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# Artificial Intelligence in Agriculture: Revolutionizing Methods and Practices in Portugal

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# Artificial Intelligence in Agriculture: Revolutionizing Methods and Practices in Portugal

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**Abstract**

Artificial Intelligence (AI) has emerged as a focal point for researchers and industry experts, continuously redefined by technological advancements. AI encompasses the development of machines impersonating human cognitive processes, such as learning, reasoning, and self-correction. Its wide-ranging applications across industries have showcased its increasing precision and efficiency, and Agriculture has also embraced AI to increase income and efficiency. In this regard a literature review to comprehensively understand the concept, existing research, and projects related to AI in agriculture was performed. Moreover, this paper approaches the potential of AI in agriculture practically, addressing the emergence of new methods and practices, using a case study approach, and analyzing the perceptions of impacts of AI in agriculture, from experts, academics, and agriculture professionals regarding the application of AI. It contributes to real application development, offering insights that resonate within academic and practical dimensions.

**JEL Classification:** D20 General; Q16 R&D, Agricultural Technology

**Keywords:** Artificial Intelligence, Agriculture, Efficiency, Quantitative analysis



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## 1. Introduction

AI stands as a technological development that has captivated both academic discourse and practical applications across diverse industries. Its evolution has been punctuated by redefined definitions, adapting to technological advancements (Kok et al., 2002). AI represents a branch of computer science dedicated to crafting machines capable of emulating human-like cognitive functions, encompassing learning, reasoning, and self-correction.

The far-reaching implications of AI are manifest across various sectors, with its penetration into industries such as manufacturing, healthcare, marketing, finance, and tourism (Dwivedi et al., 2021). However, one sector that can witness a transformative impact is agriculture, where AI's applications can potentiate a new era of innovation, efficiency, and sustainability.

In explaining AI's role in agriculture, it becomes imperative to understand its overarching definition and how it pertains to this domain. Defined broadly, AI in agriculture represents a confluence of technology and methodology aiming to revolutionize conventional agricultural practices. Its core objective is to expand, automate, and optimize farming operations, thereby enhancing productivity, mitigating risks, and ensuring sustainable food production.

The significance of agriculture as a global economic basis is very high staggering global value of $3.6 trillion and a consistent contribution of 4% to the global GDP over the past two decades, the agricultural sector highlights the socio-economic dimensions of numerous nations (FAO, 2022). However, this sector has several challenges, ranging from unpredictable weather patterns, and crop-damaging pests and diseases to the deleterious impacts of climate change and desertification (Komarek et al., 2020). These challenges create some threats to agricultural productivity, exacerbating the already mounting pressures due to an expanding of global population.

At the forefront of these challenges stands the United Nations' 2030 Sustainable Goals, notably the Zero-Hunger program, which underscores the imperative of achieving food security sustainably (United Nations, 2015). Against this backdrop, the integration of AI into agricultural practices emerges as an instrumental strategy, offering novel methodologies and technological solutions to address these challenges.

The combination of innovation technology, digitalization, and AI stands tries to mitigate the challenges that agriculture faces (Yela Aranega et al., 2022). This paradigm change indicates the need to reevaluate established agricultural practices and technologies, with a renewed emphasis on maximizing the production of crops, minimizing resource use, and decreasing labor costs.

Moreover, the strategic significance of AI in agriculture extends beyond efficiency gains. It fundamentally reshapes the agricultural business models, opening new possibilities for growth, innovation, and sustainability (Toniolo et al., 2019). These models serve as framework stating how value is created and delivered within the agricultural ecosystem.

However, despite the interest and the potential of AI in reshaping agricultural paradigms, the existing literature on AI's role in agriculture remains a work-in-progress (Cavazza et al., 2023). While there is a proliferation of studies examining the potential synergies between AI and agriculture, the depth of scholarly exploration concerning its implications on agricultural business models remains relatively limited.

The literature on AI in agriculture largely encompasses case studies that evaluate and discuss technological solutions and algorithms, spanning diverse agricultural domains (Panpatte and Ganeshkumar, 2021). Yet, the scarcity of success stories within the literature, elucidating tangible benefits reaped by farms leveraging AI technologies, is evident (Sood et al., 2022).

While the literature underscores the necessity of coupling AI with complementary technologies like IoT (Internet of things) and robotics to create a cohesive digital ecosystem in agriculture (Chiles et al., 2021; Dal Mas et al., 2023), it also delineates emerging farming techniques such as vertical farming, aquaculture, insect breeding, and precision agriculture (Davies and Wilson, 2020; Saad et al., 2021).

AI also have the potential to address multifaceted sustainability issues, including reducing agricultural pollution, optimizing resource utilization, and fostering environmentally friendly practices (Bogomolov et al., 2021; Rao et al., 2018). However, several gaps persist in the academic literature, as the shortage of comprehensive AI-driven business models in agriculture (Cavazza et al., 2023). Despite the emergence of technological solutions and algorithms, the absence of real-world case studies showing AI's potential implications on the future of agriculture remains a reality.

In response to this call for in-depth analysis rooted in real-world scenarios to contribute for the formulation, implementation and evaluation of public policies, this research adopts a multi-case study methodology. It will provide an in-depth exploration of AI's application in agriculture and its impacts.

The subsequent sections of this article delineate the current literature, develop the research question, elucidate the chosen methodology, present key findings, and engage in comprehensive discussions regarding recommendations for policy, implications, and limitations of the research.

## 2. Literature review

### 2.1 Conceptualization of AI in Agriculture

Artificial Intelligence has garnered significant attention from both scholars and practitioners in recent years. Defined broadly, AI stands as a branch of computer science aiming to develop machines capable of human-like cognitive processes (Kok et al., 2002). Its applications span various industries and notably, agriculture (Dwivedi et al., 2021).

The agricultural sector, with a global value of $3.6 trillion and a consistent contribution of 4% to the global GDP, holds immense significance (FAO, 2022). However, it faces formidable challenges—unpredictable risks like weather conditions, crop-destroying pests, and diseases, coupled with the adverse impacts of climate change and desertification (Komarek et al., 2020; FAO, 2022). The need for sustainable food security has been highlighted as a crucial goal by the United Nations (United Nations, 2015).

In response to these challenges, technology, digitalization, and AI emerge as potential solutions (Yela Aranega et al., 2022). The integration of AI in agriculture aims not only to address these challenges but also to enhance productivity and reduce human effort (Saad et al., 2021). The strategic role of AI in agriculture becomes apparent considering its potential to reshape existing methodologies and technologies for maximizing crop yield and ensuring sustainable food production (FAO, 2022).

AI's impact on agricultural business models stands as a focal point in this evolving landscape (Toniolo et al., 2019). Defined as the framework through which organizations create value, business models in agriculture are poised for transformation through AI integration (Bagnoli et al., 2019; Bagnoli et al., 2018; Biloslavo et al., 2018). This transformation not only addresses sector-specific challenges but also aligns with sustainability objectives (Biancone et al., 2022; Blackmore, et al., 2015).

Sustainability remains a pivotal theme in this context, with AI-driven solutions showing promise in supporting environmentally friendly practices (Bogomolov et al., 2021; Rao et al., 2018).

### 2.2 AI Technology applied to agriculture

Precision Agriculture, enabled by AI, empowers farmers to make data-driven decisions by harnessing information from diverse sources such as satellite imagery, drones, sensors, and weather forecasts (Qin et al., 2019; Castellini et al., 2016). Through the utilization of machine learning algorithms, farmers can optimize irrigation, fertilization, and pesticide application, resulting in heightened crop yields, diminished resource usage, and enhanced sustainability.

Crop Monitoring and Disease Detection leverage computer vision and machine learning techniques to analyze images of crops captured by drones or satellites (Mohanty et al., 2016; Castellini et al., 2016). By identifying patterns and anomalies in plant health and growth, AI systems can swiftly detect diseases, pests, nutrient deficiencies, and other issues, enabling farmers to take timely actions to mitigate losses.

Predictive Analytics plays a crucial role as AI models analyze historical data on weather patterns, soil conditions, crop yields, and market prices to forecast future trends (Hansen, 2002; Tao et al., 2018). These forecasts aid farmers in planning planting schedules, managing inventories, optimizing resource allocation, and minimizing risks associated with climate variability and market fluctuations.

Robotic Farming is on the rise with AI-powered robots and autonomous vehicles being developed to execute various tasks on the farm (Li & Wang, 2017). These tasks include planting seeds, applying fertilizers and pesticides, weeding, and harvesting crops, thereby operating with precision and consistency, reducing labour costs, and increasing operational efficiency.

Supply Chain Optimization, facilitated by AI technology, streamlines the entire agricultural supply chain from production to distribution (Tao et al., 2018). Machine learning algorithms analyse data on demand forecasts, transportation routes, storage conditions, and market dynamics to reduce waste and ensure the timely delivery of agricultural products to consumers.

In Crop Breeding and Genomics, AI techniques, including genetic algorithms and deep learning, accelerate the breeding of crops with desirable traits (Zhang et al., 2016). By identifying genetic markers associated with these traits, breeders can efficiently develop improved crop varieties.

Finally, AI-powered Farm Management Systems integrate data from various sources, automate routine tasks, and provide insights tailored to specific farm conditions (Li & Wang, 2017). These systems aid farmers in planning, monitoring, and decision-making, optimizing resource utilization, and maximizing profitability.

### 2.3 Creating a model of analysis

The analysis model provided underscores a comprehensive approach to bolstering agricultural productivity and sustainability by integrating advanced technologies and management practices. Each component plays a pivotal role in this endeavor.

Increased Production Efficiency is central to optimizing agricultural operations by leveraging advancements in machinery, automation, and resource utilization to enhance productivity, minimize waste, and streamline processes. This entails maximizing the use of available resources such as land, labor, and inputs (Rejesus, Zamora, & Reyes, 2003).

Precision in Agricultural Management harnesses technology like GPS, sensors, and drones to precisely manage farming variables such as planting, irrigation, fertilization, and pest control. By accurately targeting inputs and actions, farmers can optimize yields while minimizing costs and environmental impact (Gebbers & Böhner, 2010).

Harvest Optimization strategies and technologies are geared toward maximizing yield and quality. This includes adopting timely harvesting practices, employing post-harvest handling techniques, and utilizing equipment such as harvesters and storage facilities to minimize losses and maintain product quality (Ferguson & Burras, 2009).

Intelligent Water Resource Management acknowledges the critical role of water in agriculture and employs technology to monitor, conserve, and efficiently distribute water for irrigation. Techniques like drip irrigation, soil moisture sensors, and water recycling systems optimize water usage while sustaining crop growth (Khan & Qazi, 2012).

Improvement in Quality focuses on enhancing agricultural products through better farming practices, handling methods, and technologies. By adhering to higher quality standards, farmers can increase market value, reduce waste, and meet consumer demands for superior products (Doerge, 1999).

Decision Support systems provide farmers with data-driven insights and recommendations for informed decision-making. By analyzing data, modelling scenarios, and employing predictive algorithms, these systems assist in crop selection, planting schedules, resource allocation, pest management, and risk mitigation strategies, thereby enhancing overall farm performance and profitability (Singh et al., 2014).

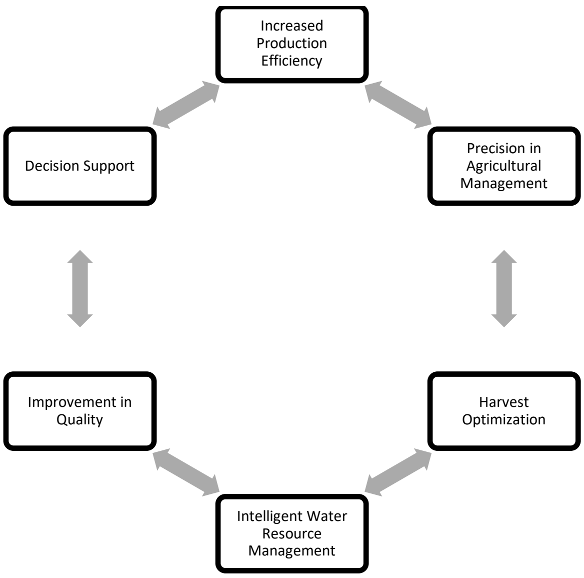


Figure 1 – Model of analysis

From the literature emerged this model of analysis (figure 1) which will guide the empirical research and the answer to the main research question: RQ: What are the main differences in perceptions of Experts and academics versus professionals of the agriculture sector regarding AI impacts in Agriculture? The following sections will be developed to reply to this question.

## 3. EU Public Policies to Promote the Digitalization of Agriculture

European Union (EU) has been actively developing policies and initiatives to promote the use of Artificial Intelligence in agriculture, aiming to foster innovation, sustainability, and efficiency in the agricultural sector. Some existing EU policies related to AI in agriculture include:

Table 1 – European Union Policies to Promote the Digitalization of Agriculture

| | |
|---|---|
| **European AI Strategy:** | The EU's AI Strategy focuses on fostering the development and deployment of AI across various sectors, including agriculture. It aims to support research, innovation, and ethical AI use while ensuring compliance with EU values and regulations |
| **Common Agricultural Policy (CAP) Reform:** | The CAP, a major EU policy for agriculture and rural development, has been undergoing reforms to incorporate digitalization, including AI technologies. The updated CAP seeks to support digital transformation in agriculture, encouraging the adoption of innovative technologies for sustainable and efficient farming practices. |
| **Digital Europe Programme:** | This EU initiative allocates funding to support digital transformation in various sectors, including agriculture. It aims to enhance digital skills, infrastructure, and technologies, fostering the adoption of AI and other digital tools in farming practices. |
| **Horizon Europe:** | The EU's research and innovation framework program, Horizon Europe, includes funding opportunities for AI-related projects in agriculture. It supports research, innovation, and collaboration to develop AI-driven solutions for sustainable agriculture, focusing on areas like precision farming and smart agri-food systems. |
| **European Data Strategy:** | The EU is working on a comprehensive data strategy to facilitate the sharing and use of agricultural data, which is crucial for AI applications in farming. Efforts to create common data spaces and standards aim to unlock the potential of AI in agriculture by enabling data-driven decision-making. |
| **Ethical Guidelines for Trustworthy AI:** | The EU has been developing ethical guidelines and regulatory frameworks for AI. These guidelines emphasize the importance of ethical AI design, transparency, accountability, and human oversight, which are relevant considerations in AI applications for agriculture. |
| **European Green Deal:** | The EU's Green Deal sets ambitious sustainability goals, including the reduction of pesticide and fertilizer use. AI |

| | |
|---|---|
| | technologies in agriculture, such as precision farming, can contribute to achieving these goals by optimizing resource utilization and minimizing environmental impacts. |

These policies and initiatives reflect the EU's commitment to fostering AI innovation in agriculture while ensuring responsible and ethical use. They aim to support farmers, promote sustainable practices, and drive digital transformation in the agricultural sector across member states.

## 4. The Context of AI in Agriculture in Portugal

### 4.1 AgTech Companies and Startups in Portugal

Modern agriculture is shaped by technological innovation changing the traditional across Portugal. Several technological startups have emerged redefining agricultural operations with cutting-edge technologies. From software platforms fostering collaboration to environmental sustainability initiatives, these startups are pioneering a revolution in the agriculture sector.

PROGROW stands tall as a software company harnessing the power of state-of-the-art IoT connectivity and data analytics. Its web platform, dedicated to industrial frontline operations, offers a transformative experience, ushering any equipment or workstation into the realm of online efficiency. Similarly, WISECROP, an Online Agricultural Operating System, orchestrates predictive indicators and business management tools, centralizing farm management and amplifying seasonal results. This convergence of technology enables access to vital information on crops, equipment, and irrigation, both on and off the field.

ABOUT AQUA FOOD, an ambitious sustainability project, aspires to produce and commercialize healthy, premium foods with maximal environmental responsibility. Their visionary endeavor metamorphosed into the Bio-Agro Concept startup, epitomizing a futuristic approach to food production. On a parallel trajectory, AGROINSIDER emerges as a guiding light within the agribusiness value chain. Their suite of consulting and technological tools, operating on SaaS solutions, champions the preservation of the invaluable asset—Natural Capital.

Navigating the intricate web of agricultural commerce, AGRI MARKETPLACE emerges as a B2B cloud-based platform facilitating real transactions of agricultural food crops. In this digital marketplace, fair food trade blossoms, simplified, expedited, and transparent, bridging the gap between Farmers and Agro-Industry Buyers. Similarly, WINE WITH SPIRIT, a Winetech company, intertwines innovation with an ancient industry, producing award-winning Portuguese wines that traverse four continents.

However, beyond technology-driven enterprises, institutions like CREDITO AGRICOLA have evolved from their agricultural roots into universal financial and insurance groups. Their practice of proximity and relationships continues to nurture and support the sector. Complementing this financial landscape, AGRISTARBIO steps in with its organic mineral fertilizer derived from biosolids, fostering sustainability amid the intensifying need for food and feedstock.

ROVENSA specializes in sustainable agricultural solutions, combating the environmental footprint of farming practices. Their commitment to safe, healthy, and nutritious food production resonates across a spectrum of companies like FARMCONTROL, offering IoT cloud software for monitoring agricultural operations, and FLOW TECHNOLOGY, simplifying industry with a manufacturing execution system.

Venturing into specialized domains, AQUAPONICS IBERIA champions sustainable, efficient aquaponics technologies, training and providing consulting services. Meanwhile, AGRIW takes center stage with its Agriculture 4.0 Smart Farming Solution, rooted in Artificial Intelligence and Machine Learning, while TERRAPRIMA champions environmental services provided by agro-forestry activities.

Echoing the technological chorus, HARKER lends support to the milk production industry, promoting health, animal welfare, and farm development. Similarly, BIOSANI steps in with biotechnical pheromones for plant protection in Organic Agriculture, blending expertise with youthful dynamism.

In the realm of quality control, CALSEG assumes a pivotal role, offering inspection services for agri-food products. Simultaneously, IBERO FOREST MASSA pioneers the production of biocarbon, innovating ecological technology through biomass transformation.

Meanwhile, AGRICIENCIA offers information management and viticulture services, and HIDROSOPH consults in irrigation management and environmental services, underlining a collective commitment to sustainability. MAGAGER, entrenched in history since the 1930s, and CUDELL, a platform advocating environmental stewardship, add unique layers to this mosaic of agricultural innovation.

Each organization, whether a technology-driven business or an agent of environmental sustainability, plays a part in the innovation process of AI application to agriculture sector in Portugal.

## 4.2 Portugal Participation in Horizon Europe Projects to promote Digitalisation in Agriculture

Portugal participated in several Horizon Europe projects focused on agriculture, contributing expertise, research, and innovation in various fields related to sustainable farming practices, digitalization, and technological advancements. While the participation in these projects might evolve, here are a few examples of Horizon Europe projects where Portugal has been involved in the agricultural sector (table 2):

Table 2 – Projects Funded by EU to Promote the Digitalization of Agriculture

| **Project** | Portuguese Consortium |
|---|---|
| **SmartAgriHubs:** Portugal was part of the SmartAgriHubs project, contributing to the establishment of Digital Innovation Hubs (DIHs) in | CONSULAI, TEKEVER, EDIA (Empresa de Desenvolvimento e Infra-Estruturas do Alqueva), |

| | |
|---|---|
| agriculture. These hubs aimed to facilitate the digital transformation of the agricultural sector by promoting the adoption of innovative technologies, including AI, IoT, and robotics, among farmers and agribusinesses. | UNPARALLEL Innovation, Instituto Nacional de Investigação Agrária e Veterinária, Centro Operativo e de Tecnologia de Regadio, Associação de Beneficiários da Obra da Vigia, e FreedomGrow. |
| **IoF2020 (Internet of Food & Farm):** Portugal participated in the IoF2020 project, which focused on integrating Internet of Things (IoT) technologies in agriculture. This project aimed to enhance farming practices, sustainability, and efficiency by leveraging IoT solutions, which might include AI-driven analytics and decision support systems. | UNPARALLEL INNOVATION LDA |
| **AGINFRA+:** Portugal contributed to the AGINFRA+ project, which aimed to develop an open data infrastructure for the agricultural community. This project sought to provide tools and services, including AI-driven analytics and data management solutions, to support agricultural research and innovation. | INESC-ID (Instituto de Engenharia de Sistemas e Computadores, Investigação e Desenvolvimento), LNEC (Laboratório Nacional de Engenharia Civil) |
| **FutureAgriculture:** Portugal might have participated in projects like FutureAgriculture, emphasizing sustainable intensification in agriculture through technology adoption. This project likely explored the application of AI, big data analytics, and precision agriculture to enhance agricultural productivity while minimizing environmental impacts. | INIAV, Instituto Superior Técnico (IST) |
| **NEFERTITI:** Portugal might have been involved in NEFERTITI, focusing on knowledge exchange and innovation uptake among farmers in Europe. While not primarily centered on AI, this project aimed to integrate innovative technologies, including digital solutions and precision agriculture, to improve farming practices. | Agroop |

Portugal's involvement in these Horizon Europe projects demonstrates its commitment to leveraging technological advancements and innovation for the benefit of its agricultural sector. However, participation might have varied across different projects and initiatives within Horizon

Europe, and new projects may have emerged since my last update. For the most current and detailed information on Portugal's participation in Horizon Europe projects related to agriculture and AI.

## 5. Methodology

Given the aim of exploring AI applications in agriculture in Portugal, the methodology for conducting this research will follow the next steps:

1. Research Objective Clarification: Clear research objectives that outline the specific aspects of AI in agriculture, to guide the entire research process.
2. Case Study Selection: Identify and select two innovative case studies in Portugal that have integrated AI technologies or innovative digital solutions in their operations. This case study selection should align with the research objectives and provide a representative example for analysis.
3. Data Collection: Utilize a mixed-method approach for data collection, including qualitative and quantitative data. Qualitative methods involve document analysis based on the theoretical model developed in this research to gather insights into AI implementation; Quantitative methods will consider a sample of observations by questionnaire (table 4) to analyse perceptions of the impacts of AI application to Agriculture.
4. Data Analysis: For qualitative data content analysis will be used to identify recurring themes or patterns. Quantitative data will be statistically analysed.
5. Recommendations: Summarize the findings and provide recommendations based on the study's outcomes, highlighting best practices, potential areas for improvement, and implications for public policies in the agricultural sector.

## 6. Empirical Study – The Impact of AI in the Agribusiness in Portugal

### 6.1 Qualitative analysis

#### A) Portuguese Olive Oil Case Study

Artificial Intelligence can be a vital resource in the production of olive oil in Portuguese agriculture, bringing with it a range of significant benefits. These technological advances can transform traditional agricultural practices, providing substantial improvements in various key areas of olive tree cultivation and olive oil production. The integration of artificial intelligence in olive oil production in Portugal not only drives efficiency and quality but also promotes a more sustainable and environmentally conscious approach. These benefits can significantly contribute to the competitiveness and excellence of the country's olive oil sector.

Using the model created based on the literature review the analysis of the application of AI in the Portuguese olive oil production is as follows:

1. Increased Production Efficiency: Esporão, a prominent olive oil producer, implements AI-driven systems that analyse historical weather data, soil moisture, and plant health metrics. This data-driven approach allows them to precisely schedule irrigation, fertilization, and other

cultivation practices, resulting in optimized resource allocation and increased olive oil yield without compromising quality.

2. Precision in Agricultural Management: Sovena, a leading olive oil company, integrates AI-based drones equipped with imaging technology to monitor olive groves. These drones identify specific areas affected by pests or diseases, enabling targeted interventions that minimize the use of pesticides and herbicides while maintaining a healthy and sustainable olive orchard.

3. Harvest Optimization: Cobrançosa, an olive oil cooperative, employs AI algorithms that process data from temperature sensors, humidity levels, and fruit ripeness. This technology aids in predicting the optimal harvest time, ensuring that olives are picked at their peak, contributing to enhanced oil quality and efficiency during harvesting.

4. Intelligent Water Resource Management: Herdade das Servas, utilizing AI-powered irrigation systems, measures soil moisture levels and climate data. This technology allows for precise water delivery to olive trees, reducing water wastage and ensuring the trees receive adequate hydration for optimal growth while conserving a scarce resource.

5. Improvement in Quality: Oliveira da Serra employs AI-based sensory analysis tools to assess olive oil quality. By analysing chemical compositions and sensory attributes, they ensure that only the highest-quality olive oil, meeting strict standards, reaches the market, enhancing consumer trust and satisfaction.

6. Decision Support: The National Association of Olive Growers utilizes AI-powered platforms that process extensive datasets on market trends, climate patterns, and consumer preferences. This data-driven insight equips farmers with valuable information for informed decision-making on plantation management, production strategies, and market positioning to optimize their olive oil business.

**B) Portuguese Winery Case Study**

In winery, AI stands as an invaluable asset revolutionizing the production processes. Its implementation in Portuguese has reshaped conventional practices and significantly enhanced various facets of grape cultivation and wine production. It leads to higher efficiency and quality but also leads to a more sustainable and environmentally conscious approach.

Using the model created based on the literature review the analysis of the application of AI in the Portuguese winery is as follows:

1. Enhanced Production Efficiency: Quinta do Vallado, a renowned winery in Portugal's Douro Valley, utilizes AI-powered systems to analyse weather data, soil moisture, and vine health. This data-driven approach enables them to optimize vineyard management, resulting in increased grape yield and improved wine quality.

2. Precision in Agricultural Management: Symington Family Estates employs AI-powered drones equipped with imaging technology to identify specific vineyard areas affected by pests

or diseases. This targeted approach allows for precise intervention, reducing the need for chemical treatments and promoting sustainable vineyard practices.

3. Harvest Optimization: Herdade do Rocim, an Alentejo winery, utilizes AI algorithms to analyze grape maturity and weather conditions. This technology assists in determining the optimal time for grape harvesting, ensuring that the grapes are picked at their peak ripeness for superior wine production.

4. Intelligent Water Resource Management: Adega Mayor, located in the Alentejo region, implements AI-driven irrigation systems that use sensors to monitor soil moisture levels. This data guides precise irrigation, ensuring the vines receive adequate water without unnecessary waste, contributing to sustainable water management.

5. Improvement in Quality: Casa Ferreirinha employs AI-powered quality control systems that analyse chemical compositions and sensory characteristics of wines at different stages of production. This meticulous analysis ensures consistency and high-quality standards in their wine offerings.

6. Decision Support: Wine Intelligence, a market research company, provides Portuguese winemakers with AI-generated insights based on consumer preferences, market trends, and competitor analysis. This information assists wineries in making informed decisions regarding production volumes, marketing strategies, and product positioning.

## 6.2 Comparative analysis – qualitative approach

To make a comparative analysis of the case studies a table (3) was created following the dimensions of the model of analysis:

Table 3 – Comparative analysis of the case studies

| | **Wine case study** | **Olive Oil case study** |
|---|---|---|
| **Increased Production Efficiency:** | AI optimizes grape cultivation by meticulously managing vineyards. By analysing diverse data sets encompassing weather patterns, soil conditions, and fertilization, AI streamlines resource allocation, leading to heightened productivity and superior wine quality during harvests. | AI is optimizing the olive tree cultivation process, enabling more effective management of plantations. It analyses data on weather conditions, fertilization, and soil management, allowing precise resource optimization, and resulting in higher productivity and quality in harvests. |

| | | |
|---|---|---|
| **Precision in Agricultural Management:** | AI systems facilitate precise management of vineyard threats such as pests, diseases, and weeds. This precision minimizes reliance on chemical interventions, fostering sustainable practices and mitigating environmental impacts. | AI systems allow for a more precise approach to managing pests, diseases, and weeds. This precision reduces reliance on pesticides and herbicides, promoting more sustainable agricultural practices and minimizing environmental impacts. |
| **Harvest Optimization:** | AI predicts the ideal time for grape harvesting, considering factors like grape ripeness and weather forecasts. This predictive capability ensures efficient harvesting, resulting in elevated wine quality. | AI can predict the optimal time for olive harvesting based on a variety of factors, such as fruit maturity and weather conditions. This results in more efficient harvesting and superior olive oil quality. |
| **Intelligent Water Resource Management:** | In a landscape where water conservation is pivotal, AI empowers smarter water utilization through sophisticated irrigation systems. These systems meticulously monitor and regulate water usage, curbing wastage and bolstering sustainability in grape cultivation. | In a context where water is a precious resource, AI enables more efficient water use through smart irrigation systems. These systems monitor and control water usage precisely, reducing waste and increasing sustainability in olive tree cultivation. |
| **Improvement in Quality:** | AI assumes a critical role in assuring wine quality by discerning patterns and traits that directly influence its excellence. This meticulous scrutiny guarantees the production | AI also plays a crucial role in the quality control of olive oil, allowing the detection of patterns and characteristics that directly affect its quality. This ensures that only the |

| | | |
|---|---|---|
| | and marketing of only the highest-grade wines. | highest-quality olive oil is produced and marketed. |
| **Decision Support:** | By processing extensive datasets, AI offers invaluable insights to winemakers, aiding in informed decisions regarding vineyard management, production forecasts, and strategic market approaches. | With the ability to analyze large volumes of data, AI provides valuable insights to farmers, helping them make informed decisions about plantation management, production forecasts, and market strategies. |

### 6.3 Quantitative analysis

To answer the research question, it was applied a quantitative methodologic approach supported by a questionnaire to identify differences between experts, academics, and agriculture professionals on AI's impact on the agricultural sector. The information was collected via a structured questionnaire that was prepared after the review of the literature. A convenience sample was used (non-probabilistic sampling procedure). When it is difficult to obtain a complete sampling, convenience sampling is suitable (Mercadé et al., 2017, 2018). The fieldwork was carried out between January and February of 2024 with a participation of 80 individuals, for a confidence level of 95% (and p=q=0.5) and an increase in data error for the estimate of the proportion of 5.8%. The next table shows a summary of the information regarding the data collection and the technical matters of the sample (Table 4).

Table 4. Fact Sheet

| | |
|---|---|
| Fieldwork | January through Feebruary 2024 |
| Sample size | 80 surveyed |
| Sample type | Convenience sampling |
| Survey type | Structured online questionnaire |
| Sampling error | 5.8% assuming p=q=0.5 and a confidence level of 95% |

### 6.4 Data Analyses and Discussion

To analyze the differences in perceptions between Experts, academics, and Agriculture professionals, a covariance analysis (ANCOVA) has been carried out. The variance due to the individual differences is estimated from the regression between the dependent variable and the covariable. The scores in the dependent variable are statistically adjusted to the covariable. Finally, an ANOVA is performed on these adjusted scores (Tabachnick and Fidell, 2007). Thus, the analysis controls the effect of the covariable, so that it eliminates the variation due to the mismatch of the ANOVA error.

In the following table (5) analyzes the adjusted means F statistics and p-value for each group.

Table 5. AI Technologies applied in the Agricultural sector.

| Variables | Experts and Academics | Agriculture professionals | F | *p* |
|---|---|---|---|---|
| Precision Agriculture | 4,112 | 3,153 | 102,323 | 0,000*** |
| Monitoring and Disease Detection | 3,780 | 3,526 | 24,762 | 0,000*** |
| Predictive Analytics | 4,211 | 3,631 | 15,626 | 0,000*** |
| Robotic Farming | 4,354 | 3,614 | 67,235 | 0,000*** |
| Supply Chain Optimization | 4,366 | 3,500 | 88,432 | 0,000*** |
| Crop Breeding and Genomics | 4,321 | 3,571 | 82,533 | 0,000*** |
| Farm Management Systems | 4,234 | 3,568 | 55,425 | 0,000*** |

*=p<0,1; **=p<0,05; ***=p<0,01

In Table 5 are displayed the adjusted means, F statistics, and p-values. The analysis shows that there are statistically significant differences in all AI technologies applied to Agriculture (p-value <0.01 in all cases), always showing a higher score in Experts and Academics responses.

As for AI impacts in the agriculture sector, a four-point Likert scale, that rate 1 as "None", 2 as "Low", 3 as "Moderate", and 4 as "High" impact, was used. The t-student test has been carried out to verify whether there are significant differences between Experts, Academics and Agriculture professionals (Table 6).

Table 6: Perceptions about AI impacts in the Agriculture Sector

| Variables | Experts and Academics Mean | Agriculture Professionals Mean | t-student | *p* |
|---|---|---|---|---|
| Increased Production Efficiency | 2,14 | 1,43 | 1,930 | 0,052* |
| Precision in Agricultural Management | 2,48 | 1,95 | 3,743 | 0,000*** |
| Harvest Optimization | 2,68 | 1,71 | 1,512 | 0,080* |
| Intelligent Water Resource Management | 2,58 | 1,40 | 7,644 | 0,000*** |
| Improvement in Quality | 2,05 | 1,77 | 1,732 | 0,03** |
| Decision Support | 2,25 | 1,81 | 4,945 | 0,001*** |

*=p<0,1; **=p<0,05; ***=p<0,01

In table 6 it can be seen that Experts and academics sample have higher scores in all the ítems analyzed, namely, the higher impacts are in Harvest optimization, Intelligent Water Resource Management, in Precision in Agricultural Management, in Decision Support, and Improvement in Quality.

Finally, to analyze whether there is a correlation between AI and its influence on efficiency and Decision Support a Cramer's test was applied (table 7).

Table 7: AI Impacts on Efficiency and Decision Support

| | **Cramer test** | ***p*** |
|---|---|---|
| AI Influences Efficiency in Agriculture | 0,373 | 0.000*** |
| AI contributes to effective decision support | 0,368 | 0.00*** |

*=p<0,1; **=p<0,05; ***=p<0,01

The results indicate that AI has an influence on both the variable's efficiency and decision support according to the perceptions of the participants in the study.

## 7. Recommendations for Public Policies to a potential promotion of AI in Agriculture

Public policies play a crucial role in fostering the integration of Artificial Intelligence in agriculture across Portugal. In this context, and emerging from this study, next are presented some recommendations that can promote AI adoption in agriculture:

1. Research and Development Funding: Government funding initiatives aimed at research and development in AI technologies specific to agriculture can incentivize innovation. Grants, subsidies, and research partnerships can encourage the development of AI tools tailored to the needs of farmers, processors, and marketers.

2. Education and Training Programs: Establishing educational programs and training initiatives focused on AI applications in agriculture can enhance the skill set of farmers and agricultural professionals. Workshops, courses, and skill development programs can facilitate the understanding and effective use of AI tools in farming practices.

3. Data Infrastructure Support: Building a robust data infrastructure that enables the collection, sharing, and analysis of agricultural data is essential. Policies supporting the creation of data-sharing platforms and frameworks for standardized data collection can aid in the development of AI-driven solutions for agriculture.

4. Regulatory Frameworks and Standards: Clear regulatory guidelines and standards specific to AI applications in agriculture are necessary. These regulations should ensure ethical AI use, data privacy, and interoperability of AI systems, fostering trust and confidence in adopting AI technologies.

5. Financial Incentives for Adoption: Providing financial incentives such as tax breaks, subsidies, or low-interest loans for farmers and producers adopting AI technologies can accelerate their uptake. These incentives can offset initial investment costs and encourage broader adoption of AI-driven solutions.

6. Collaboration and Knowledge Sharing: Encouraging collaboration between government bodies, research institutions, industry stakeholders, and tech innovators can facilitate knowledge sharing. Platforms for collaboration, exchange of best practices, and promoting partnerships can drive AI innovation in the agricultural sector.

7. Promotion of Sustainable Practices: Policies promoting the use of AI to improve sustainability in agriculture could be incentivized. AI-driven precision agriculture techniques can optimize resource utilization, reduce environmental impacts, and align with sustainability goals, thereby qualifying for support and recognition.

8. Support for Market Access: Facilitating market access for AI-enabled products and services related to agriculture is crucial. Policies that encourage the use of AI for quality assurance, traceability, and branding can enhance market competitiveness and consumer trust.

The process of integrating new practices and technologies within regulatory frameworks involves several key phases: policymaking, implementation, and evaluation; and the next figure (2) represents how these policy recommendations can be integrated into the public policy dimensions.

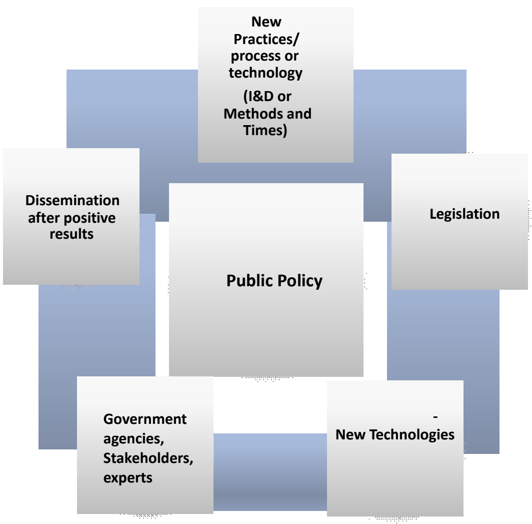


Figure 2 – Public Policy Dimensions

The policymaking phase involves the development of new policies or the revision of existing ones to accommodate advancements in agricultural practices and technologies. Policymakers, including government agencies, agricultural experts, and stakeholders, collaborate to identify emerging needs, assess available technologies, and formulate regulations/legislations that promote innovation in this case in the agriculture sector.

After the policies are formulated, it is needed to implement them by the agricultural sector, providing training and technical assistance, and establishing mechanisms for compliance monitoring and enforcement. Agricultural associations and research institutions facilitate the adoption of new practices and technologies. Moreover, incentivizing compliance through subsidies, grants, or tax incentives can encourage widespread adoption of AI and implementation.

The dissemination based on the evaluation process involves monitoring key performance indicators, such as changes in productivity and new practices and technologies implemented. This phase helps policymakers understand the effectiveness of the policies to make necessary adjustments to enhance their impact.

## 8. Conclusion, Limitations, and future research

AI's integration into agriculture represents a significant opportunity to address the sector's challenges while enhancing productivity and sustainability. By leveraging AI technologies such as precision agriculture, crop monitoring, predictive analytics, robotic farming, and supply chain optimization, farmers can make data-driven decisions, optimize resource use, and streamline operations. Furthermore, AI-driven solutions have the potential to reshape agricultural business models, fostering innovation and sustainability across the entire value chain.

Despite the promising potential of AI in agriculture as shown by this research, several challenges persist. The existing literature often lacks comprehensive real-world case studies demonstrating the tangible benefits of AI technologies on farms. Additionally, there is a shortage of AI-driven business models tailored to the agricultural sector. Moreover, the integration of AI into agriculture requires addressing technical, infrastructural, and regulatory challenges. Furthermore, the adoption of AI technologies may face resistance due to concerns about data privacy, cybersecurity, and the displacement of traditional farming practices. Finally, the scalability and accessibility of AI solutions in agriculture remain a concern, particularly for smallholder farmers.

Regarding the main limitations of this research, there is a sampling bias, because the demographic groups are underrepresented, and this limits the generalizability of the findings. As this topic is not very well studied there are no adequate scales already validated. The case studies can offer a higher in-depth exploration of the application of AI to agriculture, but there is little information available and a low number of studies.

Future research in the field of AI in agriculture should aim to advance the understanding of AI's implications for the sector. This includes conducting more comprehensive case studies that evaluate the real-world impact of AI technologies on farm productivity, sustainability, and profitability. Moreover, there is a need for research focused on developing AI-driven business models tailored to the unique needs and challenges of the agricultural sector. Additionally, interdisciplinary research collaboration is essential to address technical, infrastructural, and regulatory challenges hindering the adoption of AI in agriculture. Furthermore, future studies should explore the scalability and accessibility of AI solutions, particularly in the context of smallholder farmers. Overall, continued research in this area is crucial to unlocking the full potential of AI in transforming the agriculture sector.

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