.org/10.1509/JM.15.0414.

Kumar S., Sahoo S., Lim W.M., Kraus S., Bamel U., 2022. Fuzzy-set qualitative comparative analysis (fsQCA) in business and management research: A contemporary overview. *Technological Forecasting and Social Change*, 178: 121599. https://doi.org/10.1016/j.techfore.2022.121599.

Lajara M.B., Seva-Larrosa P., Martínez-Falcó J., García-Lillo F., 2022. Wine clusters and Protected Designations of Origin (PDOs) in Spain: an exploratory analysis. *Journal of Wine Research*, 33(3): 146-167. https://doi.org/10.1080/09571264.2022.2110051.

Landeta-Echeberría A., 2021. Marketing y ventas inteligentes en la era digital. Ediciones CEF. *Revista de Marketing y Publicidad*, 1(3): 141-142. https://revistas.cef.udima.es/index.php/marketing/article/view/714.

Liu B., Si X., Kang H., 2022. A Literature Review of Blockchain-Based Applications in Supply Chain. *Sustainability*, 14(22): 15210. https://doi.org/10.3390/su142215210.

Marchesi L., Mannaro K., Porcu R., 2021. *Automatic Generation of Blockchain Agri-food Traceability Systems*. 2021 IEEE/ACM 4th International Workshop on Emerging Trends in Software Engineering for Blockchain (WETSEB), Madrid, pp. 41-48. https://doi.org/10.1109/WETSEB52558.2021.00013.

Marlene P., 2019. La tecnología en la evolución del marketing. *Revista Perspectiva Empresarial*, 6(1): 75-91. Fundación Universitaria CEIPA. https://www.redalyc.org/articulo.oa?id=672271534006.

Marozzo V., Costa A., Crupi A., Abbate T., 2023. Decoding Asian consumers' willingness to pay for organic food product: a configurational-based approach. *European Journal of Innovation Management*, 26(7): 353-384. https://doi.org/10.1108/EJIM-10-2022-0591.

Martínez-Castañeda M., Fejioo C., 2023. Use of blockchain in the agri-food value chain: State of the art in Spain and some lessons from the perspective of public support. *Telecommunications Policy*, 47(6): 102574. https://doi.org/10.1016/j.telpol.2023.102574.

Martínez-Stanziani M.N., 2022. *Uso de la tecnología Blockchain en procesos de trazabilidad de productos alimenticios*. Master's thesis, Trabajo Final de Master, Universidad de Valladolid, pp. 12-19. https://uvadoc.uva.es/handle/10324/61408.

Meerza S.I.A., Gustafson C.R., 2019. Does prior knowledge of food fraud affect consumer behavior? Evidence from an incentivized economic experiment. *PLoS ONE*, 14(12): e0225113. https://doi.org/10.1371/journal.pone.0225113.

Moe T., 1998. Perspectives on traceability in food manufacture. *Trends in Food Science & Technology*, 9(5): 211-214. https://doi.org/10.1016/S0924-2244(98)00037-5.

Mohammed A., Potdar V., Quaddus M., Hui W., 2023. Blockchain Adoption in Food Supply Chains: A Systematic Literature Review on Enablers, Benefits, and Barriers. *IEEE Access*, 11: 14236-14255. https://doi.org/10.1109/ACCESS.2023.3236666.

Mozas-Morales A., Bernal-Jurado E., Fernández-Uclés D., Medina-Viruel M.J., 2018. Social media as a route to developing the agri-food sector in Spain. *New Medit*, 17(2): 101-112. DOI: 10.30682/nm1802h.

Muñiz-Gonzales R., Muñiz De La Torre V. (eds), 2018. *Marketing en el siglos XXI* (2ª ed.). Madrid: Ediciones CEF, Centro de Estudios Financieros, capp. 9, 13. ISBN 9788445437438.

Pappas I.O., Woodside A.G., 2021. Fuzzy-set Qualitative Comparative Analysis (fsQCA): Guidelines for research practice in Information Systems and marketing. *International Journal of Information Management*, 58: 102310. https://doi.org/10.1016/j.ijinfomgt.2021.102310.

Patrutiu-Baltes L., 2016. The impact of digitalization on business communication. *SEA-Practical Application of Science*, 4(11): 319-325. https://econpapers.repec.org/RePEc:cmj:seapas:y:2016:i:11:p:319-325.

Pérez-Pérez L., Gracia A., 2023. Consumer Preferences for Olive Oil in Spain: A Best–Worst Scaling Approach. *Sustainability*, 15(14): 11283. https://doi.org/10.3390/su151411283.

Polenzani B., Riganelli C., Marchini A., 2020. Sustainability Perception of Local Extra Virgin Olive Oil and Consumers' Attitude: A New Italian Perspective. *Sustainability*, 12(3): 920. https://doi.org/10.3390/su12030920.

Politecnico di Milano, 2023. *Lo scenario dell'innovazione digitale nel settore agri-food nel 2022 e 2021*. Osservatorio Smart Agri-food, Marzo 2022. Osservartori.net Digital Innovation. DIG - Dipartimento Ingegneria Gestionale, https://www.osservatori.net/it/ricerche/osservatori-attivi/smart-agri-food.

Ragin C.C., 2006. Set relations in social research: Evaluating their consistency and coverage. *Political Analysis*, 14(3): 291-310. DOI: 10.1093/pan/mpj019.

Ragin C.C., 2014. A Bolean Approach to Qualitative Comparaison: Basic Concepts. In: *The Comparative method: Moving beyond qualitative and quantitative strategies*. Berkeley: University of California Press, chapters 6-7-8, pp. 85-163.

Rainero C., Modarelli G., 2021. Food tracking and blockchain-induced knowledge: a corporate social responsibility tool for sustainable decision-making. *British Food Journal*, 123(12): 4284-4308. https://doi.org/10.1108/BFJ-10-2020-0921.

Rana R.L., Tricase C., De Cesare L., 2021. Blockchain Technology for a sustainable agri-food supply chain. *British Food Journal*, 123(11): 3471-3485. https://doi.org/10.1108/BFJ-09-2020-0832.

Reieb A., Keogh J.G., Treiblmaier H., 2020. How Blockchain Technology Can Benefit marketing: Six Pending Research Areas. *Frontiers Blockchain*, 3: 03. https://doi.org/10.3389/fbloc.2020.00003.

Reitano M., Pappalardo G., Selvaggi R., Zarbà C., Chinnici G., 2024. Factors influencing consumer perceptions of food tracked with blockchain technology. A systematic literature review. *Applied Food Research*, 4(2): 100455. https://doi.org/10.1016/j.afres.2024.100455.

Rifna E.J., Pandiselvam R., Kothakota A., Rao K.S., Dwivedi M., Kumar M., Thirumdas R., Ramesh S.V., 2022. Advanced process analytical tools for identification of adulterants in edible oils–A review. *Food Chemistry*, 369: 130898. https://doi.org/10.1016/j.foodchem.2021.130898.

Rocchi B., Romano D., Sadiddin A., Stefani G., 2020. Assessing the economy-wide impact of food fraud: A SAM-based counterfactual approach. *Agrobusiness an International Journal*, 36(2), 167-191. https://doi.org/10.1002/agr.21633.

Sahoo S., Kumar S., Sivarajah U., Lim W.M., Westland J. C., Kumar A., 2024. Blockchain for sustainable supply chain management: trends and ways forward. *Electronic Commerce Research*, 24(3): 1563-1618. http://dx.doi.org/10.1007/s10660-022-09569-1.

Sahut J.M., Dana L.P., Laroche M., 2019. Digital Innovations, impact on marketing, value chain and business models: An introduction. *Canadian Journal of Administrative Sciences*, 37(1): 61-67. https://doi.org/10.1002/cjas.1558.

Sanjuán-López A.I., Resano-Ezcaray H., 2020. Labels for a Local Food Speciality Product: The Case of Saffron. *Journal of Agricultural Economics*, 71(3): 778-797. https://doi.org/10.1111/1477-9552.12376.

Schneider C.Q., Wagemann C., 2010. Standards of good practice in qualitative comparative analysis (QCA) and fuzzy sets. *Comparative Sociology*, 9(3): 397-418. https://doi.org/10.1163/156913210X12493538729793.

Scuderi A., Foti V.T., Timpanaro G., 2019. The Supply Chain Value of PDO and PGI Food Products through the Application of Blockchain. *Calitatea Acces La Success*, 20(2): 580-587. http://hdl.handle.net/20.500.11769/363300.

Sehring J., Korhonen-Kurki K., Brockhaus M., 2013. *Method and Applications. Challenges and Limitations. Qualitative comparative analysis (QCA): An application to compare national REDD+ policy processes*. CIFOR, Center for International Forestry Research, Paper 121: 4-19. https://doi.org/10.17528/cifor/004278.

Sestino A, Giraldo L., Cedrola E., Zamani S.Z., Guido G., 2022. The Business Opportunity of Blockchain Value Creation among the Internet Value. *Global Business Review*, 2022. https://doi.org/10.1177/09721509221115012.

Shahid A., Almogren A., Javaid N., Al-Zahrani F.A., Zuair M., Alam M., 2020. Blockchain-Based Agri-Food Supply Chain: A Complete Solution. *IEEE Access*, 8(1): 69230-69243. DOI: 10.1109/ACCESS.2020.2986257.

Singh V., Sharma S.K., 2022. Application of blockchain technology in shaping the future of food industry based on transparency and consumer trust. *Journal of Food Science Technology*, 60: 1237-1254. https://doi.org/10.1007/s13197-022-05360-0.

Sgroi F., 2022. The role of blockchain for food safety and market efficiency. *Journal of Agriculture and Food Research*, 9: 100326. https://doi.org/10.1016/j.jafr.2022.100326.

Stranieri S., Riccardi F., Meuwissen M.P.M., Soregaroli C., 2021. Exploring the impact of blockchain on

the performance of agri-food supply chains. *Food Control*, 119: 107495. https://doi.org/10.1016/j.foodcont.2020.107495.

Tang Y., Xiong J., Becerril-Arreola R., Iyer L., 2020. Ethics of blockchain: A framework of technology, applications, impacts, and research directions. *Information Technology & People*, 33(2): 602-632. https://doi.org/10.1108/ITP-10-2018-0491.

Tessitore S., Iraldo F., Apicella A., Tarabella A., 2021. Food traceability as driver for the competitiveness in Italian food service companies. *Journal of Food Service Business Research*, 25(1): 57-84. https://doi.org/10.1080/15378020.2021.1918536.

Thompson B., Rust S., 2023. Blocking blockchain: Examining the social, cultural, and institutional factors causing innovation resistance to digital technology in seafood supply chains. *Technology in Society*, 73: 102235. https://doi.org/10.1016/j.techsoc.2023.102235.

Tiscini R., Testarmata S., Ciaburri M., Ferrari E., 2020. The blockchain as a sustainable business model innovation. *Management Decision*, 58(8): 1621-1642. https://doi.org/10.1108/MD-09-2019-1281.

Tran D., De Steur H., Gellynck X., Papadakis A., Schouteten J.J., 2024. Consumers' valuation of blockchain-based food traceability: role of consumer ethnocentrism and communication via QR codes. *British Food Journal*, 126(13): 72-93. https://doi.org/10.1108/BFJ-09-2023-0812.

Treiblmaier H., Garaus M., 2023. Using the blockchain to signal quality in the food supply chain: the impact on consumer purchase intentions and the moderating effect of brand familiarity. *International Journal of Information Management*, 68: 102514. https://doi.org/10.1016/j.ijinfomgt.2022.102514.

Treiblmaier H., Petrozhitskaya E., 2023. Is it time for marketing to reappraise B2C relationship management? The emergence of a new loyalty paradigm through blockchain technology. *Journal of Business Research*, 159: 113725. https://doi.org/10.1016/j.jbusres.2023.113725.

Tseng Y., Lee B., Chen C., He W., 2022. Understanding Agri-food Traceability System User Intention in Respond to COVID-19 Pandemic: The Comparisons of Three Models. *Environmental Research and Public Health*, 19(3): 1371. https://doi.org/10.3390/ijerph19031371.

van Hilten M., Ongena G., Pascal R., 2020. Blockchain for Organic Food Traceability: Case Studies on Drivers and Challenges. *Frontiers in Blockchain*, 3: 567175. https://doi.org/10.3389/fbloc.2020.567175.

van Ruth S.M., Luning P.A., Silvis I.C.J., Yang Y., Huisman W., 2018. Differences in fraud vulnerability in various food supply chains and their tiers. *Food Control*, 84: 375-381. https://doi.org/10.1016/j.foodcont.2017.08.020.

Vasileiou M., Kyrgiakos L.S., Kleisiari C., Prosperi P., Kleftodimos G., Ragkos A., Vlontzos G., 2024. Is blockchain a panacea for guarding PDO supply chains? Exploring vulnerabilities, critical control points, and blockchain feasibility in Greece. *Advanced Sustainable Systems*, 8(10): 2400257. https://doi.org/10.1002/adsu.202400257.

Vega-Zamora M., Gutiérrez-Salcedo M., Torres-Ruiz F.J., 2016. Communication campaigns: effects of different messages on the willingness to purchase organic olive oil. *Revista Española de Estudios Agrosociales y Pesqueros REEAP*, 244: 69-104. http://dx.doi.org/10.22004/ag.econ.249673.

Violino S., Pallottino F., Sperandio G., Figorilli S., Antonucci F., Ioannoni V., Fappiano D., Costa C., 2019. Are the Innovative Electronic Labels for Extra Virgin Olive Oil Sustainable, Traceable, and Accepted by Consumers? *Foods*, 8(11): 529. https://doi.org/10.3390/foods8110529.

Wang F., 2020. Digital marketing capabilities in international firms: a relational perspective. *International Marketing Review*, 37(3): 559-577. https://doi.org/10.1108/IMR-04-2018-0128.

Yan J., Erasmus S.W., Aguilera-Toro M., Huang H., van Ruth S.M., 2020. Food fraud: Assessing fraud vulnerability in the extra virgin olive oil supply chain. *Food Control*, 111: 107081. https://doi.org/10.1016/j.foodcont.2019.107081.

Zarbà C., Chinnici G., Matarazzo A, Privitera D., Scuderi A., 2024. The innovative role of blockchain in agri-food systems: A literature análisis. *Food Control*, 164: 110603. https://doi.org/10.1016/j.foodcont.2024.110603.

Zeng Y., Jia F., Wan L., Guo H., 2017. E-commerce in agri-food sector: a systematic literature review. *International Food and Agribusiness Management Review*, 20(4): 439-460. http://dx.doi.org/10.22434/IFAMR2016.0156.

Zhang Y., 2023. *Consumers attitudes toward blockchain food traceability technology in Sweden*. Master´s Degree Thesis in Sustainable Development, Uppsala University. https://uu.diva-portal.org/smash/record.jsf?pid=diva2%3A1772199.

Zhao G., Liu S., Lopez C., Lu H., Elgueta S., Chen H., Boshkoska B.M., 2019. Blockchain technology in agri-food value chain management: a synthesis of applications, challenges and future research directions. *Computer in Industry*, 109: 83-99. https://doi.org/10.1016/j.compind.2019.04.002.

Zheng Y., Xu Y., Qiu Z., 2023. Blockchain traceability adoption in agricultural supply chain coordination: an evolutionary game analysis. *Agriculture*, 13(1): 184. https://doi.org/10.3390/agriculture13010184.

Zutshi A., Grilo A., Nodehi T., 2021. The value proposition of blockchain technologies and its impact on Digital Platforms. *Computer & Industrial Engineering*, 155: 107187. https://doi.org/10.1016/j.cie.2021.107187.

Application of the entropy based COPRAS model in determining the most appropriate irrigation systems for agricultural enterprises producing maize

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Abstract

The aim of this study is to determine the most effective irrigation systems for agricultural enterprises producing maize due to decreasing water resources. The study was conducted on 95 agricultural enterprises producing corn in Çumra District of Konya Province. In the study, the importance levels of 10 criteria determined in the decision process were analyzed by Entropy method. The results revealed that the most important criteria are Energy Cost, Labor Requirement and Price, respectively. Irrigation system alternatives were evaluated using the COPRAS method, one of the Multi-Criteria Decision Making (MCDM) methods. In the study, linear irrigation systems were identified as the most suitable irrigation system for the study area. The rapid increase in input costs has led agricultural enterprises to implement cost saving measures. The potential of modern irrigation systems to reduce energy costs has made this criterion a priority factor in irrigation system selection. In this context, the importance of irrigation systems that provide energy efficiency and labor saving plays a critical role for the sustainability of agricultural production.

Keywords*: Maize, Irrigation Systems, MCDM, COPRAS, Entropy.*

1. Introduction

Water is a vital natural resource for living things to survive. However, due to the increasing population and the effects of global warming, water resources are decreasing and access to these resources is becoming increasingly difficult. These challenges cause people to search for ways to save water and develop more efficient water use methods. This necessitates the implementation of more informed and effective strategies for the sustainable management of water. While 97.5% of the world's water is saltwater, only 2.5% is freshwater. Water consumption is distributed in different ways across different areas such as the sustainability of people, animals and natural life, agricultural irrigation, energy production and industrial activities.

Looking at the sectoral distribution of water consumption in the world, 69% of water is used for agricultural activities, 19% for industrial sectors and 12% for drinking water and daily use

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(WWF, 2014). Despite many technological and biological innovations, agriculture is considered one of the most vulnerable sectors to the negative impacts of climate change (Oğuz *et al.*, 2024). If this situation is ignored and the necessary measures are not taken, there is a risk of a serious water crisis in the coming years. In this context, it is of great importance to develop urgent and effective strategies for the efficient management and the conservation of water resources (Özsoy, 2009). In Turkey, 77 % of water (Ministry of Environment, Urbanization and Climate Change, 2023) is used for agricultural irrigation. While the irrigation systems determine how the water is applied to the soil, the irrigation system includes all the tools and equipment necessary to apply these systems (Eryılmaz, 2022). Irrigation systems are an important factor for agricultural development and food security (Haffaf *et al.*, 2021). The high water consumption in agricultural irrigation requires the development of careful strategies for the management and sustainable use of water resources. Planning is necessary in many areas, such as the structure of crops depending on the amount of water, modern irrigation systems, the selection of seeds, the method of tillage and the analysis of plant water needs. The cultivation pattern is of great importance for agricultural businesses because it is both adapted to the climatic conditions and enables high profit margins; as the right product selection supports both efficient production processes and economically sustainable success. The diversity of climatic conditions in Turkey makes it possible to grow different crops in different regions. Precipitation, one of the climatic factors, has a direct impact on the productivity of agricultural activities and the health of ecosystems. The 2023 areal precipitation average in Turkey was 641.5 mm, about 12% above the long-term average (573.4 mm for the 1991-2020 period) (MGM, 2023a). In Konya province, which accounts for 7.86% of Turkey's agricultural area, the average annual precipitation between 1929 and 2023 was 329.7 mm, which is lower than the national average (MGM, 2023b).

Despite the low rainfall in Konya province, farms favour water-intensive crops such as maize, alfalfa, sugar beet and potatoes for reasons of profitability. In 2023, 10.03 million quintals of cereals and 1.85 million quintals of maize were grown in Konya (TurkStat, 2023).

Although cereal crops generally require less water, water-intensive crops such as maize require careful management of water resources and careful planning of irrigation strategies due to the low average rainfall in the region. The water requirement of the maize plant under regional conditions is 788 mm, which is significantly higher than the current amount of precipitation (TAGEM, 2017). This situation emphasizes the importance of water efficiency solutions and effective irrigation systems to increase crop yields and make agricultural production sustainable through the effective use of limited water resources. The research area is one of the driest provinces of Turkey and also constitutes one of the most important grain production areas. Although some studies have discussed the extent to which investments will be made in the products produced in the region (Kaya, 2017; Oğuz and Yener, 2017; Oğuz *et al*., 2024). Since producers are not trained on water use and restrictions, profitability in production comes to the fore. It would be beneficial for the state, universities and local governments to be sensitive about this issue and to provide training to farmers on water scarcity and usage. Otherwise, there will not be much change in the region.

It is important to select suitable irrigation systems for efficient utilization of water resources. Multi-criteria decision making methods (MCDM) are one of the methods used to determine the most suitable irrigation system considering various criteria. Since these methods are able to find the best solution by evaluating different factors, they attract a lot of interest and are widely used. The MCDM method helps to determine the most appropriate option among the available solution alternatives by taking into account multiple criteria (Çiftci, 2024). The impact of MCDM on theories and models that contribute to more systematic and reasonable decision-making processes has increased significantly (Manos *et al.*, 2009). MCDM is an intelligent and effective method that helps decision makers determine the best option according to various criteria (Tian *et al.*, 2023). This

approach aims to increase both resource efficiency and support sustainable agriculture as an important tool in optimizing water management and irrigation strategies. In the literature, many studies on water and irrigation systems have conducted comprehensive and effective analyses used MCDM methods. Some of these studies; (Duckstein *et al.*, 1994) and (Raju and Pillai, 1999) used MCDM to evaluate the performance of irrigation systems, (Salgado *et al.*, 2009) evaluated water supply system alternatives with MCDM method, (Sun *et al.*, 2017) used MCDM to evaluate the performance of irrigation systems, (Hosseinzade *et al.*, 2017) proposed a decision-making model to select an appropriate channel structure in the irrigation system, used the Entropy method to determine the weights of the criteria, and the TOPSIS method to rank the alternatives, (Sapkota *et al.*, 2018) evaluated water supply system alternatives with the MCDM method and (Assefa *et al.*, 2018) used the MCDM technique and geographic information system (GIS) to evaluate potentially irrigable areas. (Karleuša *et al.*, 2018) stated that AHP, PROMETHEE and ELECTRE are suitable MCDM methods for decision making on irrigation systems. (Elshaikh *et al.*, 2018) stated that AHP, which is a MCDM method, is one of the four most widely used methods for evaluating irrigation system performance. (Hadelan, 2020) used the AHP method to compare and rank three possible locations for constructing an irrigation system in different regions of Croatia. (Karleuša *et al.*, 2019) used MCDM to solve various water management problems. (Veisi, 2022) used the AHP method in sustainable water management by developing a set of indicators to determine the most suitable irrigation system that has an impact on agricultural sustainability. (Tork *et al.*, 2021) used the AHP and COPRAS methods for weighting and ranking criteria for the modernization of the surface water distribution system.

The aim of this study is to determine the most effective method among the irrigation systems of the enterprises producing maize and to determine the weights of the criteria that are effective in choosing this method and to make policy recommendations according to these results. The COPRAS method, one of the MCDM methods, was used in determining the irrigation system preferences of the agricultural enterprises producing maize in the Çumra district of Konya province. The Entropy method was preferred in the weighting of the criteria in the mentioned method. This approach provides a comprehensive analysis to evaluate the efficiency of irrigation systems and to select the most appropriate system.

2. Material and methods

Primary data were used in the study and these data were collected using survey technique. The data were collected at the end of the 2024 harvest and were obtained by the researcher himself. Çumra district of Konya province was selected as the research area. The reason for choosing this district is that it ranks first in maize production in Konya province. While maize production is carried out in a total area of 185,505 hectares in Konya province, 35.20% of this area, that is, 35,200 hectares, is in Çumra district (TurkStat, 2023). By using these data, a total of 6000 maize producing enterprises were identified for the main sampling frame in the region. It emphasizes the share and importance of Çumra in maize production. The research data were obtained using survey technique and the surveys were conducted face to face with agricultural enterprises producing maize on a voluntary basis.

In the study, the sample size volume was calculated according to the formula below using simple random probability sampling based on finite main population ratios (Miran, 2003; Oğuz & Karakayacı, 2017).

$$n = \frac{N \times p \times (1-p)}{(N-1) \times \sigma^2_{p^x} + p \times (1-p)} \quad (1)$$

Formula;

n= Sample volume

N= Number of maize producing agricultural enterprises in the sampling frame (6000 units)

$\sigma^2_{p^x}$ = Variance

p=0.50

q=1-p

Using the formula in Equation (1), the sample volume was calculated as 95 with a 10% margin of error and 95% confidence interval.

2.1. *The methods applied in the selection of the most appropriate irrigation systems for maize production enterprises*

In order to determine the decision-making factors that are important in the selection of irrigation systems to be used in maize production, the opinions of corn (grain) producers as well as subject matter experts working in universities, public institutions and other organisations were taken. In addition, other studies conducted in the study area were also utilized. In a study conducted in Çumra district of Konya province, it was reported that 85% of the producers used sprinkler and drip irrigation methods (Kaya, 2017). In another study conducted in the same region, it was stated that sprinkler, drip irrigation, circular moving irrigation and linear moving irrigation systems were widely used for 9 different crops and the internal profitability of these systems were calculated (Ağızan, 2018). In another study conducted by Oğuz *et al.* (2021) in Çumra district, it was revealed that the rate of adoption of innovations in modern irrigation systems by producers was high, and the effects of sprinkler irrigation, drip irrigation and pivot irrigation systems on yield and profitability in corn production were determined. The aim of this process was to better understand the factors that will increase the effectiveness and efficiency of irrigation systems and to offer the most appropriate options to producers. The data obtained in this context will help to make informed and effective decisions on the selection of irrigation systems. The 10 criteria to be considered in the selection of irrigation systems were determined as brand, price, quality, product type, durability, labour requirement, economic life, energy cost, service facility and water saving. These criteria were evaluated on a 7-point scale (Very Poor (1), Poor (2), Somewhat Poor (3), Medium (4), Somewhat Good (5), Good (6) and Very Good (7)) for 5 alternative irrigation systems namely Sprinkler Irrigation, Drip Irrigation, Pivot Irrigation, Linear Irrigation and Drum Irrigation. COPRAS method was used to select the most appropriate irrigation system and entropy method was used to weight the criteria. These methods are given below.

2.1.1. *Entropy Method*

The entropy theory developed by Shannon in 1948 emphasizes that the quality and quantity of information in decision-making processes play a critical role in determining correct and reliable solutions. According to the entropy theory, the amount of information available determines the effectiveness in solving the problem and is a tool used to realize different evaluation situations in the decision-making process and helps to measure the amount of information provided (Wu *et al.*, 2011). The entropy method is not based on the subjective judgement of decision makers; instead, it functions as an objective weighting method and usually consists of five stages.

Step 1 - Determining the decision matrix: To construct the decision matrix, if you have k selection criteria and l alternatives, this matrix is usually presented with k criteria organized as columns and l alternatives as rows. In the matrix, x_{ij}, represents the performance value of the i. alternative according to the j. criterion.

$$A_{ij} = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1k} \\ x_{21} & x_{22} & \dots & x_{2k} \\ \vdots & \vdots & \vdots & \vdots \\ x_{l1} & x_{l2} & \dots & x_{lk} \end{bmatrix} \quad (2)$$

In the study, 10 (k=10) criteria (brand, price, quality, product type, durability, labour requirement, economic life, energy cost, serviceability and water saving) and 5 (l=5) alternatives (sprinkler irrigation, drip irrigation, pivot irrigation, linear irrigation and drum irrigation) were determined.

Step 2 - Decision Matrix Normalisation: In order to use different scale dimensions together, the initial matrix elements need to be standardized. This is done by using Equation (3) for normalisation of benefit-based criteria and Equation (4) for normalisation of cost-based criteria. These standardization steps ensure comparability of data at different scales.

$$r_{ij} = \frac{x_{ij}}{\max\limits_{j} x_{ij}} \quad (i = 1,2,\dots,l; j = 1,2,\dots,k) \quad (3)$$

$$r_{ij} = \frac{\min\limits_{j} x_{ij}}{x_{ij}}, \ \min\limits_{j} x_{ij} \neq 0 \ (i = 1,2,\dots,l; j = 1,2,\dots,k) \quad (4)$$

i = Alternative value,
j = Criterion value,
r_{ij} = Normalized value.

After the indices are standardized, they are shown in the normalized index matrix $R=\left[r_{ij}\right]_{l\times k}$.

In this study, while normalizing the decision matrix for weighting the criteria, price and energy cost criteria were determined as cost criteria. On the other hand, brand, quality, product type, durability, labour requirement, economic life, serviceability and water saving criteria were considered as benefit criteria.

Step 3 - Calculation of Entropy: In this step, first the values are calculated using Equation 5,

$$f_{ij}=\frac{r_{ij}}{\sum_{i=1}^{l} r_{ij}} \tag{5}$$

The values obtained in Equation (5) are used in Equation (6) to calculate the entropy value for each criterion. In this formula t; t=1/ln (m) the constant value used represents a value obtained by a specific calculation method.

$$e_j=-t\sum_{j=1}^{k} f_{ij}.\ln f_{ij}\ \ \left(i=1,2,...,l;\ j=1,2,...,k\right) \tag{6}$$

Since there are 5 decision alternatives in the above equation, the value of m is determined as 5. By substituting this value in the formula, the t value was calculated and used in Equation (6) as t=1/ln(5)=0.621.

Step 4 - Determining the entropy weight of the criteria: The magnitude of the entropy weight of the criteria indicates how effective that criterion is in the decision-making process and clarifies the importance of each criterion in the decision-making process. These weights were determined by calculating as specified in Equation (7).

$$w_j=\frac{1-e_j}{\sum_{j=1}^{k}\left(1-e_j\right)},\ \sum_{j=1}^{k} w_j=1,\ \left(j=1,...,k\right) \tag{7}$$

w_j = Weight value,
e_j = Entropy value.

The entropy method is an evaluation method that can be easily applied by calculations made directly on the data, independent of subjective evaluations, and provides completely objective results, and the criteria weights obtained from this method are then used in the COPRAS method.

2.1.2. *COPRAS Method*

The COPRAS (COmplex PRoportional ASsessment) method, developed by Zavadskas *et al.* in 1994, helps to determine the most appropriate option by providing an effective comparison of alternatives in multi-criteria decision-making problems. The method determines the appropriate solution by calculating the direct and indirect ratios of each alternative with the best and worst solutions while choosing the best one among many alternatives (Yücenur *et al.*, 2019). The basic calculation steps of the COPRAS method are as follows (Zolfani *et al.*, 2018).

Step 1: When constructing the decision matrix, if there are k selection criteria and l alternatives, this matrix is usually presented with k criteria organized as columns and l alternatives as rows. In the matrix a_{ij}, the performance value of the $i.$ alternative according to the $j.$ criterion is represented.

$$A=\left[a_{ij}\right]_{l\times k}=\begin{bmatrix} a_{11} & a_{12} & ... & a_{1k} \\ a_{21} & a_{22} & ... & a_{2k} \\ : & : & : & : \\ a_{l1} & a_{l2} & ... & a_{lk} \end{bmatrix} \tag{8}$$

Step 2 - Constructing the Standardized Decision Matrix: After the decision matrix A is obtained, the normalization process is performed using equation (9) and the normalized decision matrix $\bar{A}$ specified in equation (10) is reached.

$$\bar{a}_{ij}=\frac{a_{ij}}{\sum_{i=1}^{l} a_{ij}}\ \ \left(i=1,2,...,l;\ j=1,2,...,k\right) \tag{9}$$

i = Alternative value,
j = Criterion value,
$\bar{a}_{ij}$ = Normalized value.

$$\bar{A}=\left[\bar{a}_{ij}\right]_{l\times k}=\begin{bmatrix} \bar{a}_{11} & \bar{a}_{12} & ... & \bar{a}_{1k} \\ \bar{a}_{21} & \bar{a}_{22} & ... & \bar{a}_{2k} \\ : & : & : & : \\ \bar{a}_{l1} & \bar{a}_{l2} & ... & \bar{a}_{lk} \end{bmatrix}$$

$$\left(i=1,2,...,l;\ j=1,2,...,k\right) \tag{10}$$

Step 3 - Constructing the Weighted Standardized Decision Matrix: Each element of the decision matrix standardized by Equation (11) is multiplied by the relevant criteria weights. This is done to obtain the weighted performance values of each alternative with respect to the criteria.

$$\hat{a}_{ij} = \overline{a}_{ij} \times w_j \tag{11}$$

After this process is completed, the $\hat{A}$ weighted standardized decision matrix is obtained as shown in Equation (12).

$$\hat{A} = \left[\hat{a}_{ij}\right]_{l\times k} = \begin{bmatrix} \hat{a}_{11} & \hat{a}_{12} & ... & \hat{a}_{1k} \\ \hat{a}_{21} & \hat{a}_{22} & ... & \hat{a}_{2k} \\ : & : & : & : \\ \hat{a}_{l1} & \hat{a}_{l2} & ... & \hat{a}_{lk} \end{bmatrix}$$

$$\left(i = 1,2,...,l; j = 1,2,...,k\right) \tag{12}$$

In the study, a weighted standardized decision matrix was obtained by using the criteria weights obtained by Entropy method.

Step 4 - Calculation of S_{+1} and S_{-1} values: According to whether the criteria are of benefit or cost type, the total weighted standardized values are calculated by S_{+1} and S_{-1}. Here, S_{+1} represents the sum of benefit criteria and S_{-1} represents the sum of cost criteria. With the help of Equations (13) and (14), $\hat{a}_{+ij}$ and $\hat{a}_{-ij}$ represent the performance values with benefit and cost criteria, respectively.

$$S_{+i} = \sum_{j=1}^{v} \hat{a}_{+ij} \quad \left(i = 1,2,...,l; j = 1,2,...,v\right) \tag{13}$$

$$S_{-i} = \sum_{j=1}^{k} \hat{a}_{-ij} \quad \left(i = 1,2,...,l; j = 1,2,...,k\right) \tag{14}$$

Step 5 - Calculation of Relative Importance values: The relative importance value Q_i of the i. alternative is calculated using equation (15) and this value reflects the level of satisfaction achieved by the alternative. A higher value of Q_i indicates that the alternative is closer to the ideal alternative. Each alternative has a value between 0 and 100 per cent.

$$Q_i = S_{+i} + \frac{\sum_{i=1}^{l} S_{-i}}{S_{-i} \times \sum_{i=1}^{l} \frac{1}{S_{-i}}} \tag{15}$$

Step 6 - Calculation of performance index values and obtaining rankings: The performance index value is calculated by dividing the Q_i value of each alternative by the maximum Q_i value. The proportional similarity of any alternative to the ideal alternative is found in this step.

$$P_i = \left[\frac{Q_i}{Q_{\max}}\right] \times 100\% \quad \left(i = 1,2,...,l\right) \tag{16}$$

Finally, the preference ranking of the alternatives is determined by ranking the calculated P_i values from largest to smallest.

3. Research findings and discussion

At this stage of the study, irrigation systems were evaluated and ranked according to the criteria determined by using the Entropy and COPRAS methods. Firstly, an initial decision matrix was formed by taking the arithmetic mean of the scores given for each criterion for the determination of irrigation systems in maize producing enterprises. In the next step, the importance coefficients of the criteria were calculated with the Entropy method and the ranking of the irrigation systems was carried out with the COPRAS method. Calculations were made in Microsoft Excel.

3.1. *Obtaining Criteria Weights with Entropy*

Step 1 - Creating the Decision Matrix: In the construction of the decision matrix; the answers of 95 agricultural enterprises for each criterion were summed and averaged and the decision matrix in Table 1 was obtained.

Step 2 - Decision Matrix Normalization: The values determined as cost criteria are standardized by dividing by the maximum value. Other values determined as benefit criteria were normalized by dividing by the minimum value. The standardized values obtained are presented in Table 2.

The rows of the standardized values of the decision matrix contain the evaluation criteria and the columns contain the decision alternatives.

Table 1 - Decision Matrix for irrigation system.

CRITERIA	*Irrigation System*						
	Sprinkler Irrigation	*Drip Irrigation*	*Pivot Irrigation*	*Linear Irrigation*	*Drum Irrigation*	*Max*	*Min*
Brand	4	4,4	5,2	5,7	5,2	5,7	4
Price	3,5	3,8	5,6	5,7	6	6	3,5
Quality	3,7	3,9	5,2	6,1	5,2	6,1	3,7
Product Type	4,9	5	4,9	5	4,8	5	4,8
Durability	3,6	3,5	5,2	5,8	5,4	5,8	3,5
Labour Requirement	2,9	5,1	6,2	6,8	6,2	6,8	2,9
Economic Life	3,4	3,2	5	5,1	4,9	5,1	3,2
Energy Cost	4,6	2,9	1,6	1,3	1,6	4,6	1,3
Service Facility	4,5	4,6	4,8	4,8	4,8	4,8	4,5
Water Saving	3,8	5,1	6,1	7	6	7	3,8

Table 2 - Standardized values for irrigation system.

CRITERIA	*Irrigation System*					*Total*
	Sprinkler Irrigation	*Drip Irrigation*	*Pivot Irrigation*	*Linear Irrigation*	*Drum Irrigation*	
Brand	0,701	0,771	0,912	1,000	0,912	4,298
Price	1,000	0,921	0,625	0,614	0,583	3,743
Quality	0,606	0,639	0,852	1,000	0,852	3,951
Product Type	0,980	1,000	1,000	0,980	0,960	4,920
Durability	0,621	0,603	0,896	1,000	0,931	4,051
Labour Requirement	0,426	0,750	0,911	1,000	0,911	4,000
Economic Life	0,666	0,627	1,000	0.981	0,961	4,235
Energy Cost	0,282	0,448	0,812	1,000	0,812	3,355
Service Facility	0,937	0,958	1,000	1,000	1,000	4,895833
Water Saving	0,542	0,728	0,871	1,000	0,857	4,000

Step 3 - Calculation of entropy: In this step, f_{ij} is first normalized using equation (4). These values can be seen as the re-standardization of the standardized matrix elements. When calculating the values, the values in each row in Table 2 are normalized by dividing them by the sum of the rows to which they belong. The decision matrix obtained after normalization is shown in Table 3.

Then $\ln f_{ij}$ is obtained for the realisation of the operations in Equation (5). After calculating this value, $f_{ij} \times \ln f_{ij}$ is found. Moreover, the k value in Equation (5) is the entropy coefficient and represents the logarithmic form of the number of alternatives in the decision matrix. The entropy values (e_{ij}) obtained with the help of Equation (5) are presented in Table 4.

Step 4 - Calculation of entropy weight: Using the entropy values (e_{ij}) obtained in Equation (5), the weight value for each criterion obtained in Equation (6) is obtained in Table 4.

The obtained weight values (w_i) will be used as weight values in the COPRAS method to be used in irrigation system selection. While selecting the most suitable irrigation system in the study, the standardized values in Table 3 were calculated by using the pairwise

Table 3 - Normalized decision matrix.

CRITERIA	*Irrigation System*				
	Sprinkler Irrigation	*Drip Irrigation*	*Pivot Irrigation*	*Linear Irrigation*	*Drum Irrigation*
Brand	0,163	0,179	0,212	0,232	0,212
Price	0,267	0,246	0,166	0,164	0,155
Quality	0,153	0,161	0,215	0,253	0,215
Product Type	0,199	0,203	0,203	0,199	0,195
Durability	0,153	0,148	0,221	0,246	0,229
Labour Requirement	0,106	0,187	0,227	0,250	0,227
Economic Life	0,157	0,148	0,236	0,231	0,226
Energy Cost	0,084	0,133	0,242	0,297	0,242
Service Facility	0,191	0,195	0,204	0,204	0,204
Water Saving	0,135	0,182	0,217	0,250	0,214

Table 4 - Entropy and weight values of the criteria.

Criteria	*Brand*	*Price*	*Quality*	*Product Type*	*Durability*	*Labour Requirement*	*Economic Lifetime*	*Energy Cost*	*Service Facility*	*Water Saving*
e_{ij}	0,995	0,983	0,989	0,999	0,986	0,977	0,987	0,947	0,999	0,987
w_i	0,033	0,114	0,074	0,0004	0,091	0,154	0,0831	0,361	0,002	0,0835

comparison matrix in Table 1 and the weights were determined by using the Entropy values in Table 4. According to the data obtained in Table 4, it was determined that the most important criterion in irrigation system selection was 'Energy Cost' with a weight of 36.16%. The increase in agricultural production and the development of agricultural technology have increased the need and demand for energy all over the world (Moghaddasi and Pour, 2016). Energy consumption has increased with the effect of increasing demand, especially with the use of fossil fuels, bringing both economic and environmental challenges. As a matter of fact, in addition to preventing environmental pollution by reducing the consumption of fossil fuels, it has become a necessity to use energy effectively and efficiently in agriculture in order to save energy and reduce input costs (Mohammedi *et al.*, 2008). When modern irrigation systems are designed for energy efficiency, they can provide lower energy costs and better performance. This can benefit both economically and environmentally. Keeping energy costs low allows farmers to sell their products at more competitive prices and increase profits. Furthermore, energy sources used for agricultural irrigation are limited and can be difficult or costly to access in some regions. Therefore, energy efficiency and cost are critical to the sustainability of the irrigation system.

After the Energy Cost criterion, 'Labour Requirement' ranks second and has an impact of 15.49% in decision making. Systems that require more labour often require more time and effort, and in recent years there have been difficulties in accessing sufficient and skilled labour. The average age in agricultural enterprises is increasing day by day. The decrease in the number of people participating in the labour force in rural areas, the increase in migration from rural to urban areas, finding temporary workers due to the intermittent nature of agricultural production, and the inadequate wages of workers have led enterprises to employ migrant and asylum-seeker workers (Fuglie, 2018). As a matter of fact, these problems play an important role in the fact that labour requirement takes the second place in the criteria weighting. Automated irrigation sys-

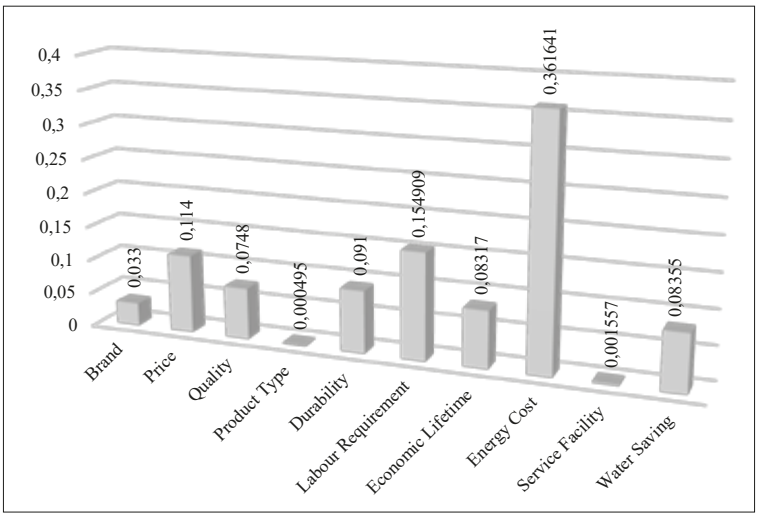

Figure 1 - Importance weights of criteria and their place in the rankings.

tems used to reduce labour requirements generally require less manpower, which reduces operating costs. Automation can make irrigation processes more efficient by minimising the need for labour.

Among the decision criteria, 'Price' criterion ranks third with a weight of 11.43%. It is an expected result that the price ranks third in the preference criteria of the enterprises to increase the level of equipment. Agricultural enterprises usually work with limited budgets and price directly influences the choice of an irrigation system by the agricultural enterprise. Price influences farmers or agribusinesses to choose according to their initial investment budget. An affordable system can shorten the return on investment period and reduce start-up costs. Especially for small-scale enterprises, investment cost is very important in terms of sustainability. In countries where small-scale agricultural enterprises are widespread, it is necessary to meet capital needs from foreign sources (Işıklı *et al.*, 1994). Investment in tools and equipment in agriculture is critical to increase productivity and optimise the workforce. However, price plays a major role in these investments, not only in terms of initial cost, but also in terms of long-term productivity and cost-effectiveness. High quality and correctly priced equipment can save time and labour at every stage of the farming process. In addition, choosing affordable yet reliable equipment can reduce the total cost of ownership by minimising maintenance and repair costs. Therefore, price is a strategic factor in agricultural equipment investments in terms of both initial expenditure and long-term economic efficiency. As a matter of fact, price is very important in terms of investment cost, product performance, operating profitability balance and sustainability.

In other criteria, 'Durability' ranks fourth with 9.16%, 'Water Saving' ranks fifth with 8.35%, 'Economic Life' ranks sixth with 8.31%, 'Quality' ranks seventh with 7.47%, 'Brand' ranks eighth with 3.39%, 'Service Facility' ranks ninth with 0.15% and 'Product Type' ranks last with 0.04%. In the study region, where the severity of drought has increased due to climate change, a significant withdrawal of groundwater is observed. (Chebil *et al.*, 2024), in a study conducted in Tunisia, found that providing training on new technologies and water saving, providing financial support and incentives contributed to early adoption by providing access to these technologies.

As seen in Figure 1, the importance weights of the 10 criteria are listed as follows: Energy Cost > Labour Requirement > Price > Durability > Water Saving > Economic Life > Quality > Brand > Service Facility > Product Type. The sum of the weight values assigned to each of these criteria is equal to 1. This ranking shows the relative importance of each criterion in the total evaluation.

3.2. *Irrigation Systems Ranking with COPRAS Method*

Step 1 - Creating the Decision Matrix: In the first step of the COPRAS method, the decision matrix is created. This step is the same as the first step of the Entropy method. The values in Table 1 will also be used in the COPRAS method.

Step 2 - Constructing the Normalized Decision Matrix (R): Equation (8) in the COPRAS method was used in the normalization process to convert the criterion values of the alternatives into fixed units. The normalized decision matrix is shown in Table 5.

Step 3 - Constructing the Weighted Normalised Decision Matrix: The weighted normalized decision matrix in Table 6 was obtained by multiplying each *i.*alternative value over the normalized decision matrix in Table 5 by the criteria weights determined in Table 4 obtained in the last step of the Entropy method.

Step 4 - Obtaining S_{+1} and S_{-1} values: In this step, the total weighted standardized values of the decision alternatives according to whether the criteria are of benefit or cost type are calculated using Equation (12) and Equation (13). The solution sets obtained as a result of the calculations are presented in Table 7.

Table 5 - Normalized decision matrix according to COPRAS method.

CRITERIA	*Irrigation System*				
	Sprinkler Irrigation	*Drip Irrigation*	*Pivot Irrigation*	*Linear Irrigation*	*Drum Irrigation*
Brand	0,163265	0,179592	0,212245	0,232653	0,212245
Price	0,142276	0,154472	0,227642	0,231707	0,243902
Quality	0,153527	0,161826	0,215768	0,253112	0,215768
Product Type	0,199187	0,203252	0,199187	0,203252	0,195122
Durability	0,153191	0,148936	0,221277	0,246809	0,229787
Labour Requirement	0,106618	0,1875	0,227941	0,25	0,227941
Economic Life	0,157407	0,148148	0,231481	0,236111	0,226852
Energy Cost	0,383333	0,241667	0,133333	0,108333	0,133333
Service Facility	0,191489	0,195745	0,204255	0,204255	0,204255
Water Saving	0,135714	0,182143	0,217857	0,25	0,214286

Table 6 - Weighted normalized decision matrix values.

CRITERIA	*Irrigation System*				
	Sprinkler Irrigation	*Drip Irrigation*	*Pivot Irrigation*	*Linear Irrigation*	*Drum Irrigation*
Brand	0,00552	0,006072	0,007176	0,007867	0,007176
Price	0,01619	0,017578	0,025904	0,026367	0,027755
Quality	0,011423	0,01204	0,016054	0,018832	0,016054
Product Type	9,82E-05	0,0001	9,82E-05	0,0001	9,62E-05
Durability	0,013965	0,013578	0,020172	0,0225	0,020948
Labour Requirement	0,016437	0,028907	0,035141	0,038542	0,035141
Economic Life	0,013781	0,012971	0,020267	0,020672	0,019861
Energy Cost	0,137966	0,086979	0,047988	0,038991	0,047988
Service Facility	0,000297	0,000303	0,000316	0,000316	0,000316
Water Saving	0,011285	0,015145	0,018115	0,020788	0,017818

Step 5 - Calculation of Relative Importance Values: In this step, the relative importance value of the *i*. alternative, Q_i, is calculated using Equality (14). The obtained Q_i value is shown in Table 8.

Step 6 - Calculation of performance index values and obtaining rankings: In the last step of the COPRAS method, the performance index value of each alternative is calculated. This value is obtained by dividing the Q_i value of each alternative by the highest Q_i value and is expressed using Equality (15). The P_i performance index values obtained as a result of the application are presented in Table 8.

As seen in Table 8, the system with the highest performance index score is linear irrigation. The linear irrigation system is followed by pivot irrigation with 89.51 in the second place, drum irrigation with 88.47 in the third place, drip irrigation with 65.69 in the fourth place and sprinkler irrigation with 49.41 in the last place. The results obtained in Table 8 support the findings of Neisi *et al.* (2020) and determined that linear and drip irrigation systems were generally the most suitable systems. In addition, Veisi *et al.* (2022) emphasized that pressurized irrigation systems are the best systems for developing sustainable water management in agriculture. Bigdeli (2021) revealed that the linear irrigation system is more effective than the wheel-moving (pivot) irrigation system in terms of water distribution in different climatic conditions. Rahmani *et al.* (2017) stated that pressurized irrigation systems can be an effective technology for improving production and reducing input costs by reducing water consumption by 17%.

The data obtained as a result of the survey conducted with agricultural enterprises in the study area were analyzed using the COPRAS method. As a result, the order of preference among irrigation system alternatives was determined as Linear Irrigation > Pivot Irrigation > Drum Irrigation > Drip Irrigation > Sprinkler Irrigation (Figure 2).

In the study, it was determined that modern irrigation systems are widely used. It has been determined that agricultural enterprises in the research region are open to innovations and are aware of the contributions of modern irrigation

Table 7 - S_{+1} and S_{-1} values of alternatives.

Irrigation System	S_{+1}	S_{-1}
Sprinkler Irrigation	0,07280	0,15415
Drip Irrigation	0,08911	0,10455
Pivot Irrigation	0,11734	0,07389
Linear Irrigation	0,12961	0,06535
Drum Irrigation	0,11741	0,07574

Figure 2 - Score obtained according to the COPRAS method (%).

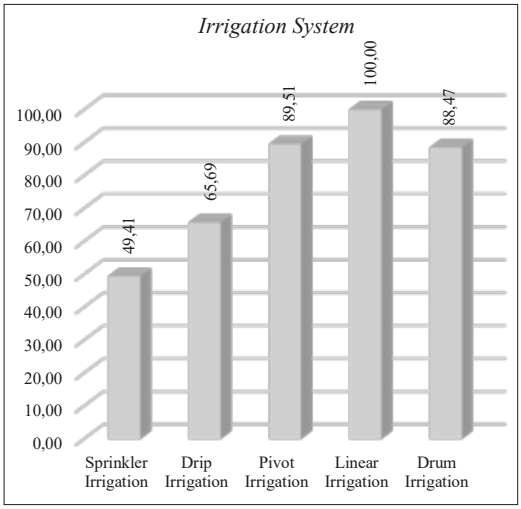

Table 8 - Alternatives Q_i, scores and rankings.

Irrigation System	S_{+1}	S_{-1}	1/ S_{-1}	Q_i	P_i	*Ranking*
Sprinkler Irrigation	0,072807	0,154157	6,486907	0,125708	49.41	5
Drip Irrigation	0,089117	0,104557	9,56418	0,167113	65.69	4
Pivot Irrigation	0,11734	0,073893	13,53314	0,227704	89.51	2
Linear Irrigation	0,129617	0,065357	15,30048	0,254394	100	1
Drum Irrigation	0,117412	0,075743	13,20255	0,22508	88.47	3

systems to energy, water and labor efficiency. The fact that these systems ensure the effective use of water resources and reduce input costs has made a significant contribution to increasing the awareness of producers. Additionally, it has been stated that modern irrigation systems increase the profitability of businesses by reducing input costs (Oğuz *et al.*, 2021). Factors such as the increase in the average age in agricultural enterprises, the problem of finding foreign labor, energy costs, the closed basin of the region and the decrease in groundwater in recent years have played an important role in the spread of modern irrigation methods.

4. Conclusions and recommendations

In recent years, increasing competition conditions, developing seed technology, deepening of the current labor force problem in agriculture with the increase in the average age of enterprises, drought that has increased in severity with the effect of climate change, increase in input costs, technological developments in equipment and machinery used in agriculture, equipment and machinery incentives of the Ministry of Agriculture and Forestry, subsidized loans of banks have made significant contributions to the development of technology usage level of enterprises. In the recent period, the provision of some supports on the condition of economical irrigation systems has been an important factor in preferring modern irrigation systems. It is known that certain criteria as well as the capital power of enterprises play a role in the preference of these systems. Therefore, the MCDM model has been proposed in this study in order to determine the important factors in the selection of irrigation systems for agricultural enterprises.

In the first stage, criteria for irrigation system selection were determined by literature review, then ten criteria were included in the study based on expert opinions. The Entropy method was used to determine the weights of the criteria and irrigation systems were evaluated with COPRAS method. The findings show that energy cost ranks first and labor requirement ranks second in the order of weight of irrigation system criteria. According to the study results, it was understood that the most preferred system among the determined irrigation systems is the linear irrigation system.

The most important criterion in determining the criteria affecting irrigation systems was determined to be energy cost. The rapid increase in input costs and the increase in energy costs forced operators to take saving measures. The potential of modern irrigation systems to reduce energy costs has made this criterion a priority factor in irrigation system selection. At the same time, the fact that these systems minimize the need for human labor has been determined as the second choice criterion for labor. In regions where maize is cultivated intensively due to its high profitability, the fact that these two basic criteria are at the forefront and the linear irrigation system stands out as the most preferred system shows that the Ministry of Agriculture and Forestry's increasing incentives to support this area and the banks' offering subsidized loans to these systems are critical for the sustainability of production in the study region. In addition, since the requirement of only drip irrigation in the maize Differential Payment Support of the Ministry of Agriculture and Forestry and the fact that producers who irrigate with pivot irrigation systems are not allowed to benefit from the support restricts the use of this modern irrigation system, it is thought that the scope should be expanded and producers who irrigate with pivot (pivot, linear, drum) irrigation systems should also benefit from the differential payment support. It is noteworthy that water saving ranks fifth among the criteria; irregularities in rainfall and the decrease in groundwater require producers to be more careful in this regard. Farmers who grow grain, sugar beet, carrot, sunflower and forage crops for cattle in the region should be trained on water conservation and use, and the region's water availability should be taken into account within the scope of production planning. It is recommended that the Ministry of Agriculture and Forestry switch to a planned production model starting from the 2025 production season, and that irrigation systems that will save water be expanded in the study area, which is in the water constraint region, and that more farm-

er meetings, public service announcements and symposiums be organized to raise awareness among producers.

References

Ağızan S., 2018. *Tarımsal sulama sistemlerinin karşılaştırmalı yatırım analizi*; Konya ili Çumra ilçesi örneği. Selçuk Üniversitesi Fen Bilimleri Enstitüsü.

Assefa T., Jha M., Reyes M., Srinivasan R., Worqlul A.W., 2018. Assessment of suitable areas for home gardens for irrigation potential, water availability, and water-lifting technologies. *Watermark*, 10(4): 495. https://doi.org/10.3390/ w10040495.

Atalık A., 2005. *Küresel Isınma, Su Kaynakları ve Tarım Üzerine Etkileri*. Ankara: Ziraat mühendisleri odası yayınları.

Bigdeli Z., Ojaghlou H., 2021. Performance Assessment of Wheel Move and Linear Moving Irrigation Systems in Different Climatic Conditions. *Irrigation Sciences and Engineering*, 44(2): 11-24.

Chebil A., Thabet C., Rached Z., Koussani W., Souissi A., Setti M., 2024. Explaining drivers of farmers' willingness for early adoption of enhanced irrigation technologies: Case of Tunisia. *New Medit*, 23(1): 95-102.

Çiftci F., 2024. Determination of Factors Affecting the Cumin Production Decision of Agricultural Enterprises: The Case of Konya Province. *Turkish Journal of Agriculture-Food Science and Technology*, 12(8): 1281-1286.

Duckstein L., Treichel W., Magnouni S.E., 1994. Ranking ground-water management alternatives by multicriterion analysis. *Journal of Water Resources Planning and Management*, 120(4): 546-565. https://doi.org/10.1061/(ASCE)07339496(1994)120:4(546).

Elshaikh A.E., Jiao X., Yang S.H., 2018. Performance evaluation of irrigation projects: Theories, methods, and techniques. *Agricultural Water Management*, 203: 87-96.

Eryılmaz G.A., Kılıç O., Gülser C., 2022. Sinop ilinde çiftçilerin sulama yöntemleriyle ilgili tercihleri. *Türkiye Tarımsal Araştırmalar Dergisi*, 9(2): 209-215.

Fuglie K., 2018. Is agricultural productivity slowing? *Global Food Security-Agriculture Policy Economics and Environment*, 17: 73-83.

Hadelan L., Jez Rogelj M., Gugic J., Crncan A., Zrakic M., 2020. Multi-criteria evaluation of locations for irrigation system implementation. *Irrigation and drainage*, 69(5): 1022-1032.

Haffaf A., Lakdja F., Meziane R., Abdeslam D.O., 2021. Study of economic and sustainable energy supply for water irrigation system (WIS). *Sustainable Energy, Grids and Networks*, 25: 100412.

Hosseinzade Z., Pagsuyoin S.A., Ponnambalam K., Monem M.J., 2017. Decision-making in irrigation networks: Selecting appropriate canal structures using multi-attribute decision analysis. *Science of the Total Environment*, 601: 177-185.

Işıklı E., Üzmez Y., Güler S., Atlı F., Pekince Ö., 1994. *Türkiye Tarımında Sermaye Sorunları*, *Tarım Haftası Sempozyumu*. Ankara: Ziraat Mühendisleri Odası.

Karleuša B., Hajdinger A., Tadić L., 2018. Use of multicriteria analysis method DEXi to define priorities in implementation of irrigation plans. *MDPI - Proceedings*, 11(2): 663.

Karleuša B., Hajdinger A., Tadic L., 2019. The application of multi-criteria analysis methods for the determination of priorities in the implementation of irrigation plans. *Water*, 11(3): 501. https://doi.org/10.3390/w11030501.

Kaya N., 2017, *Konya ili sulama birliklerinin tarımsal sulama işletmeciliğindeki yeri*; Çumra Sulama Birliği örneği, Selçuk Üniversitesi Fen Bilimleri Enstitüsü.

Manos B., Moulogıannı C., Papathanasıou J., Bournarıs T., 2009. A fuzzy multicriteria mathematical programming model for planning agricultural regions. *New Medit*, 8(4): 22-27.

MGM (General Directorate of Meteorology), 2023a. *2023 Yılı Yıllık Yağış Değerlendirmesi*, https://www.mgm.gov.tr/FILES/arastirma/yagisdegerlendirme/2023yagisdegerlendirmesi.pdf.

MGM (General Directorate of Meteorology), 2023b. *T.C. çevre, şehircilik ve iklim değişikliği bakanlığı - Meteoroloji Genel Müdürlüğü* (accessed: 9 November 2024) https://www.mgm.gov.tr/veridegerlendirme/il-veilceleristatistik.aspx?k=undefined&m=KONYA.

Ministry of Environment, Urbanization and Climate Change, 2023. *Çevresel Göstergeler*. https://cevreselgostergeler.csb.gov.tr/su-kullanimi-i-85738, Ankara.

Miran B., 2003. Temel İstatistik, *Ege Üniversitesi Basımevi.* İzmir: Bornova.

Moghaddasi R., Pour A A., 2016. Energy consumption and total factor productivity growth in Iranian agriculture. *Energy Reports*, 2: 218-220.

Mohammedi A., Tabatabaeefar A., Shahin S., Rafiee S., Keyhani A., 2008. Energy use and economical analysis of potato production in Iran a case study:

Ardabil Province. *Energy Conversion and Management*, 49(3): 566-3570.

Neissi L., Albaji M., Nasab S.B., 2020. Combination of GIS and AHP for site selection of pressurized irrigation systems in the Izeh plain, Iran. *Agricultural Water Management*, 231: 106004.

Oğuz C., Çiftci İ., Çiftci F., 2021. The effects of different irrigation techniques on the cost of production of maize: sample case from Çumra District of Konya, Turkey. *Custos e Agronegocıo Online*, 17(1): 286-302.

Oğuz C., Karakayacı Z., 2017. *Tarım ekonomisinde araştırma ve örnekleme metodolojisi.* Konya: Atlas Akademi, 183 pp.

Oğuz C., Örs A., Öğür A.Y., Çelik Y., 2024. Determining the factors affecting the climate-friendly innovative technology usage levels of sheep farms. *New Medit*, 23(1): 55-72.

Oğuz C., Yener A., 2017. Economic analysis of dairy cattle enterprises: The case of Konya Province. *European Countryside*, *Sciendo*, 9(2): 263-273. DOI: 10.1515/euco-2017-0016, Mendeliu University.

Özsoy S., 2009. *Su ve yaşam: suyun toplumsal önemi.* Ankara: Ankara Üniversitesi Sosyal Bilimler Enstitüsü. Yüksek lisans tezi.

Rahmani S., Yazdani S., Mahmoudi A., Shokat Fadaei M., Souri A., 2017. An investigation into the economic benefits and savings resulting from the pressurized irrigation system development in Ardabil province. *J. Hydrol. Sci. Environ*., 1(2): 1-11. https://doi.org/10.22111/JHE.2017.3353.

Raju K.S., Pillai C.R.S., 1999. Multicriterion decision making in performance evaluation of an irrigation system. *European Journal of Operational Research*, 112(3): 479-488. https://doi. org/10.1016/S0377-2217(98)00007-1.

Salgado P.P., Quintana S.C., Pereira A.G., del Moral I.L., Mateos, B.P., 2009. Participative multi-criteria analysis for the evaluation of water governance alternatives. A case in the Costa del Sol (Málaga). *Ecological Economics*, 68(4): 990-1005. https://doi.org/10.1016/j.ecolecon.2006.11.008.

Sapkota M., Arora M., Malano H., Sharma A., Moglia M., 2018. Integrated evaluation of hybrid water supply systems using a PROMETHEE–GAIA approach. *Watermark*, 10(5): 610. https://doi.org/10.3390/w10050610.

Sun H., Wang S., Hao X., 2017. An improved analytic hierarchy process method for the evaluation of agricultural water management in irrigation districts of North China. *Agricultural Water Management*, 179: 324-337. https://doi.org/10.1016/j.agwat.2016.08.002.

TAGEM (Tarımsal Araştırmalar ve Politikalar Genel Müdürlüğü), 2017. *Türkiye'de Sulanan Bitkilerin Bitki Su Tüketimleri*. https://www.tarimorman.gov.tr/TAGEM (accessed: 12 August 2024).

Tian G., Lu W., Zhang X., Zhan M., Dulebenets M.A., Aleksandrov A., Fathollahi-Fard A.M., Ivanov M., 2023. A survey of multi-criteria decision-making techniques for green logistics and low-carbon transportation systems. *Environmental Science and Pollution Research*, 30(20): 57279-57301.

Tork H., Javadi S., Shahdany S.M.H., 2021. A new framework of a multi-criteria decision making for agriculture water distribution system. *Journal of Cleaner Production*, 306: 127178.

TurkStat, 2023. *Bitkisel Üretim İstatistikleri*, https://www.tuik.gov.tr (accessed: 20 July 2024).

Veisi H., Deihimfard R., Shahmohammadi A., Hydarzadeh Y., 2022. Application of the analytic hierarchy process (AHP) in a multi-criteria selection of agricultural irrigation systems. *Agricultural Water Management*, 267: 107619.

Wu J., Sun J., Liang L., Zha Y., 2011. Determination of weights for ultimate cross efficiency using Shannon entropy. *Expert Systems with Applications*, 38(5): 5162-6165. https://doi.org/10.1016/j.eswa.2010.10.046.

WWF (Doğal Hayatı Koruma Vakfı Türkiye), 2014. *Türkiye'nin Su Riskleri Raporu*, https://www.wwf.org.tr/?4180/turkiyenin-su-riskleri-raporu (accessed: 20 July 2024).

Yücenur N.G., Şenkan Ç., Kara G.N., Türker Ö., 2019. Birleştirilmiş SWARA-COPRAS yaklaşımını kullanarak trüf mantarı yetiştirilmesi için bölge seçimi. *Erzincan University Journal of Science and Technology*, 12(3): 1232-1253.

Zavadskas E.K., Kaklauskas A., Šarka V., 1994. The new method of multicriteria complex proportional assessment of projects. *Technological and Economic Development of Economy*, 1(3): 131-139.

Zolfani S.H., Pourhossein M., Yazdani M., Zavadskas E.K., 2018. Evaluating construction projects of hotels based on environmental sustainability with MCDM framework. *Alexandria Engineering Journal*, 57(1): 357-365.

Why is there a shortage of agricultural labor in Algeria? Evidence from M'zirâa, southern Algeria's leading vegetable market

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Abstract

The amplification of labor shortages has become an inescapable reality for many Algerian farmers in recent years. To study this issue, systemic surveys were conducted in 125 farms in the vegetable crops pole of M'zirâa (southern Algeria). A labor shortage is reported on 56.80% of farms. The primary causes, as identified by respondents, are poor working and living conditions (76.67%) and low wages, which are considered insufficient by both workers and new settlers (70.67%). On the other hand, employment opportunities in the tertiary sector offer more interesting incomes compared to agricultural activity, which is becoming less remunerative and less attractive. Furthermore, the employment policies help the unemployed to create their micro-enterprises (78.67%). However, human capital (62.67%), personal behavior (76.00%) and the socio-economic situation of the young workforce (55.33%) explain their negative work perception of work in agriculture. The logistic regression results show that remuneration and incentives, employment opportunities and youth personal behavior affect significantly the likelihood of a labor shortage. Policymakers should focus on improving labor conditions, incentivizing wages, and promoting labor-saving technologies to address agricultural labor shortages and enhance the sector's appeal, particularly for youth.

Keywords: *Agricultural labor market, Labor shortage, Labor segmentation, Human capital, Vegetable crops, Algeria.*

1. Introduction

Over the past 20 years, agricultural employment has declined from 40% to 27% of total world employment. Highly contrasting variations have been observed between low-income countries (59%) and high-income countries (3%). In contrast to employment growth in the service sector (40% to 50%) and a slight increase in industry (20% to 23%), unemployment rates fluctuate between 6.1% and 6.9%, with unemployment among young people aged 15 to 24 rising from 13.1% to 17.2% (ILO, 2021). Research on agricultural labor

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issues has captured the attention of various scientific disciplines such as sociology, ergonomics, and economics. These fields have introduced diverse research methodologies and analytical approaches, covering topics such as occupational health in agriculture, immigration trends and the dynamics of agricultural and rural labor markets, gender disparities and wage discrimination, working conditions, household strategies for allocating family labor, organizing farm work, and the management of employment within global value chains (Malanski *et al.*, 2019; 2021; 2022).

1.1. *Understanding the global phenomenon of agricultural labor shortage*

The agricultural labor shortage is attributed to a perceived hysteresis in certain qualifications and the reluctance of agricultural workers who migrate to non-agricultural sectors due to the significant wage gap disparities between the two sectors. This evidence is confirmed in Richards and Patterson's (1998) study of the farm labor market in Washington State. The shortage is evident in the United States across various agricultural productions such as arboriculture, vegetable and livestock farming, and across several states, particularly California (Taylor, 2010; Hertz and Zahniser, 2013; Richards, 2018; Taylor and Charlton, 2019a). In France, non-agricultural employment in rural regions has grown faster than agricultural employment since the 1980s (Blanc and Perrier-Cornet, 1999). Industrialization has led to a significant rural exodus as high wages attract the poorest rural residents to urban areas. The workers' shortage is evident in cities, but more so in rural areas, particularly for manual and low-paid arduous work (Darpeix, 2013). Even in developing countries such as Togo and Benin, farmers complain about labor shortages during peak periods due to inadequate family support and the scarcity and high cost of manual labor (Batawila and Pleines, 2010). In Ethiopia, labor shortages are associated with transportation delays and the cancellation of coffee production contracts. Local labor shortages forced cocoa producers in Ghana, tea producers in India and Kenya to increase working hours (ILO, 2022).

The problem of agricultural labor shortage stills relevant in high-income countries with a long tradition of importing foreign labor. In the United States, migrant worker acquisition programs - mainly Mexican - have been in place since 1917 for seasonal (Martin, 2007; Taylor, 2010; Martin, 2014; Charlton and Taylor, 2016; Taylor and Charlton, 2019a). Despite immigration restrictions, Western European countries in particular (France, Spain, Italy, Germany, Great Britain) have continued to import seasonal workers from Eastern Europe (Albania, Poland, Romania, Bulgaria) and North Africa (Morocco, Tunisia) (Morice and Michalon, 2008). Farmers in these countries face challenges in attracting migrant workers due to precarious employment and working conditions, which are denounced by farmworker advocates who urge governments to strictly enforce labor laws. However, these unfavorable conditions, characterized by low wages, lack of social security and informal contracts with labor organizations, are indispensable to maintain the profitability of fruit and vegetable farming activities, which are the main sectors for hiring immigrant workers (Morice and Michalon, 2008).

1.2. *Algeria's labor market context: major challenges for agricultural employment*

In the Algerian labor market context, the overall labor market situation highlights a decrease in the unemployment rate from 28.9% in 2000 to 11.4% in 2019, marked by a very slight increase over the last decade, but it remains higher among young people in the 16-24 age group, ranging from 54.9 to 26.9% (ONS, 2021a). These changes are the result of demographic mutations, in particular the evolution of the active population, mainly young people, and their activity patterns, with still low female participation, as well as economic development and various employment policies (Musette, 2014). Moreover, a third of Algeria's active population (around 12.3 million workers) was located in rural areas in 2017, with an unemployment rate of 9.4% compared to a rate of 12.9% recorded in urban areas (ONS, 2017). In fact, apart from the high concentration of unemployed people in urban areas, living in rural areas facilitates access to agricultural em-

ployment, often as family workers, but restricts opportunities for informal urban employment (Hammouda and Souag, 2012; Lassassi and Hammouda, 2012a). The rural labor force has no alternative but to engage in several off-farm activities to earn substantial external income, or to settle in small farms due to the limited promotion of rural employment (Bessaoud, 2006). The share of agricultural labor in total employment has been steadily declining, falling from 14.1% to 9.6% over the past 20 years (ONS, 2021a), compared to 51% in 1966 (Bedrani and Cheriet, 2012). The service and trade sectors strongly attract more than 60% of total employees (ONS, 2021a). Although agriculture is the main sector providing employment in rural areas, its share of the total employed population declined from 39.5% to 22.3% between 2001 and 2017. At the same time, trade and services captured more rural workers, increasing from 39% to 46.4 % (ONS, 2001; 2017). This paradoxical evolution can be explained by the improving life quality of the rural residents, made possible by the redistribution of oil rents, which simulates their preference for non-agricultural jobs (Bedrani and Cheriet, 2012). Rural exodus has undoubtedly contributed to the reduction of agricultural workforce, boosted by the expansion of the industrial sector in the early 1970s, which promised advantageous incomes. Agriculture, previously the largest employer with 48% of the workforce in 1970, fell to 40% by 1973. Meanwhile, underemployment disproportionately affected those remaining in rural areas, impacting 31.7% of wage earners (Lassassi and Hammouda, 2012b).

In parallel to long-term unemployment – 63% of the unemployed (ONS, 2019) – there is talk nowadays of a shortage of agricultural labor. Rather, it is a question of a labor force that refuses to work, particularly young people (Bessaoud *et al.*, 2019). When discussing this point, it would be interesting to mention that the NEET rate in Algeria – referring to young people aged 16-24 who are neither employed nor in education or training – reached 26.2% in 2019 (ETF, 2021). This high rate, as in the MENA region (Middle East and North Africa), can be partly explained by youth discouragement, stemming from poor working conditions in the formal sector and high unemployment due to a mismatch between high education levels and employability in the labor market, as highlighted in the same report. Researchers have observed a number of reasons for the labor shortage, fundamentally due to the arduous living conditions in rural areas: hard agricultural work, low wages, insecure jobs outside the scope of employment legislation, weak professional qualifications and training, and more underemployed rural population with low education levels (Bessaoud, 2006; Omari *et al.*, 2012; Bessaoud *et al.*, 2019).

1.3. *Research hypotheses*

This paper presents an analysis of the agricultural labor market, as well as the extent of labor shortage and its causes. We formulate the following hypotheses in response to the research question.

Hypothesis 1. *Farm labor reveals the characteristics of a secondary segment of the labor market: low real wage levels, less-skilled, precarious, unprotected jobs and poor working conditions.*

Since the pioneering work of Doeringer P.B. and Piore M.J. in the 1960s and 1970s on the dual labor market theory (Zajdela, 1990), the labor market is no longer considered as homogeneous as the neoclassical orthodoxy assumes. Dualism explains wage inequalities and working conditions that are not directly related to human capital by identifying two opposing labor markets. The first is the primary market, characterized by stable, skilled, and well-paid jobs with favorable working conditions and strong employee bargaining power. In contrast, the secondary market consists of unstable, low-skilled jobs with poor working conditions, often occupied by young people, women, and immigrants. Mobility between these two markets is notably limited (Perrot, 1992).

Hypothesis 2. *Young people's preferences, based on their human capital and their personal and socio-economic characteristics, tend towards alternative employment opportunities. These in-*

clude accessible urban jobs in the tertiary sector and government-supported initiatives for establishing their own micro-enterprises.

Although they constitute the basis of the duality of the labor market, the macroeconomic model of Lewis (1954) and the microeconomic model of Harris and Todaro (1970) elucidate the inter-sectoral mobility of workers: from agriculture or rural areas (unprotected sectors) to industry and services (protected sectors), which further explains the wage differentials that encourage these transitions. These classic models do not, though, overlook the urban informal sector (Hammouda and Souag, 2012; Adair and Bellache, 2018).

2. Materials and Methods

2.1. *Study area*

We have chosen a market-gardening region for our study because of the diversity of labor contracts and market configurations, probably segmented, that can be observed there. The vegetable crops pole of M'zirâa in the Algerian Sahara, east of Biskra (about 480 km from Algiers), is dominated by a greenhouse and field vegetable production, as shown in Figure 1. Added to a small existence of date palm farming representing 0.7% of the total production of dates in Biskra (DSA, 2017). A large part of the population of M'zirâa (65.3%) lives in dispersed housing, while 34.7% live in the chief town and secondary agglomerations. In 2016, the population was primarily young people aged 15-29 (32%) and children (32.8%), with the 30-59 age groups representing 29% (DPSB, 2017).

In the wilaya (province) of Biskra, 52.5% of total employees work in agriculture, 24.1% in administration, and 11.6% in trade and services. In 2017, official statistics recorded an unemployment rate of 5.18%, lower than the national figure of 11.7% (ONS, 2017). The wilaya has experienced a major boom in market gardening at the national level, characterized by intensive greenhouse production (Bouammar, 2010; Daoudi, 2016; Laouar *et al.*, 2023). It comes in first place, accounting for 52% of national plasticulture production in 2019 (MADR, 2021). The commune of M'zirâa is the largest in the wilaya in terms of plasticulture and open field area (22% and 18%), accounting for 22% and 17% of the wilaya's total production, respectively (DSA, 2017). This commune alone contributes 11.23% of national plasticulture production, with 1,216,996 quintals in 2016. Since 2009, the plasticulture system with canary greenhouses has characterized this region, occupying more than 70% of the total area under canary greenhouses in Biskra. This hyper-intensive system is enjoying a remarkable dynamism, thanks to the young sharecroppers (Naouri *et al.*, 2015), but also to the qualified migrants.

Figure 1 - General characteristics of farms and their production systems in the different localities of M'zirâa (photos taken in 2019): *(a)* Dominant occupation of agricultural land with a strong activity of plasticulture and field vegetable production, and a low existence of date palm culture; *(b)* Tomato crop (*Tofane* hybrid variety) in canary greenhouse of one hectare before the first harvest.

(a)

(b)

2.2. *Empirical approach*

To study supply and demand labor on farms, we developed a cross-analysis between employer and employee trajectories, i.e. interviewing farmers and their family workers as well as salaried employees. This method was used in the case study by Madelrieux *et al.* (2009) on the itineraries of employees on livestock farms in the northern Alps (France). For our empirical analysis, primary data were collected during the 2018 and 2019 crop years through questionnaires with 132 operators and co-operators, and 18 employees present on 125 farms. Only on 12 farms it was possible to interview both the employer and his employee. The operators and co-operators represent 88% of the respondents, including 54 owners, 28 tenants, one associate and 49 sharecroppers, i.e. one respondent per farm, except for seven farms with two respondents. On the other hand, the employees interviewed (12%) are constituted of seven wage earners, nine sharecroppers and two family workers. The sharecropper is the person who essentially takes charge of the work on the farm, and is remunerated by a percentage of the achieved production (Daoudi *et al.*, 2017). He may also be involved in another type of arrangement, such as land tenure (access to land and contributions of the rest of the factors of production) or partnership as (equilibrated association) (Colin, 2003).

Two questionnaires have been developed: the first one with farmers, it covered four parts: 1) individual farmer characteristics; 2) farm labor supply and demand and labor shortages; 3) working conditions, bargaining conditions, and other aspects; and finally, 4) managing farm labor shortage and understanding its causes. The second questionnaire was submitted to seasonal and permanent workers. It was divided into four sections: 1) individual worker characteristics; 2) qualifications and career path inside/outside the agriculture; 3) occupations on the farm and working conditions; and finally, 4) employment ambitions and opinions on labor shortage. We started with exploratory surveys, conducting semi-structured interviews with a dozen experienced large-scale farmers, resource persons, an inputs supplier, and officials from agricultural institutions and administrations involved in employment sector in the wilaya of Biskra. Farmers were selected via snowball sampling and chance encounters. The Surveys coincided with various farm activities, avoiding peak periods like transplanting to prevent disruption. It should be noted that it was difficult to interview casual workers organized in groups during peak periods, as well as illegal migrants and women workers, given that requires the organization of homogeneous focus groups.

We divided the study region into four large zones, close to secondary agglomerations and distinguished by their vegetable crops potential. Farmers were selected using a stratified random sample and proportional to farm size, drawn using Excel's "*Rand*" function from lists of farmers available from the department Chamber of Agriculture. We took into account replacements for unavailable individuals who were absent or registered under different names, or who had changed zones of activity or farm size. Two categories of vegetable crops producers were then distinguished in each zone according to their main activity: plasticulture and open field production, each with three classes of vegetable crops producers according to the size of their farms: small (<0.5 ha of greenhouses or <2 ha), medium (0.5-1 ha of greenhouses or 2-5 ha), and large (1+ ha of greenhouses or 5+ ha). With no reference for farm economic size, farmers were classified according to regional standards; for instance, a farm with fewer than six greenhouses is considered small.

The number of farms surveyed is determined using Bernoulli's formula:

$$n = Z^2 \times N / Z^2 + L^2(N - 1)$$

where: n is the sample size to be surveyed; N is the total number of vegetable crops producers, equal to 733 farmers selected from 1,103 farmers of all productions; Z is the deviation corresponding to a 95% confidence level according to the reduced normal distribution, equal to 1.96; L is the width of the range expressing twice the margin of error, equal to 0.16 (margin of error of 8%).

3. Results and Discussion

3.1. *General configuration of the farm labor market in M'zirâa*

Labor analysis moves away from orthodox analysis, which postulates a general market equilibrium and full employment, by embracing heterodox approaches to explore issues relating to unions and wage bargaining, employment policy intervention, etc. (Cahuc *et al.*, 2014; Vercherand, 2014). Or a more detailed analysis using historical facts from the 19th century and hypotheticals targeting the framework of Juglar and Kondratieff crisis cycles (Vercherand, 2014). Figure 2 outlines the general configuration of the agricultural labor market in M'zirâa[1], wrought by institutions like social conventions of sharecropping, setting it distinct from other markets.

Farm labor demand comes from diverse figures: landowners, tenants, and sub-tenants those who rent entire parcels of land and lease out locations for greenhouse tunnels sites. Sharecropper designed as co-operator, is part of the "one-third production partnership" may lack full range of decisions regarding the technical itinerary and commercialization. Experienced sharecroppers from wilayas such as Batna and Khenchela (≤150 km from M'zirâa), or those from Tipaza (510 km from M'zirâa) who have long experience in plasticulture can take the initiative in managing the farm with the owner's agreement. Labor demand depend on several factors such as input and product prices, technological progress and changes in farming practices (Huffman, 2001; 2014).

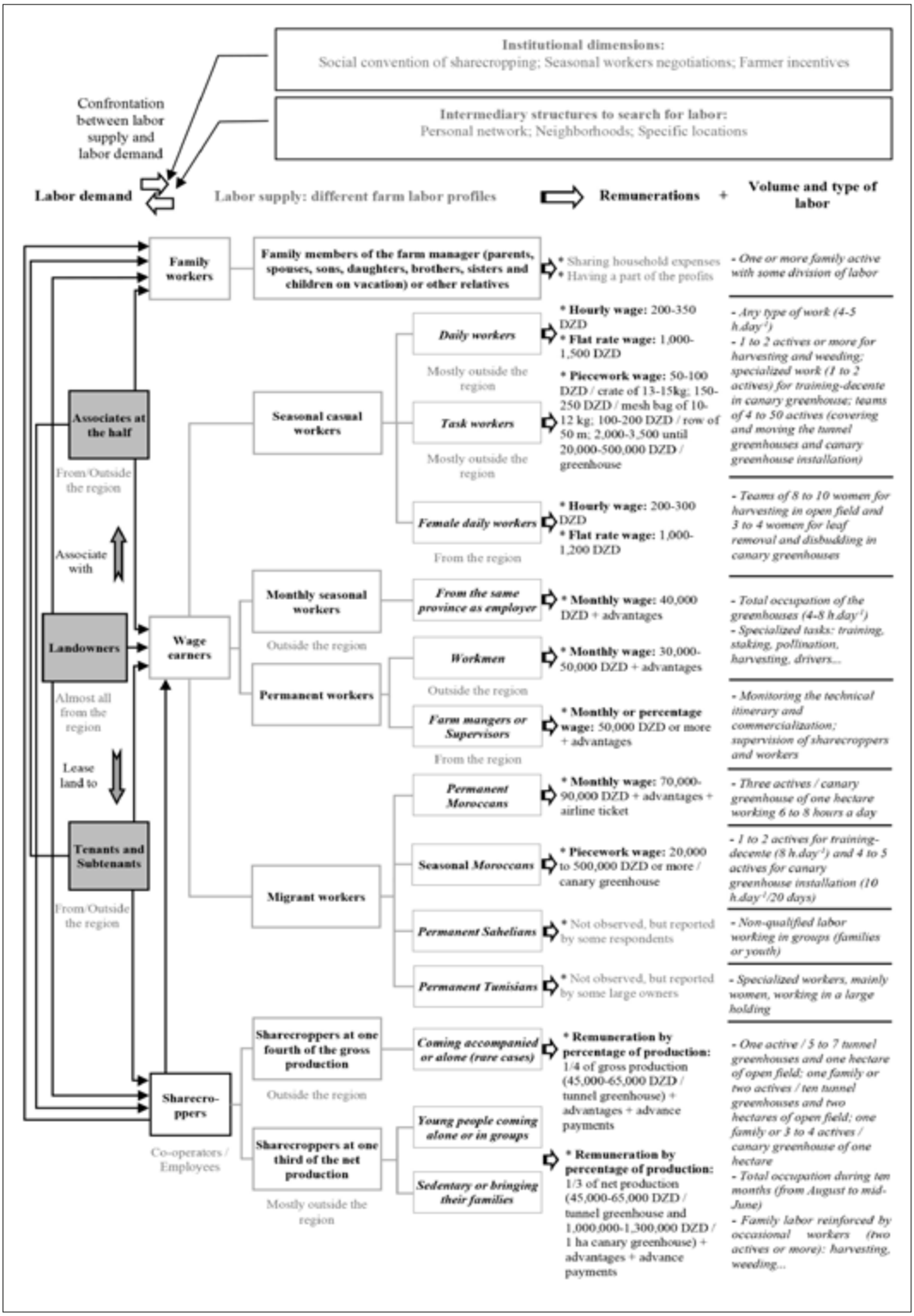
Farm labor supply is principally sourced from family labor, i.e. members of the farm manager's family and other relatives, and external labor, i.e. employees and sharecroppers classified as "work relationships", remunerated as associated at one-third of production. Facing difficult local conditions and limited job opportunities, sharecroppers join farms as permanents, given to initial financial constraints, and often arriving with their families. Schematically, two prevalent work contractual arrangements are deciphered in Biskra: salaried employment for seasonal workers and sharecropping for permanent workers assisting owners, tenants and subtenants switching between market gardening and date palm cultivation (Amichi *et al.*, 2015; Ouendeno *et al.*, 2015).

Permanent and seasonal skilled Moroccan migrants were present on 18% of surveyed farms, but only 5% actively recruited them in 2018-2019. Since 2009, this migration has impacted the availability of skilled labor and brought a new know-how in canary greenhouses production, imported from the Souss region of Agadir (Morocco) (Naouri *et al.*, 2015), itself of Spanish origin. The specific tasks that encourage the employment of Moroccan workers include installing canary greenhouses, tomato trellising techniques and fractioning fertilizer units. Their shrinking numbers stems from absence of work permits while they used tourist visas and the search for opportunities closer to home.

Some owners reported the presence of Sahelians from Mali and Niger, refugees coming from conflict zones, and Tunisians sought for specialized tasks in large holdings producing high-value crops such as cherry tomatoes under multi-span greenhouses. The working conditions of Sahelian migrants are under-researched due to limited access to these workers, as with other migrant groups. They often work discreetly in groups for several days or months, performing unskilled tasks like surveillance, weeding and harvesting. In constant labor scarcity, large owners can train them for more skilled jobs. Thus, labor migration, fueled by economic prospects, bears reminiscent economic and social implications for both sending and receiving regions, and is often influenced by wage differentials, skills requirements and immigration policies (Taylor, 2010; Taylor and Charlton, 2019b). The categories of full-time or part-time wage earners, local or foreign, under various contracts, are underscored in contemporary literature concerning their responsibilities and skills, which are *crescendo* replacing family labor in many countries around the world (Bignebat *et al.*, 2019; Dedieu, 2019).

[1] The applied wage range is 1 EUR = 1.12 USD = 133.67 DZD (Algerian Dinar) at the average official exchange rate and 200 DZD on average on the parallel market in 2019.

Figure 2 - General configuration of farm labor market in M'zirâa.



Female labor demand is almost nonexistent in tunnel greenhouses due to the hard atmosphere, while in canary greenhouses it is mainly for harvesting legumes and sporadically for leaf removal and disbudding. To address daily laborers shortages, some farmers consider hiring only women for lighter tasks. Though their productivity may be lower for urgent harvesting, they perform tasks with patience and precision. Women from sharecroppers' families may also undertake harder work, like spreading and burying manure, hoeing and weeding. Women's rural employment in Algeria is often misrepresented, as it requires specific tools to measure seasonal and part-time work (Musette, 2014).

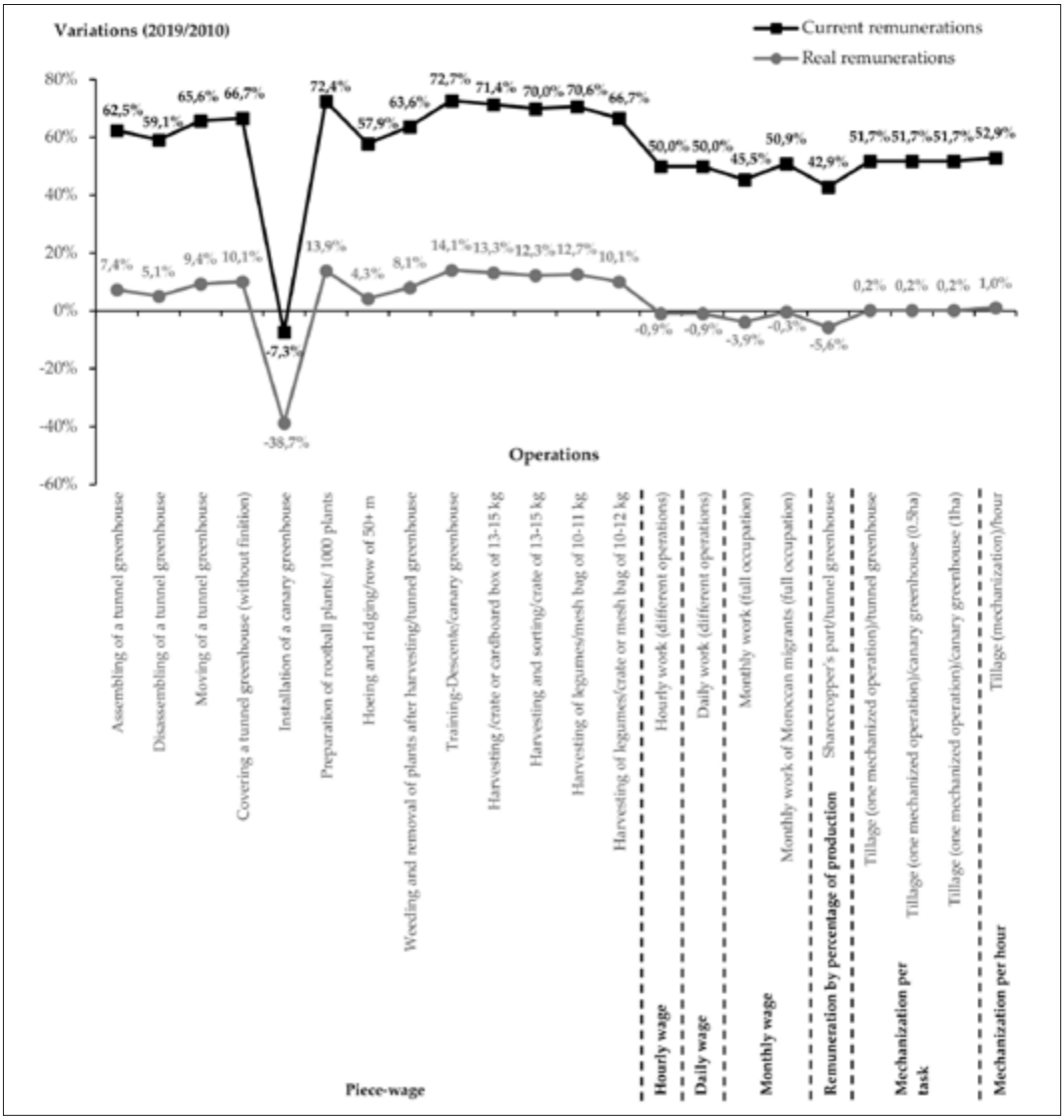
Hourly wages for casual workers differ between men and women particularly where farms are far-flung or where the work is difficult. Hourly/daily wages remain benchmarks, offering a fixed salary when task duration is unknown in the absence of agricultural minimum wage laws. Workers prefer piece-wages, as they generate flash income based on physical quantities achieved, and so do employers, as they do not have to supervise the workers. The dilemma is that the work is done quickly, but may damage the plants. Seasonal workers native from the same province as their employers (Tipaza) are recommended to reinforce farm's activities for 2 to 3 months and are rewarded by a fixed daily wage, even on off days. Permanent Moroccans receive monthly salaries in euros at the parallel market exchange rate. Family members generally work together, except for a few specific tasks assigned to one of them, such as commercialization, fertigation and rootball plants preparation. Unpaid family work can be reimbursed by a share of profits in the case of operators living in compound households.

The sharecroppers agree with the operators for a third of the net production, and very rarely for a quarter of the gross production. The sharecropping convention, in sense of a non-negotiable contract that determines the local contractual arena (Colin, 2002) or in sense of social and wage negotiations (Cahuc *et al.*, 2014), is a locally entrenched tribal institution, whereas the formation of a committee named "*Djemâa*", made up of notables and farmers from the region, acting as an enforcement mechanism of the agreement. From August to June, the sharecropper handles: nursery work, greenhouse covering, manure spreading, transplanting/seeding, irrigation, crop maintenance tasks and harvesting. For more responsibilities, he contributes a third of the costs of: tillage, manure, seeds or rootball plants, fertilizers, phytosanitary products, agricultural twines, mulch, drip lines and commercialization. The sharecropper assumes no fixed costs or climatic or production risks, but is in charge of paying casual workers. This whole process of arranging sharecropping terms and enforcement mechanisms mirrors practices in the west of Biskra, with differences in the proportions of costs and benefits, the linked contracts and the range of decisions (Amichi *et al.*, 2015; Ouendeno *et al.*, 2015; Ouendeno, 2022). The wage-earning and sharecropping contracts are exclusively verbal, and trust and reputation remain the capital values that manages these arrangements. Similar to other transactions between partners or with input suppliers (Daoudi, 2016; Laouar *et al.*, 2023). In 2014, collective negotiations took place between sharecroppers, employees, local landowners and the *Djemâa* to uplift labor conditions, boost wages and amend the sharecropping agreement. Exemptions in labor contract pursued to streamline processes and curtail transaction costs, i.e. the costs of negotiation, control and supervision, as happens in large oil palm plantations in Indonesia where the paternalistic control dominates (Barral, 2014). These adjustments reflect the labor market segmentation, where workers are treated differently as per their productivity, bargaining power, and pursuit of improved status on a primary market: skilled daily workers aspire to be sharecroppers or permanents in large holdings, in analogy with the antagonisms between insiders and outsiders (Perrot, 1992; Cahuc *et al.*, 2014).

3.2. *Wages and remunerations: trends and incidences on the availability of labor force*

The study of wage trends helps to assess labor costs and the increased labor demand, and therefore the possibility of shortages, or the response to collective bargaining or employment policies aimed at increasing workers' purchasing pow-

Figure 3 - Evolution of average current and real wages for different manual and mechanized agricultural works between 2010 and 2019 (2010 = 100).



er (Cahuc *et al.*, 2014). Figure 3 examines the evolution of wages for different farming tasks (2010-2019), after calculating real wages using the consumer price indices in Algeria provided by the International Monetary Fund (2022), which have a base 100 for the year 2010 and a value of 151.36 for the year 2019.

M'zirâa's average current remunerations – excluding salary costs – saw significant growth between, raised from 42.9% for sharecropper's part/tunnel greenhouse to 72.7% for training-descente. Only installing canary greenhouses, at first done by seasonal skilled Moroccan migrants, witnessed a sharp decline (-38.7%). This drop is attributed to a shift to trained locals and increased competition among service providers. Real wages tell a different story, particularly for sharecroppers and permanents, which declined by -5.6% and -3.9% respectively. Moroccan migrants, initially the highest earners given their mastery of the entire technical itinerary, also faced low real wage growth of -0.3%.

Real piece-wages rose sharply in activities requiring teams of workers, like field harvesting (10.1% to 12.7% increase) and greenhouse preparation (5.1% to 10.1%). The same for one-off tasks like weeding before mulching and greenhouse cleaning and hoeing and ridging (4.3% to 8.1% increase). Additionally, moving the greenhouses replaced the activity of assembling/disassembling which is a costly operation, especially for tenants who change their farms location. Legume harvesting wages favored for easily picked crops always in bags like broad beans and peas compared with beans. Harvesting in greenhouses, not requiring large teams, registered a 13.3% real wage increase, compared to simultaneous sorting (12.3%) generally handled by the employer. Rootball plants preparation and training-decente remained the most profitable tasks, with an increase in real terms of 13.9% and 14.1% respectively, because of their time-sensitive nature and rigorous monitoring. Before the demand in canary tomato greenhouses increased, training and knowledge exchange were primarily mutual aid acts among former Moroccan workers. Mechanized tasks, which only include tillage operations, i.e. ploughing, disking, digging furrows and an optional milling, tend to increase remuneration slightly more than manual operations (except piecework), averaging 1,000 DZD/tunnel and 1,200 DZD/hour in open field. Both hourly and per-task real rates show positive trends. Mechanization per hour has increased, since the mechanization service provider can work on more than one greenhouse at the same time. Most operations remain manual, minimizing mechanization's impact on overall wages.

By offsetting the striking effect of inflation, the increases of different remunerations may indicate the existence of a local farm labor shortage. As echoed in U.S. farms, evinced by wage adjustments for hired workers, mostly immigrants (Martin, 2007; Hertz and Zahniser, 2013). Hourly wages in California fluctuated seasonally from 9 to 14 USD between 2002 and 2014, despite the availability of advanced mechanization and migrant labor (Taylor and Charlton, 2019a). Some equilibrium models predicted higher wages by 22% if even half of illegal farm workers leave (Richards, 2018). Some greenhouse growers may offer sharecropping contracts to qualified permanent migrants with relief from some charges, or even propose sharecropping at ⅓ of the gross of production, owing to the high transaction costs of remunerating them. Future remuneration in both sharecropping and wage-earning contracts may evolve in line with working conditions and labor shortages. Similarly for sharecropping at ¼ of the gross production in the western region of Biskra from which some famers will propose sharecropping at ½ to remedy the lack of arms (Ouendeno, 2022).

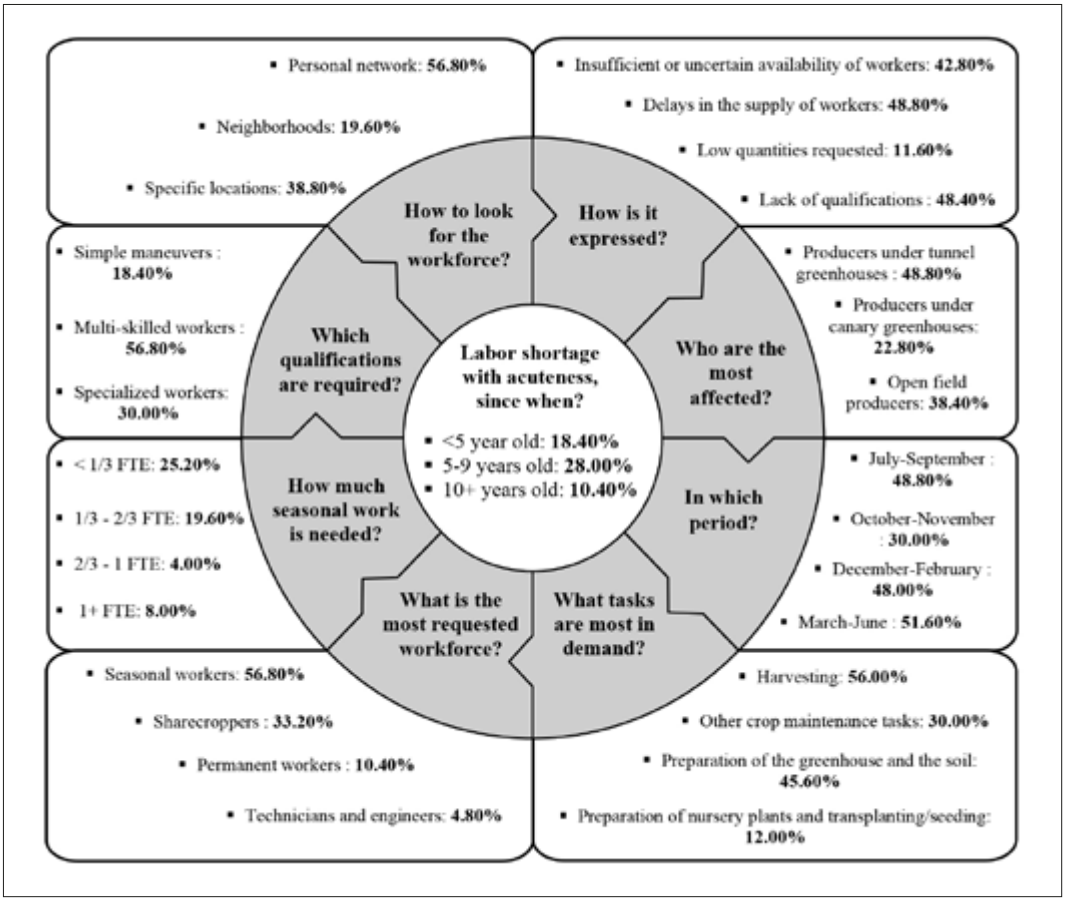
3.3. *Labor shortages in vegetable crops farms: where does the situation stand?*

The scarcity of workers has been a source of concern for 56.80% of surveyed farms. Its extent differs from year to year and is illustrated in Figure 4. Estimating labor shortage poses challenges without quantitative data on labor demands and available workforce. Arrival delays of workers after lengthy search process or pending appointments, unsatisfactory qualifications and insufficient or uncertain crews' availability during intensive operations are the major facets of farm labor shortage.

Labor shortage intensified since 2010 following the development of modern greenhouse techniques, and peaked between 2012 and 2014 when many sharecroppers achieved good campaigns, leading some of them to subsequently become tenants. The situation worsened the last five years after the collective sharecropping negotiations and the rises in inputs prices, and became permanently dire for more than ten years in the farms of the large and old producers. The farms suffering with labor shortage during the 2018 and 2019 campaigns are experiencing a serious consequences. Activities like open field vegetable crops were abandoned, with the possibility of returning to the activity. Vital tasks such hoeing, ridging and the last 2-3 tomato harvests suffered delays or even stoppages.

Of 61 afflicted farms, the labor shortage appears from a plasticulture area equivalent to ten greenhouses or a canary greenhouse of 0.5 ha, cultivated mainly with tomatoes (31%), chili and

Figure 4 - The extent of the labor shortage on the 125 farms surveyed from the expression of the labor shortage by affected farmers to the process of finding workers.



peppers (39.6%), melons (10.61%), eggplants (6.72%) and zucchinis and beans (4.42%), rotating with melon cultivation (7%), whether accompanied by open field gardening or not. From an area of 3.5 ha of open field crops alone, the farmer is exposed to labor shortage, especially for pea and green bean harvesting by daily laborers, or for onion planting and harvesting by teams of more than ten men. Small greenhouse growers with less than nine greenhouses, who cultivate open field crops on 0.5 to 4 ha, also suffered from labor shortage due to their lack of seniority in the region or the absence of family workers.

All farms in short supply need seasonal workers instead of permanent workers, who account for 10.40% of total demand. The seasonal nature of farm work imposes internal and external labor flexibility to meet demand variations (Mundler and Laurent, 2003). However, sharecropping is an important way to compensate for family labor deficiency and is preferred to hiring permanent labor. The *ex-ante* demand for sharecroppers is made in one-third of farms. The demand for technical managers remains weak (4.80%), even among large-scale producers. In this respect, technicians and engineers from agro-supply firms and local input suppliers play a key role in the dissemination of technical innovations and agricultural advice in the wilaya of Biskra. This approach reinforces private extension mechanisms and builds customer loyalty (Laouar *et al.*, 2023).

Qualification is not linked to professional training or higher education, but it is translated to years of experience (1+ year). Multi-skilling is imperative in all farms affected by labor shortage, because it showcases workers' ability

to acquire new skills and his availability in the event of breakdowns or missing/absent posts. Compared to a simple worker, a multi-skilled worker has a degree of autonomy to work unsupervised and can participate in future farm decisions (Vincq and Granié, 2014). In 30% of farms, specialized skills are indispensable from highly skilled tasks like tomato maintenance to meticulous work without paying too much attention to the qualifications, as in harvesting legumes by female laborers.

Quantifying working time helps to clarify the organization of farm work and its efficiency and flexibility, and to predict the availability of labor on/off the farm (Dedieu, 2019). A quarter of the farms are looking to hire less than 0.33 FTE[2] and 8% for more than 1 FTE, of which producers cultivate open fields between 3.5 and 6 ha or mainly under canary greenhouses. We calculated 65,977 needed work hours on farms in labor shortage. Harvesting tasks consume 61% of the work volume from winter until early summer, followed by greenhouse and soil preparation operations in summer (25%) and crop maintenance in autumn until spring (11%). Nursery plants begin in late July and August, and transplanting, which can extend to the end of September for some late season varieties, make up 3%.

In the absence of formal recruitment mechanisms, farmers tap first and foremost personal networks through contacts with previous workers, team leaders, input suppliers, etc. Employers harness their social capital to uphold trust and reputation of workers, as well as workers who inquire about good employers fearing moral hazards. Secondly, farmers resort to the spot market to find seasonal labor in specific locations like cafeterias, wholesale markets, etc. Thirdly, neighborhoods constitute proximity networks for legume harvesting and mutual assistance during transplanting. Intermediaries can mitigate high labor transaction costs when information is asymmetric. These intermediaries can be: 1) specialized individuals usually linked to workers by family, territory or ethnicity, similar to Senegalese agropastoralists (Wane *et al.*, 2018); 2) enterprises that place workers under numerous contracts, as in France (Darpeix, 2013); or 3) Farm Labor Contractors (FLC) to hire and move teams of seasonal workers in the United States (Martin, 2014).

3.4. *Determinants of farm labor shortage and low youth participation in agricultural activities*

We examine the causes of labor shortage in M'zirâa's vegetable crops farms using a binary logistic regression model. We analyze the impact of proposed hypotheses on the likelihood of labor shortage. Studies on the segmentation and functioning of the Algerian labor market employed diverse econometric analyses as multinomial/binary logit/probit models, etc., corrected by statistical methods and tests (Heckman, Fisher test...) to explain occupational choices in the different employment segments (Hammouda and Souag, 2012; Adair and Bellache, 2018; Merouani *et al.*, 2021). As also found in studies demonstrating on-farm versus non-farm work choices (Tocco *et al.*, 2012). The binary logistic model in Table 1 tests six nominal predictor variables based on respondents' declarations affected or not by labor shortage, in addition to a cause considered obvious. We added a nominal control variable related to the expression of cryptogamic disease and pest risks in all types of farms.

The likelihood ratio test for the dependent variable, annexed by the degrees of freedom, Wald chi2 and p-value statistics, compares the fit of the full model to a model without the predictor variables, and evaluates the significance of the independent variables in explaining the variation in the outcome, as shown in Table 2.

The model demonstrates a good predictive capacity, with a reliability test confirming 72.67% of correct predictions. The results of the logistic regression model show that the model as a whole is significant, indicating that the predictors collectively have a significant effect on the likeli-

[2] Full-time equivalent, determined at 1800 h/year as the legal working time on farms defined in the 1996 Labor Code.

Table 1 - Logit model of main causes of labor shortage and low participation in farm labor market.

	Labor shortage	*Coef.*	*Std. Err.*	*z*	*P>|z|*	*[95% Conf.*	*Interval]*
Hypothesis 1	Remunerations-incentives	-1.602	0.495	-3.23	0.001	-2.573	-0.631
	Working-living conditions	-0.547	0.491	-1.11	0.265	-1.508	0.415
Hypothesis 2	Job opportunities	1.146	0.560	2.05	0.041	0.049	2.242
	Personal behavior	1.208	0.485	2.49	0.013	0.257	2.159
	Human capital	0.013	0.418	0.03	0.976	-0.807	0.833
	Socioeconomic situation	0.321	0.420	0.76	0.445	-0.502	1.144
Evident cause	Increase in area-farm size	0.591	0.782	0.76	0.450	-0.941	2.123
_cons		-1.249	0.843	-1.48	0.139	-2.903	0.404
Disease-pest risks		1	(offset)				

Table 2 - Logistic regression parameters of full and reduced model.

Full model						
Wald chi2 (7)	Prob > chi2	Log likelihood	Likelihood-ratio test			
			LR chi2 (7)		Prob > chi2	
24.88	0.0008	-80.8106	42.47		0.0000	
Reduced model						
			Number of obs	=	150	
			LR chi2(0)	=	-0.00	
			Prob > chi2	=	.	
			Pseudo R2	=	-0.000	
			Log likelihood	=	-102.044	
Labor shortage	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
_cons	0.323	0.165	1.95	0.051	-0.001	0.647

hood of labor shortage. The Wald chi2 value is 24.88 indicates a statistical significance of the model at 1%.

3.4.1. *The obvious cause of the labor shortage*

It is evident to 90.67% of respondents that as farm area and size increase, the demand for labor rises, making the labor shortage more severe. Between 2007 and 2016, vegetable crops areas in M'zirâa expanded from 126 to 1,249 ha for plasticulture and from 1,424 to 2,600 ha for open field (DSA, 2017). Their average annual growth rate was 10.2% (DSA, 2017), surpassed the wilaya and national averages, with rates of 8% and 4.2%, respectively (MADR, 2019). The extension of the areas of irrigated farms in Biskra has been spurred by the agricultural policies implemented (Bouammar, 2010), but also by the burgeoning of a tenancy land market that is inclusive of both native and non-native farmers (Daoudi *et al.*, 2017). As for the variable "Increase in the area and size of the farm" in the logistic regression, its coefficient (0.590) is not statistically significant (p-value = 0.450), yielding its limited impact on labor shortage probability. The low coefficient may reflect the fact that this evident cause may have a greater impact in other contexts (newly introduced crops and techniques, large farm models, etc.). Interestingly, in developed countries showing positive agricultural economic growth due to factors productivity growth driven by technical progress, farm size expansion is a fact, accompanied by

a decline in the share of agricultural employment and seasonal labor shortages, largely migrants (Christiaensen *et al.*, 2021).

3.4.2. *Causes of the first hypothesis*

Dual agricultural model in oil palm plantations in Indonesia leads to the segmentation of the local labor market between temporary and permanent workers. The latter benefit from superior advantages and remuneration, including social protection, access to credit, housing and a degree of autonomy in work organization. This segmentation fades due to a labor shortage, forcing employers to accept the conditions of seasonal workers, including their participation in other informal activities, which is the same thing sought by permanents in the absence of an adequate retirement system (Barral, 2017).

In comparison to our case, 70.67% of respondents perceived actual remuneration and incentives as low, with 62.67% attributing low agricultural wages to declining purchasing power and the infrequent use of efficiency incentives to encourage youth in particularly difficult conditions and time-sensitive tasks. Real wage increases have been positive only for piece-rate wages (section 3.2). In 2019, the gross monthly salary of a permanent employee in M'zirâa, without taking into account benefits and advance payments, averaged 40,000 DZD (27,500 DZD in 2010) for all qualifications, below the national average net salary of 41,800 DZD (26,893 DZD in 2010) in the public and private non-agricultural sectors, excluding administration (ONS, 2021b). All received remunerations are never declared to the social security or employment authorities. This is because employers do not declare their workers, who are themselves unaffiliated. Workers also would rather benefit from direct contributions than have them deducted from their wages to pay into an uncertain insurance. The reasons expressed are consistent with those cited by workers excluded from social security or who chose voluntary the informal employment in the Maghreb countries, determined by individuals' risk aversion and temporal preferences (Merouani *et al.*, 2021). Interestingly, a few part of respondent believed in wage discrimination against Sahelian migrants, who are unaware of the terms of the social convention and the wages offered. Skilled migrants are the best paid, close to the national "executives" who receive 81,000 DZD net, without a high level of education, but some workers hold vocational training diplomas in agriculture. Along with other benefits (housing, food, etc.), they effectively occupy a niche in the primary segment of M'zirâa's local labor market.

The poor living and working conditions are relatively high in the study area, as 76.67% of the respondents affirmed. Laborious work is not the least reason for refusing to work in agriculture, that is tiring and requires considerable physical effort in relation to the workload and the acceleration in the rhythm of some tasks, which sometimes complicates the organization of work on the farm for those who do not have enough workers in quickly transplanting, harvesting green beans to avoid hardening the fruit after ripening, carrying out several crop maintenance tasks at the same time, etc. The agricultural profession is considered risky given the recurrence of accidents at work, the lack of hygiene and health protection measures (especially in tomato and eggplant greenhouses), and numerous climatic (heat waves, frost) and natural (scorpion and snake attacks) hazards. For 62.67% of the respondents, the precariousness and seasonality of the work are not conducive to attracting more workers. The examination of working conditions on farms is a pivotal social factor in attracting and retaining labor. It is the focal point of numerous of scientific publications, particularly in ergonomics and agricultural medicine, which delve into the study of health problems in the agricultural workplace, such as musculoskeletal disorders, workload, occupational accidents, mental health, stress, job satisfaction, and pesticide exposure, etc. (Malanski *et al.*, 2019; 2021; 2022).

Working conditions in greenhouses could depend on other factors that significantly influence safety knowledge and practices, notably age, gender, education, health and safety training, work experience, tasks implemented and use of personal protective equipment, as relevant for many vulnerable groups of workers handling hazardous pesticides in extreme weather in the Ethiopian floriculture sector (Geleta *et*

al., 2021). In our study, 39% of the respondents reported that agricultural work is carried out with inadequate hygiene and safety protocols for phytosanitary applications that could make respiratory or allergy-related issues. Additionally, 62% believe they work in harsh conditions and environments fraught. Of these, 8% have experienced direct encounters with scorpions or snakes. During our surveys, the average maximum temperatures recorded between May and September ranged from 39.51 to 42.91°C, with a peak of 48.80°C in July 2019 (NASA, 2023). Hot periods coincide with critical tasks like harvesting, transplanting, etc. restricting greenhouse access after 10 AM.

An in-depth study is recommended to understand female day laborers' market, focusing on their social profiles, negotiations with team leaders, and working conditions. Quantifying their farm contributions and estimating their domestic workload could use methods like the "work balance" approach applied in Morocco's oasis systems (Sraïri and Naqach, 2022). Female agricultural workers in the Global North face strenuous physical and mental stress due to the dual farm and family responsibilities and limited healthcare access. Exposure to chemicals and challenging climates also puts their reproductive and overall health at risk (Wheeler and Nye, 2024). Women's contributions on Greek family dairy and small ruminant farms have been crucial for economic resilience. Their extensive farm work reduces the need for hired labor and boosts productivity, allowing husbands to pursue off-farm income (Ragkos *et al.*, 2018). These findings underline the need to recognize and address women's needs in agricultural policies to promote equity, well-being, and job satisfaction.

On the basis of official data from various administrations up to 2016 (DPSB, 2017), we can put into perspective some of the reasons of poor living conditions cited by 44.67% of respondents. M'zirâa is the last commune in terms of school enrolment for children under 15 years (73.50%) and the second last for high school students aged 15-19 (20.7%). No secondary school was built before 2016. The children of sharecroppers are vulnerable to abandoning school and being hired at an early age owing to the long distance or the absence of schools. Household connections to the potable water and sanitation networks are 95% and 93%, respectively, mainly in the peri-urban areas. There are no sports or youth facilities in the municipality. However, the level of progress of various vital structures and facilities in the commune improved after 2017. Farmers offer lodgings to their sharecroppers and permanent workers, and even to tenants, but these appear to be in modest or moderately acceptable condition.

In our logistic model, any decrease in remunerations and incentives, or working-living conditions, increases the probability of labor shortage. Wages are good predictors with a coefficient of -1.602 and p-value of 0.001, more so than the coefficient of the conditions (-0.546) with a p-value of 0.265, which means there is no strong evidence to conclude that working-living conditions have a significant effect on the likelihood of labor shortage (-80.810). Separating the working conditions variables from living conditions using longitudinal analysis methods could provide more solid evidence for the explanatory variable in question. For the participants surveyed, the working conditions are surmountable, since they all suffer the same difficulties, and it will be more difficult for outsiders to the sector, who make an occupational arbitrage based principally on remuneration; a problem that requires ergonomic solutions. Working conditions are also considered acceptable/livable in terms of demands for free time and reduced working hours for both farmers and workers (Dedieu, 2019). In 2019, 34.3% of the unemployed in Algeria declared that they accept arduous or unhealthy jobs, 54.3% accept jobs outside their wilayas and 81.6% of the unemployed are willing to work in low-paid jobs (ONS, 2019).

3.4.3. *Causes of the second hypothesis*

For our logit model, the coefficient of "employment opportunities" is positive (1.145) and statistically significant (p-value = 0.041), indicating that an increase in opportunities to work in other non-agricultural sectors, as well as opportunities to create micro-enterprises and own jobs, are associated with an increase in the probability of labor shortage. This result accounted for 78.67% of responses. If we consider that

agricultural wages in M'zirâa are net, deducting only the social security contribution without any other taxes or allowances, and compare them with wages in other economic sectors in 2019 (ONS, 2021b), agricultural workers are underpaid in relation to workers in other sectors, since the average net wage (36,400 DZD/month) is 80% of the average net wage in trade, 34% and 85% in extractive industries (hydrocarbons and mining) and manufacturing, 59% in financial activities and 78% in transport and communications, but 1.14 times higher than in construction, 1.04 times in hotels and restaurants and 1.05 times in real estate. Furthermore, agriculture is becoming increasingly less profitable and less attractive, particularly for new entrants with less than five years of experience in the region. In 2019, faced with a low share of agricultural employment, only 4.1% of the unemployed who have previously worked answered that their last job was in agriculture, but 65% of them left the service and administrative sectors (ONS, 2019).

The other cause of the labor shortage, according to 65.33% of the respondents, is the recourse of young people to government subsidies for the creation of their own jobs, especially credits for the creation of micro-enterprises through the National Youth Employment Support Agency "ANSEJ" (now known as ANADE). Agriculture has become the leading sector attracting more projects financed by ANSEJ than any other sector in the wilaya of Biskra since 2011, peaking in 2014 (72% of projects) (ANSEJ, 2018); period of a critical labor shortage in the region. Here is an example of how young people are attracted to these projects. In a successful scenario, a sharecropper working in six chili or bell pepper greenhouses can generate a gross margin of 360,000 DZD/10 months. After paying his debts, he is left with a net income of 210,000 DZD, equivalent to what a daily laborer could earn in a year. This income allows him to buy a greenhouse (used metal frame + new plastic film). Therefore, *ceteris paribus*, he can invest in six full greenhouses after six years of work, saving, in the best cases, a rental lease for one year that is 1/8 to 1/10 of the acquisition value of the greenhouses. The ANSEJ in Biskra can finance six new greenhouses in the first year at a value of 1,500,000 DZD and offer additional support. A sharecropper or a simple worker will shorten the number of years he spends paying off his debts, without having to follow the professional ladder to create his own job.

The coefficient for "personal behavior" is positive (1.208) and statistically significant (p-value = 0.013), which means that certain personal characteristics are associated with an increased probability of youth labor shortage; it is considered inevitable cause by 76% of respondents. The demotivation of young people given the examples of the failure of new farmers, the refusal to work the land for subjective reasons, the attraction to easy, urban jobs even if they are less well paid and the fact that agricultural work is seen as temporary and financially uncertain and poorly esteemed, are factors contribute largely to this outcome. The attitudes towards the low social perception of agricultural are also influenced by the low recognition and undervaluation of agricultural work by some employers, and the bad employment relationships conducive to labor conflicts. These issues are a priority for authors who are interested in improving of workers' personal development in terms of skills and social relations, and who propose evaluation grids for job satisfaction on the farm (Dedieu, 2019). Finally, a quarter of respondents claimed that young people demand more than employers' capabilities and the advantages offered in the social agreement, such as food, transport to home, payment worth half the harvest in difficult conditions at the end of the season, remuneration of sharecroppers at one-third of the gross production, etc. It symbolizes implicit collective negotiations, where syndicate representation and government intervention are absent (Cahuc *et al.*, 2014), or where bilateral negotiations dominate over profit-sharing resulting from employee dissatisfaction (Perrot, 1992).

Job fulfillment often goes beyond improving working conditions, as demonstrated by dairy farmers in the Puy-de-Dôme department (France), who adopt agroecological practices not only to reduce chemical exposure and enhance environmental and human health, but also to achieve economic and decision-making autonomy, optimize work organization, produce

high-quality goods and ensure animal welfare, ultimately to foster a positive professional image (Duval *et al.*, 2021). Our study lacks a detailed analysis of wage earners' feeling and job satisfaction, but insights from Sabillón *et al.* (2022) offer useful perspectives. This research examines how working conditions affect European farmers' well-being and job satisfaction, emphasizing factors such as working hours, age, financial status, and community engagement. Four key dimensions of job satisfaction in farming were identified: daily tasks, work-life balance, professional identity, and decision-making autonomy, all of which influence quality of life.

The coefficient of "human capital" is very low (0.0128) and not statistically significant (p-value = 0.976). This indicates that human capital factors (such as age, education, social capital, qualifications outside agriculture...) do not have a significant impact on the probability of labor shortage in our model. The impact of education is low relative to skill specialization on agricultural labor market participation, typically in the context of technical change (Huffman, 2001). In reduced form models, education has a minimal improvement effect on wages in the United States, with each additional year of education contributing to an increase in average hourly wages of less than 1% (Richards, 2018). Compared to what was reported by 62.67% of respondents, the shortage of young laborers in agriculture is mainly due to the fact that farm management skills are less prevalent amid people from non-agricultural environment, and the more educated individuals are less willing to work in agriculture. Late entry into farming diminishes the desirability of agricultural work for youth. It is noteworthy that 88% of our surveyed individuals began working in agriculture as family workers or wage earners before the age of 19, with over 2/3 started before the age of 15. However, people with qualifications or experience outside agriculture have little chance of working in agriculture.

The coefficient of "socio-economic status" (0.320) is low and statistically insignificant (p-value = 0.445), suggesting that socio-economic characteristics of the youth labor force, do not have a significant effect on the probability of labor shortages rather than what 55.33% of respondents indicated. Married individuals, particularly heads of households or eldest sons within compound households, are more inclined to engage in agricultural activities. The sharecropper with his family, whose children attend school, is preferred because he will stay for the whole season. Nevertheless, the lack of stability due to the movement of workers, especially with their families, reduces the chances of participation in agricultural work. It should be remembered that 54% of our respondents came accompanied, outside the municipality. Declining interest of youth in agriculture for reasons of other financial resources (pension from parents, rent of premises, etc.) and challenges of access to land seem to be unconvincing reasons. Econometric models analyzing wage disparities between different segments in the Algerian labor market and the employment prospects therein divulged the following findings: women, young people under 30, single people and the less educated (below secondary level) participate much more in urban informal labor market as self-employed, undeclared workers, home-based active women or family workers, and to a lesser extent in agricultural employment (Hammouda and Souag, 2012; Lassassi and Hammouda, 2012a; Adair and Bellache, 2018). Including variables related to socio-economic characteristics into the human capital variable could improve our logistic model, as realized in these studies.

4. Conclusion and Perspectives

The results of the logistic regression amalgamating insights from 150 employers and employees suggest that: the level of agricultural remunerations and incentives, employment opportunities in other sectors and government support for the creation of self-employment, and the personal behavior of the youth labor force are the central factors influencing the probability of labor shortage. The disparity in wages and incentives delineate a segmentation that thwarts workers from achieving a good professional status, who in turn change their qualifications or move to other sectors. Factors such as working and living conditions, human capital and the socio-economic status of young people, as well as the increase in the area and size

of farms in the region, which is considered an evident cause, do not appear to have significant effects. If young people are demotivated and refuse to work in agriculture, preferring easy urban jobs, it is because they also consider agricultural work to be precarious, arduous and with no social security cover. These factors explain why more than three-quarters of respondents believe that young people find agricultural work repellent and insufficiently valued.

As with the development of labor-saving technologies, work in the greenhouses or open fields at M'zirâa is highly hand-dependent, given the numerous maintenance activities that do not allow easy access to large equipment. Ergonomic improvements to a number of tools (e.g. seeding/transplanting equipment, rolling elevators to facilitate trellising and harvesting at height) could be a springboard for other innovations, helping to respond efficiently to the uncertain labor availability. Today, the robotization of agricultural tasks is a new agricultural revolution. These intelligent technologies still pose the challenge of combining three fundamental functions as long as human pickers can do it naturally: 1) the discernment (detection capacity); 2) the speed of task execution; and 3) the dexterity (avoiding damage to delicate fruit) (Taylor and Charlton, 2019c). Policy implications can also play a part in remedying labor shortage or underemployment through modification of labor regulations and social protection tailored to the agricultural sector; enhancement of more incentivized agricultural remuneration as offered in employment support programs; and encouragement of employer groups or private enterprises for intermediation and provision of labor services, handling or new mechanization technologies. These structures can provide a better framework for the formation of worker's human capital, which responds to good work organization on the farm and synchronization of labor demands and helps to minimize discrepancies between different segments of the agricultural labor market. At the same time, self-organization of actors around *ad hoc* labor market arrangements should be guaranteed.

The perspectives gleaned from the International Symposium on Work in Agriculture (2nd version in 2021) showcase pertinent issues weathering the future of work in agriculture in developing and developed countries, particularly in the OECD countries: 1) the transition to more sustainable agriculture via agro-ecology and digitalization; 2) internal and international migration flows in rural areas and protection of migrants; 3) the role of agricultural policies and labor regulations; 4) ethnic inequalities and working conditions; 5) the active emergence of women in the workplace and the social recognition of agricultural professionals; 6) the development of value chains that influence changes in agricultural practices and exchanges with other sectors; 7) bolstering labor productivity, especially in sub-Saharan countries, by offering attractive and decent working conditions to the young population that will have the highest growth rates in the world between 2030 and 2050 (Dedieu *et al.*, 2022).

Multiple key limitations hinder deeper analysis of the agricultural labor market, highlighting the need for future research on topics such as worker behavior through qualitative methods within a behavioral economics framework, and labor contracts for women, migrants, and vulnerable groups within the segmented agricultural labor market. The concepts of decent work and job satisfaction represent a significant avenue for exploration, helping to identify factors that could enhance the attractiveness of agricultural employment for youth. Santhanam-Martin *et al.* (2024) provide a framework for applying decent work principles to enhance employee satisfaction and retention in the Australian orchard industry amid labor shortages. Grounded in psychological contract theory, the study evaluates employees' perceptions of employer promise fulfillment across six major items, compared to the International Labour Organization (ILO) decent work domains, including safety and security, autonomy, resources to perform quality work, opportunities for training and skill development, employee benefits and increased responsibilities. The authors suggest broadening this framework to other dimensions like equal opportunity and social dialogue to better align with the Global Sustainable Development Agenda's commitment to decent work.

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References

Adair P., Bellache Y., 2018. Labor market segmentation and occupational mobility in Algeria: Repeated cross-sectional and longitudinal analyses (2007 to 2012). *Review of Development Economics*, 22(4): 1765-1783. https://doi.org/10.1111/rode.12519.

Amichi F., Bouarfa S., Lejars C., Kuper M., Hartani T., Daoudi A., Amichi H., Belhamra M., 2015. Des serres et des hommes : des exploitations motrices de l'expansion territoriale et de l'ascension socioprofessionnelle sur un front pionnier de l'agriculture saharienne en Algérie. *Cahiers Agricultures*, 24(1): 11-19. https://doi.org/10.1684/agr.2015.0736.

ANSEJ (National Youth Employment Support Agency of the wilaya of Biskra), 2018. *Projects financed by sector of activity and by municipality between 1998 and 31/07/2018*.

Barral S., 2014. Paternalistic Supervision of Labour in Indonesian Plantations: Between Dependence and Autonomy. *Journal of Agrarian Change*, 14(2): 240-259. https://doi.org/10.1111/joac.12063.

Barral S., 2017. Chapitre 4 - Travail précaire, travail permanent, travail indépendant. Diversité et coexistence des formes de travail dans l'agriculture de plantation. In: Purseigle F., Nguyen G., Blanc P. (eds), *Le nouveau capitalisme agricole : De la ferme à la firme*. Paris: Presses de Sciences Po, pp. 125-152. https://doi.org/10.3917/scpo.purse.2017.01.0125.

Batawila G.D., Pleines T., 2010. *Etude sur la main d'œuvre agricole au Togo et au Bénin*. Fribourg - Lomé: Brücke / Le pont - CRISTO, 47 pp. https://docplayer.fr/9129084-Main-d-oeuvre-agricole-au-togo-et-au-benin.html.

Bedrani S., Cheriet F., 2012. Quelques éléments pour un bilan d'un demi siècle de politiques agricoles et rurales. *Les cahiers du CREAD*, 28(100): 137-162. https://www.asjp.cerist.dz/en/article/2053.

Bessaoud O., 2006. La stratégie de développement rural en Algérie. In: Chassany J.P., Pellissier J.-P. (eds.), *Séminaire sur les Politiques de Développement Rural Durable en Méditerranée dans le Cadre de la Politique de Voisinage de l'Union Européenne*, "Options Méditerranéennes : Série A. Séminaires Méditerranéens", n. 71. Montpellier : CIHEAM, pp. 79-89. https://om.ciheam.org/article.php?IDPDF=6400059.

Bessaoud O., Pellissier J.-P., Rolland J.-P., Khechimi W., 2019. *Rapport de synthèse sur l'agriculture en Algérie*. Montpellier: CIHEAM-IAMM, 81 pp. http://www.iamm.ciheam.org/ress_doc/opac_css/doc_num.php?explnum_id=18246.

Bignebat C., Delame N., Hugonnet M., legagneux B., Nguyen G., Piet L., 2019. Partie 1 - Trois tendances structurantes : concentration, sous-traitance et diversification des exploitations. In: Forget V., Depeyrot J.N., Mahé M., Midler E., Hugonnet M., Beaujeu R., Grandjean A., Hérault B. (eds.), *Actif'Agri. Transformations des emplois et des activités en agriculture*. Paris: La Documentation Française, pp. 31-47. https://hal.inrae.fr/hal-02437659.

Blanc M., Perrier-Cornet P., 1999. Emploi agricole : les cadres d'analyse à l'épreuve des dynamiques actuelles. *Économie rurale*, 253: 8-14. https://doi.org/10.3406/ecoru.1999.5107.

Bouammar B., 2010. *Le développement agricole dans les régions sahariennes. Etude de cas de la région de Ouargla et de la région de Biskra (2006-2008)*. PhD thesis, University Kasdi Merbah - Ouargla, Algeria, 296 pp. https://www.raddo.org/content/download/19401/419572/version/2/file/THESE_DOCTORAT_BOUAMMAR_BOUALEM_DiskStation_Aug-13-0917-2015_Conflict.pdf.

Cahuc P., Carcillo S., Zylberberg A., 2014. *Labor Economics*, 2nd edition. Cambridge (MA): The MIT Press, 1043 pp.

Charlton D., Taylor J.E., 2016. A Declining Farm Workforce: Analysis of Panel Data from Rural Mexico. *American Journal of Agricultural Economics*, 98(4): 1158-1180. https://doi.org/10.1093/ajae/aaw018.

Christiaensen L., Rutledge Z., Taylor J.E., 2021. Viewpoint: The future of work in agri-food. *Food Policy*, 99: 12. https://doi.org/10.1016/j.foodpol.2020.101963.

Colin J.-P., 2002. Contrats agraires ou conventions agraires ? *Économie rurale*, 272: 57-73. https://doi.org/10.3406/ecoru.2002.5357.

Colin J.-P., 2003. *Figures du métayage : étude comparée de contrats agraires au Mexique*. Paris: IRD Editions, 355 pp.

Daoudi A., 2016. Le financement informel du secteur maraîcher en Algérie : le cas du crédit fournisseur. *Techniques Financières et Développement*, 124/125: 107-116. https://doi.org/10.3917/tfd.124.0107.

Daoudi A., Colin J.-P., Derderi A., Ouendeno M.L.,

2017. Le marché du faire-valoir indirect vecteur de nouvelles formes d'exploitation dans la néo-agriculture saharienne (Algérie). *Géographie, économie, société*, 19: 307-330. https://doi.org/10.3166/ges.19.2017.0015.

Darpeix A., 2013. La main-d'œuvre salariée en agriculture : histoire d'une invisibilité, *Le Déméter 2013 : économie et stratégies agricoles*. Paris: Club Déméter, pp. 269-296. https://www.clubdemeter.com/_files/ugd/f650b7_b638fdc49fda46618bdc1cdbd07db2a4.pdf.

Dedieu B., 2019. Transversal views on work in agriculture. *Cahiers Agricultures*, 28(8): 9. https://doi.org/10.1051/cagri/2019008.

Dedieu B., Nettle R., Schiavi S.M.d.A., Sraïri M.T., Malanski P.D., 2022. Which perspectives for work in agriculture? Food for thought for a research agenda. *Frontiers in Sustainable Food Systems*, 6: 14. https://doi.org/10.3389/fsufs.2022.857887.

DPSB (Budget Programming and Monitoring Directorate of the Wilaya of Biskra), 2017. *Monography of the Wilaya of Biskra - 2016*. Algeri, 205 pp.

DSA (Directorate of Agricultural Services of the Wilaya of Biskra), 2017. *Statistics on agricultural production by municipalities in the wilaya of Biskra*.

Duval J.E., Blanchonnet A., Hostiou N., 2021. How agroecological farming practices reshape cattle farmers' working conditions. *Agroecology and Sustainable Food Sys*tems, 45(10): 1480-1499. https://doi.org/10.1080/21683565.2021.1957062.

ETF (European Training Foundation), 2021. *Youth in transition in the Southern and Eastern Mediterranean: Identifying profiles and characteristics to tap into young people's potential*, Turin, 129 pp. https://www.etf.europa.eu/en/publications-and-resources/publications/youth-transition-southern-and-eastern-mediterranean.

Geleta D.H., Alemayehu M., Asrade G., Mekonnen T.H., 2021. Low levels of knowledge and practice of occupational hazards among flower farm workers in southwest Shewa zone, Ethiopia: a cross-sectional analysis. *BMC Public Health*, 21(232): 12. https://doi.org/10.1186/s12889-021-10254-5.

Hammouda N.-E., Souag A., 2012. *Segmentation du marché du travail en Algérie et la détermination du salaire dans les secteurs agricole, moderne non protégé et modernes protégé*. Working Papers n. 699, Cairo, Economic Research Forum, 17 pp. https://erf.org.eg/app/uploads/2014/08/699.pdf.

Harris J.R., Todaro M.P., 1970. Migration, Unemployment and Development: A Two-Sector Analysis. *The American Economic Review*, 60(1): 126-142. https://www.jstor.org/stable/1807860.

Hertz T., Zahniser S., 2013. Is There A Farm Labor Shortage? *American Journal of Agricultural Economics*, 95(2): 476-481. https://doi.org/10.1093/ajae/aas090.

Huffman W.E., 2001. Chapter 7 - Human capital: Education and agriculture. In: Gardner B.L., Rausser G.C. (eds), *Handbook of Agricultural Economics*, vol. 1A, 1st ed. Amsterdam: Elsevier, pp. 333-381. https://doi.org/10.1016/S1574-0072(01)10010-1.

Huffman W.E., 2014. Volume 1 A - Agricultural Labor: Demand for Labor. In: Van Alfen N.K. (ed.), *Encyclopedia of Agriculture and Food Systems*, vol. 1, 2nd ed. Oxford: Academic Press, pp. 105-122. https://doi.org/10.1016/B978-0-444-52512-3.00100-5.

ILO (International Labour Organization), 2021. *Employment in agriculture, industry and services, and total and youth of 15-24 years old unemployment rates*. https://data.worldbank.org (accessed on March 21, 2023).

ILO (International Labour Organization), 2022. *Decent work deficits among rural workers: Key findings and recommendations for trade unions*. Switzerland: Bureau for Workers' Activities (ACTRAV), 45 pp. https://www.ilo.org/wcmsp5/groups/public/---ed_dialogue/---actrav/documents/publication/wcms_850582.pdf.

International Monetary Fund, 2022. *Consumer price index (2010 = 100) - Algeria*. https://data.worldbank.org/indicator/FP.CPI.TOTL?locations=DZ. Accessed on July 1, 2023.

Laouar N., Daoudi A., Dugue P., 2023. Les vendeurs d'intrants agricoles, des traducteurs locaux d'un système d'innovation agricole mondialisé. Cas du maraîchage sous serre à Biskra (Algérie). *Les cahiers du CREAD*, 39(2): 177-200. https://doi.org/10.4314/cread.v39i2.6.

Lassassi M., Hammouda N.-E., 2012a. Le fonctionnement du marché du travail en Algérie : population active et emplois occupés. *Region et Developpement*, 35: 99-120. https://regionetdeveloppement.univ-tln.fr/wp-content/uploads/6_LASSASSI.pdf.

Lassassi M., Hammouda N.-E., 2012b. 50 ans d'indépendance : quelle évolution de la situation du marché du travail en Algérie ?. *Les cahiers du CREAD*, 28(100): 101-136. https://www.asjp.cerist.dz/en/article/2052.

Lewis W.A., 1954. Economic Development with Unlimited Supplies of Labour. *The Manchester School*, 22(2): 139-191. https://doi.org/10.1111/j.1467-9957.1954.tb00021.x.

Madelrieux S., Dupré L., Rémy J., 2009. Itinéraires croisés et relations entre éleveurs et salariés dans

les Alpes du Nord. *Économie rurale. Agricultures, alimentations, territoires*, 313-314: 6-21. https://doi.org/10.4000/economierurale.2367.

MADR (Ministry of Agriculture and Rural Development), 2019. *Agricultural statistics. Agricultural areas and productions*. Series B-2016. Algeri, 86 pp. https://madr.gov.dz/wp-content/uploads/2022/04/SERIE-B-2016.pdf.

MADR (Ministry of Agriculture and Rural Development), 2021. *Agricultural statistics. Agricultural areas and productions*. Series B-2019. Algeri, 87 pp. https://madr.gov.dz/wp-content/uploads/2022/04/SERIE-B-2019.pdf.

Malanski P.D., Dedieu B., Schiavi S., 2021. Mapping the research domains on work in agriculture. A bibliometric review from Scopus database. *Journal of Rural Studies*, 81(75): 305-314. https://doi.org/10.1016/j.jrurstud.2020.10.050.

Malanski P.D., Schiavi S., Dedieu B., 2019. Characteristics of "work in agriculture" scientific communities. A bibliometric review. *Agronomy for Sustainable Development*, 39(36): 16. https://doi.org/10.1007/s13593-019-0582-2.

Malanski P.D., Schiavi S.M.d.A., Dedieu B., 2022. Le travail en agriculture dans la littérature académique internationale (2010–2019). *Cahiers Agricultures*, 31(27): 10. https://doi.org/10.1051/cagri/2022021.

Martin P., 2007. *Farm Labor Shortages: How Real? What Response?*. Backgrounder reports. Washington D.C.: Center for Immigration Studies, 15 pp. https://cis.org/sites/cis.org/files/articles/2007/back907.pdf.

Martin P., 2014. Volume 1 A - Agricultural Labor: Labor Market Operation. In: Van Alfen N.K. (ed.), *Encyclopedia of Agriculture and Food Systems*, Vol. 1, 2nd edition. Oxford: Academic Press, pp. 131-142. https://doi.org/10.1016/B978-0-444-52512-3.00102-9.

Merouani W., El Moudden C., Hammouda N.E., 2021. Social Security Enrollment as an Indicator of State Fragility and Legitimacy: A Field Experiment in Maghreb Countries. *Social Sciences*, 10(7): 25. https://doi.org/10.3390/socsci10070266.

Morice A., Michalon B., 2008. Les migrants dans l'agriculture : vers une crise de main-d'oeuvre ? *Études rurales*, 182: 9-28. https://doi.org/10.4000/etudesrurales.8749.

Mundler P., Laurent C., 2003. Flexibilité du travail en agriculture : méthodes d'observation et évolutions en cours. *Ruralia. Sciences sociales et mondes ruraux contemporains*, 12/13: 18. https://journals.openedition.org/ruralia/pdf/336.

Musette M.S., 2014. *Employment policies and active labour market programmes in Algeria*. European Training Foundation (ETF). Turin, 35 pp. https://www.etf.europa.eu/sites/default/files/m/3F6D27A7987C47FEC1257CE60024C937_Employment%20policies_Algeria.pdf.

Naouri M., Hartani T., Kuper M., 2015. Mobilités des jeunes ruraux pour intégrer les nouvelles agricultures sahariennes (Biskra, Algérie). *Cahiers Agricultures*, 24(6): 379-386. https://doi.org/10.1684/agr.2015.0778.

NASA, 2023. *Agroclimatology data for the location of M'ziraâ "Latitude 34.7288 Longitude 6.2953" from 1981 to 2022*. https://power.larc.nasa.gov/data-access-viewer (accessed on March 21, 2023).

Omari C., Moisseron J.-Y., Alpha A., 2012. L'agriculture algérienne face aux défis alimentaires. Trajectoire historique et perspectives. *Revue Tiers Monde*, 210: 123-141. https://doi.org/10.3917/rtm.210.0123.

ONS (National Office of Statistics), 2001. *La population active et le niveau de chômage au 07-09-2001*. https://www.ons.dz/spip.php?article64 (accessed on August 30, 2023).

ONS (National Office of Statistics), 2017. *Activity, Employment & Unemployment (September 2017)*. Employment and Unemployment, 796. Algeria, 20 pp. https://www.ons.dz/IMG/pdf/Activite_emploi_et_chomage_Septembre_2017.pdf (accessed on February 2, 2018).

ONS (National Office of Statistics), 2019. *Activity, Employment & Unemployment (May 2019)*. Employment and Unemployment, 879. Algeri, 20 pp. https://www.ons.dz/IMG/pdf/emploi_chom_mai_2019.pdf.

ONS (National Office of Statistics), 2021a. *Chapter 2 - Employment. Statistical Retrospective 1962 - 2020*, Algeri, pp. 65-96. https://www.ons.dz/IMG/pdf/CH2_Emploi1962_2020Fr.pdf.

ONS (National Office of Statistics), 2021b. *Chapter 3 - Wages. Statistical Retrospective 1962 - 2020*. Algeri, pp. 97-113. https://www.ons.dz/IMG/pdf/CH3_Slaires1962_2020Fr.pdf.

Ouendeno M.L., 2022. L'institution du métayage au Ziban (Algérie) et le développement de cultures maraîchères sous serres. *Alternatives Rurales*, 9: 3-24. https://doi.org/10.60569/9-A1.

Ouendeno M.L., Daoudi A., Colin J.-P., 2015. Les trajectoires professionnelles des jeunes dans la néo-agriculture saharienne (Biskra, Algérie) revisitées par la théorie de l'agricultural ladder. *Cahiers Agricultures*, 24(6): 396-403. https://doi.org/10.1684/agr.2015.0793.

Perrot A., 1992. *Les nouvelles théories du marché du travail*. Paris: La Découverte, 125 pp.

Ragkos A., Koutsou S., Theodoridis A., Manousidis T., Lagka V., 2018. Labor management strategies in facing the economic crisis. Evidence from Greek livestock farms. *New Medit*, 17(1): 59-71. https://doi.org/10.30682/nm1801f.

Richards T.J., 2018. Immigration Reform and Farm Labor Markets. *American Journal of Agricultural Economics*, 100(4): 1050-1071. https://doi.org/10.1093/ajae/aay027.

Richards T.J., Patterson P.M., 1998. Hysteresis and the Shortage of Agricultural Labor. *American Journal of Agricultural Economics*, 80(4): 683-695. https://doi.org/10.2307/1244056.

Sabillón B.H., Gerster-Bentaya M., Knierim A., 2022. Measuring farmers' well-being: Influence of farm-level factors on satisfaction with work and quality of life. *Journal of Agricultural Economics*, 73: 452-471. https://doi.org/10.1111/1477-9552.12457.

Santhanam-Martin M., Wilkinson R., Cowan L., Nettle R., 2024. Elaborating Decent Work for Agriculture: Job Experiences and Workforce Retention in the Australian Orchard Industry. *Journal of Rural Studies*, 111: 9. https://doi.org/10.1016/j.jrurstud.2024.103330.

Sraïri M.T., A., B Naqach Y., 2022. Comparing the uses of available labor and capital in diversified farming systems in Drâa oases (Morocco). *New Medit*, 21(5): 21-34. https://doi.org/10.30682/nm2205b.

Taylor J.E., 2010. Agricultural Labor and Migration Policy. A*nnual Review of Resource Economics*, 2: 369-393. https://doi.org/10.1146/annurev-resource-040709-135048.

Taylor J.E., Charlton D., 2019a. Chapter 8 - The End of Farm Labor Abundance. In: Taylor J.E., Charlton D. (eds.), *The Farm Labor Problem: A Global Perspective*. Oxford: Academic Press, pp. 181-204. https://doi.org/10.1016/B978-0-12-816409-9.00008-2.

Taylor J.E., Charlton D., 2019b. Chapter 6 - Farm Labor and Immigration Policy. In: Taylor J.E., Charlton D. (eds.), *The Farm Labor Problem: A Global Perspective*. Oxford: Academic Press, pp. 121-154. https://doi.org/10.1016/B978-0-12-816409-9.00006-9.

Taylor J.E., Charlton D., 2019c. Chapter 9 - Robots in the Fields. In: Taylor J.E., Charlton D. (eds), *The Farm Labor Problem: A Global Perspective*. Oxford: Academic Press, pp. 205-225. https://doi.org/10.1016/B978-0-12-816409-9.00009-4.

Tocco B., Davidova S., Bailey A., 2012. *Key Issues in Agricultural Labour Markets: A Review of Major Studies and Project Reports on Agriculture and Rural Labour Markets*. Factor Markets Working Papers, 20. Brussels: CEPS, 38 pp. http://aei.pitt.edu/58523/1/Factor_Markets_20.pdf.

Vercherand J., 2014. *Labour. A Heterodox Approach*. London: Palgrave Macmillan, 214 pp.

Vincq J.-L., Granié A.-M., 2014. Chapitre 9 - Les figures du salariat agricole : le cas du secteur des fruits et légumes en Languedoc-Roussillon. In: Jeanneaux P., Perrier-Cornet P. (eds.), *Repenser l'économie rurale*. Versailles: Éditions Quæ, pp. 142-154. https://doi.org/10.3917/quae.jean.2014.01.0142.

Wane A., Touré I., Njiru N., Mballo A.D., 2018. Securing Sahelian pastoralism by using a remunerated workforce for livestock keeping activities: the ambivalence of commodification. *Cahiers Agricultures*, 27(3): 6. https://doi.org/10.1051/cagri/2018024.

Wheeler R., Nye C., 2024. The Health and Well-Being of Women in Farming: A Systematic Scoping Review. *Journal of Agromedicine*: 1-21. https://doi.org/10.1080/1059924X.2024.2407385.

Zajdela H., 1990. Le dualisme du marché du travail : enjeux et fondements théoriques. *Économie & prévision*, 92-93: 31-42. https://doi.org/10.3406/ecop.1990.5155.

NOTES

Food loss and waste in Mediterranean cities

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The technical webinar "*Coordinating local and national actions to reduce food loss and waste in Mediterranean cities*," organized by the SFS-MED Platform as part of the Food is Never Waste Coalition, was one of a series of technical webinars initiated in 2022. These webinars focused on topics crucial to achieving a sustainable food systems transformation in the Mediterranean region. The primary goal of the series was to utilize the extensive knowledge and expertise of the SFS-MED network, which comprises researchers, development practitioners, and decision-makers.

The SFS-MED Platform has achieved positive results from 2020 to 2024, including dialogues within the UN Food Systems Summit and the World Conference on the Mediterranean Diet, the network has reached up to 3500 contacts across 98 countries, and our joint effort with FAO to support food security and sustainable development has been recognized by the UfM and CIHEAM Member Countries during the recent Ministerial events.

The Mediterranean region faces a significant challenge with Food Loss and Waste (FLW), threatening global food security and environmental sustainability. With over 70 percent of the region's population living in urban areas – a figure expected to grow in the coming decades, cities are major food consumers and waste generators, but they can also innovate and create systemic change. Reducing and repurposing food waste benefits the environment, society, and the economy and contributes to the transition towards sustainable food systems.

In 2022, the European Union recorded 59 million tons of fresh food lost or wasted, averaging 132 kilograms per person, with households accounting for 54% of this total (71 kilograms per person). By comparison, this figure is lower in Eastern Europe, with an average of 53 kilograms per person at household level, and considerably higher in the Near East and North Africa region, with food waste at household levels averaging 114 kilograms per capita annually.

To achieve these benefits, we need coordinated action and multi-stakeholder collaboration, including municipalities, civil society, research networks, and national governments. The SFS-MED Platform provides a crucial space for this collaboration.

Recent studies and events emphasized the importance of multiple stakeholders in addressing food loss and waste: Municipalities are directly implementing sustainable food governance and waste reduction initiatives, often collaborating with international organizations. Civil society organizations are taking the lead in promoting sustainability and reducing food loss in the restaurant industry and agricultural sector. Research networks are essential for facilitating knowledge exchange and collaboration between cities to prevent

food loss and waste. National governments play a crucial role by establishing supportive frameworks and providing legislative and financial incentives to drive waste reduction strategies at the city level and within the private sector.

The loss of human resources and knowledge, particularly traditional farming practices and local wisdom passed down through generations, poses a significant barrier to sustainable development. Additionally, it is crucial to emphasize that food loss and waste represent a squandering of vital natural resources, including water, land, and energy, which are essential for food production and overall environmental well-being.

Food Loss and Waste (FLW) occurs throughout the food supply chain and requires multifaceted solutions such as infrastructure, technology, and training to reduce it. Cities are major contributors to FLW, and tackling this issue demands a holistic approach encompassing the entire urban food system.

Transitioning to a circular economy model is essential, where food waste is repurposed into valuable resources, promoting sustainability and job creation. Additionally, scientific research, innovation, and education are pivotal in driving the transformation towards sustainable food systems and reducing FLW.

We must move beyond blaming consumers solely and recognize the shared (distributed) responsibility among all stakeholders, including retailers. Addressing food waste necessitates a broader discourse on sustainable consumption.

Taking immediate action is imperative, as reducing food loss and waste is fundamental for achieving sustainable food systems and ensuring food security for all. Public Food Procurement programs play a significant role in supporting local producers, promoting sustainable agriculture, and enhancing nutrition in public institutions. Cities are crucial in implementing policies that foster sustainable food consumption and minimize waste, and their initiatives must be integrated into national and global strategies. Therefore, cities need to be empowered with the necessary tools and authority to effect meaningful change.

The SFS-MED platform is a vital tool for fostering regional collaboration and formulating effective strategies to combat food loss and waste. Our continued engagement in initiatives like the *Food is Never Waste* coalition is essential for achieving broader sustainability objectives. As previously highlighted, education is key to shifting consumer behavior, particularly among younger generations. Together with simple and practical solutions, we would be able to produce substantial impacts in reducing household waste.

CIHEAM reaffirms its commitment to supporting the SFS-MED Platform and its Coordination Desk, in line with the novel 2030 strategic vision on *sustainable food systems*. We will maintain close collaboration with FAO, UfM, and PRIMA, while expanding our partnerships to encompass other countries, organizations, and the private sector.

A successful and sustainable food system hinges on a network of interconnected stakeholders, collaborating across multiple levels and perspectives to build a shared understanding of the intricate dynamics within the food system itself. This collaborative approach fosters a holistic view, enabling the development of comprehensive and effective solutions to address the complexities of food sustainability.

NEW MEDIT

Scope

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