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BIOFUNCTIONAL FOOD PRODUCTION FROM SMART ORGANIC TABLE OLIVE FARMS

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ABSTRACT

This study investigates the integration of smart sensor technologies into organic table olive farming to enhance the production of biofunctional olive foods and develop novel vegan products. The research was conducted on two organic olive farms in Messolonghi, Greece, utilizing Sentek Drill & Drop sensors to monitor soil moisture, temperature, and salinity at multiple depths. An integrated supply chain data management system was implemented, and three new olive-based products were developed (semolina-olive pasta, olive instant soup mix, and savory energy bar). Smart soil monitoring enabled real-time optimization of irrigation and nutrient management while adhering to organic farming principles. The integrated approach successfully combined the four IFOAM principles (Health, Ecology, Justice, and Care) with modern technology. All three developed products met nutritional claim criteria (low in saturated fats, high in fiber and proteins). Water activity levels (0.442-0.625) allowed storage at room temperature. This study demonstrates that combining organic farming practices with smart sensor technology creates a scalable model for sustainable, high-quality olive production that meets both ecological and nutritional objectives, setting new standards for modern organic agriculture. This research bridges the gap between traditional organic farming and functional food production through technological innovation while maintaining environmental sustainability.

Keywords: Organic farming, IFOAM principles, Olive production, Soil monitoring, Biofunctional quality, Table olives, Nutritional value

1. INTRODUCTION

Global food security remains fragile, despite food abundance and technological progress. According to the FAO (2021), sustainable agriculture promotes sustainable development, while international organizations prioritize sustainable food systems. The concept of sustainability is guided by the four principles of organic agriculture – health, ecology, justice and care –that is essential for the maintenance of resilient food systems (IFOAM, 2005).

Organic agriculture constitutes a foundational pillar for sustainable nutrition and environmental conservation, as it emphasizes food production without the use of synthetic chemicals (Reganold and Wachter, 2016). Sustainable nutrition includes foods that are nutritious, affordable, produced responsibly and directly linked to health and social well-being (Carvalho et al., 2024). The integration of organic production into everyday life depends on taste, price and nutritional value, with the challenge being their wider adoption. Overall, organic agriculture and its products represent a viable strategy for mitigating environmental degradation and promoting biodiversity. Despite ongoing challenges, organic farming promotes sustainable development and the well-being of rural communities, requiring more support and research to achieve its full potential (Gamage et al., 2023).

Organic food systems encompass production, processing, distribution, consumption and waste management, integrating social, cultural and environmental contexts. They link agricultural activities with trade, energy and agricultural health (Zhang et al, 2024; Fanzo et al., 2022). A sustainable food system (SFS) meets current nutritional needs while maintaining economic, social and environmental foundations for future generations (HLPE, 2014). The United Nations Sustainable Development Goals (SDGs) seek food systems that ensure food security, health and environmental sustainability by 2030, with the goal of providing nutritious food for all (United Nations, 2023). However, the increased consumption of processed foods with low nutritional value has created new challenges. Organic agriculture offers solutions, minimizing environmental impacts and enhancing resilience (Gamage et al., 2023). However, the lower efficiency of organic systems can affect global supply (Tuomisto et al. 2012). To address these problems, integrated strategies that enhance production efficiency, promote the adoption of consistent sustainable practices and strengthen collaboration among stakeholders are proposed, aiming to enhance sustainability and reduce negative impacts (Thompson et al., 2022; Ammirato et al., 2021).

The sustainability of organic products concerns environmental, social and economic levels, but confusion among food producers, consumers and scientists is common due to different views and approaches (Sharma, et al, 2025). Furthermore, social and economic impacts are less frequently

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considered, despite their crucial role in overall sustainability (Hariram et al., 2023). Organic farming can have positive impacts at all these levels but requires a holistic approach to maximize its benefits (Reganold and Wachter, 2016).

The smart agricultural production systems and the innovative products are emerging as key tools for the transition towards a more sustainable agri-food model (Zhang, 2024). The development of smart organic table olive farms and innovative functional products is based on the management of olive groves with new technologies and organic practices, reducing the environmental burden. At the same time, it enhances product quality, the economic robustness of producers and environment protection (Muhie, 2022). Smart olive grove management and innovation are tools to promote sustainability and implement the UN Sustainable Development Goals nutrition (Liopa-Tsakalidi et al., 2025; Kabato et al., 2025).

The global demand for functional foods has surged in recent years, driven by increasing consumer awareness of the health benefits associated with bioactive compounds. Table olives, a cornerstone of the Mediterranean diet, are rich in polyphenols, antioxidants, and monounsaturated fats, making them a prime candidate for functional food production. With global table olive production exceeding 3 million tons annually (International Olive Council, 2023), their significance extends beyond traditional culinary uses. Scientific research has highlighted their potential as functional foods due to their bioactive compound profiles, particularly phenolic compounds, which exhibit antioxidant, anti-inflammatory, antimicrobial, and cardioprotective properties (Lanza and Ninfali, 2020; Duval et al., 2021; Martínez-Navarro et al., 2022). Furthermore, research has demonstrated that the microbiota presents in fermented table olives possess distinct probiotic characteristics, making olives effective carriers for delivering probiotics to the host, while also being naturally free from lactose and cholesterol (Bonatsou, 2017).

The growing consumer preference for organic products, fueled by concerns about food safety, environmental sustainability, and nutritional quality (Seufert et al., 2023), has further amplified interest in organic olive cultivation. Organic farming practices, which avoid synthetic pesticides and fertilizers, have demonstrated potential for enhancing the functional properties of table olives (Zhu et al., 2024).

However, traditional organic farming methods often lack the precision required to simultaneously optimize yield and bioactive compound content, presenting a significant challenge for producers. To address this limitation, the integration of "smart farming" technologies, using sensors, offers real-time monitoring of key parameters, improving both productivity and food functionality within organic constraints (Sheikh et al., 2025). However, research on drone sensor technology in organic table olive production is limited, especially regarding its impact on the functional properties of the

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olives. This research gap hinders the full understanding and potential application of these technologies.

This gap presents a unique opportunity to revolutionize organic table olive production by integrating advanced sensing technologies to optimize agronomic practices and functional food outcomes. This study aims to bridge this gap by investigating the integration of drone sensor technologies into smart organic table olive farming systems to enhance the production of biofunctional olive foods. Specifically, the research explores how these technologies can optimize agricultural practices in organic olive farms, focusing on improving yield and the quality of biofunctional olive products as well as in the development of novel vegan products. By doing so, this work contributes to the advancement of smart organic farming practices and functional food production, with potential implications for sustainable agriculture and public health.

2. METHODS

2.1 Study Area and Farm Selection

Organic farmers of the Agricultural Cooperative of the Regional Unit of Aitoloakarnania participated in the integration of sensor technology in organic table olive cultivation. Initially, the cultivation practices applied to organic table olives of the Kalamon variety were recorded, with the aim of adapting innovative technologies to existing production methods. Two farms with different soil compositions and irrigation practices -one with drip irrigation and one dry-farm without irrigation- were selected for sensor installation to ensure a comprehensive representation of diverse agricultural conditions. The sensors were selected after evaluation, confirming their suitability for real-world applications in organic olive cultivation.

2.2 Soil Physicochemical Characteristics

In the area of the Municipality of Messolonghi, two organic olive orchards owned by farmers of the agricultural cooperative were selected, located in Giolakas Neochorio (latitude 38°23'49.1"N, longitude 21°15'29.6"E, area 0.51 ha, 7 years old), hereinafter referred to as "Farm A" and Agia Triada Aitoliko (38°24'38.9"N, 21°20'02.1"E, area 45.96 ha, 200 years old), referred to as "Farm B". Farm A had a clay loam (CL) soil, slightly alkaline (pH 7.85), with 1.8% organic matter, while Farm B had sandy clay loam (SCL) soil, also slightly alkaline (pH 7.55), with 3% organic matter. Throughout growth season meteorological data for the study area were collected from the local meteorological stations of Neochori (for Farm A) and Evinochori (for Farm B).

2.3 On-site Monitoring of Soil and Climate Parameters

Two Sentek Drill & Drop, TriSCAN, Bluetooth capacitance-based technology sensors were installed in the olive groves in early February to monitor soil moisture (SWC), temperature (ST),

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and salinity. The sensors recorded SWC, ST, and salinity at depths of 5-55 cm, at 10-minute intervals. The Drill & Drop sensor, which enables a remote soil moisture monitoring system, consists of a sealed plug and rod inserted into the soil, protecting the electronics from damage. Bluetooth enables real-time data transmission to mobile devices. Powered by a lithium battery, it works for up to two years. The components are organized: the cap holds the battery and antenna, and the sensors are on the bar. Sensors every 10 cm allow detailed ground monitoring. Temperature accuracy is ±2°C for reliable data in various conditions (Sentek, 2018). Measures were implemented to protect the sensors from environmental factors, thus ensuring reliable and uninterrupted data collection. A central data logging system was established to continuously record sensor data. Data collection units equipped with storage capabilities and wireless communication units were developed to facilitate remote data transmission. Robust data management protocols were implemented to ensure data integrity, security, and accessibility throughout the growing season.

2.4 Integrated Supply Chain Data Management System

A comprehensive data collection system was established to monitor each stage of the organic table olive production chain, encompassing olive tree cultivation, harvesting, and processing operations. The system captured detailed information, including the geographical coordinates of each farm, meteorological data, and soil condition parameters such as moisture, temperature, and salinity. It also documented key cultivation practices, including fertilization, plant protection measures, pruning, irrigation, fruit harvesting, and subsequent olive transport. At the processing facilities, receipt batches were systematically recorded, with verification procedures applied to shipping documentation, including Global Location Numbers (GLNs), Serial Shipping Container Codes (SSCCs), packing lists, received quantities, and the initial quality assessment of the olives (classified as suitable for processing or rejected). Furthermore, quality control of the final product - edible olives - was performed based on sensory and physical attributes such as appearance, color, aroma, taste, and texture. The olives derived from this traceable and monitored system were subsequently used as raw, destoned and blended material for the development of biofunctional food products.

2.5 New product development process

Three different products were developed based on traditional recipes, using Thermomix Vorwerk TM6. The composition of the products is presented in Table 1. Water activity (aw) was measured using the LabSwift-aw. The nutritional value of the developed products was evaluated using the Nutranalysis28 software.

Table 1: Composition and images of the developed products

Semolina-olive pasta product ('Trahanas')	Olive instant soup mix	Savory energy bar
0.44% oregano	1.14% oregano	0.11% oregano
0.44% smoked paprika	0.57% smoked paprika	0.45% smoked paprika
0.22% garlic powder	0.28% garlic powder	0.23% garlic powder
0.22% onion powder	0.57% onion powder	0.23% onion powder
40.85% semolina	0.28% mustard powder	42.52% oat flakes
13.62% organic olive paste	0.28% curcumin	14.17% organic olive paste
0.54% sugar	19.89% organic olive paste	0.23% sugar
0.11% salt	0.57% sugar	0.11% salt
43.57% water	2.27% salt	34.01% water
	59.66% potato flakes	7.94% tomato paste
	4.26% potato starch	
	10.23% maltodextrin	
		

3. RESULTS AND DISCUSSION

3.1 Applying IFOAM Principles in Organic Olive Farming

The application of the four core principles of organic agriculture, as outlined by IFOAM-*Health, Ecology, Justice, and Care*-forms the foundation of advanced organic olive farming practices (Fig. 1). The prominence of organic table olives within this system highlights how these principles converge to foster sustainable and beneficial production methods.

The framework supports the principle of *Health* by monitoring soil vitality, addressing deficiencies, and implementing soil improvements. Through the use of sensor technology, soil moisture, temperature, and salinity were continuously monitored, promoting the optimal growth of olive trees. Additionally, Quality Assurance protocols were developed to ensure superior olive fruit quality, thereby contributing to enhanced consumer health.

This framework adheres to the principle of *Ecology* by applying site-specific strategies and selecting farms with diverse soil and irrigation practices. It incorporates climate-smart adaptation by utilizing meteorological data to optimize irrigation, thereby reducing water waste. Additionally, it advances sustainable management by mitigating environmental impacts and optimizing resource use across the supply chain.

The principle of *Justice* in organic farming promotes fairness in environmental stewardship, livelihoods, and resource access. It empowers farmers by involving them in sensor deployment and data collection, ensures fair trade through comprehensive documentation, and integrates traditional knowledge with innovative technologies to modernize sustainable agriculture while guaranteeing equitable market opportunities and resource distribution.

The principle of *Care* underscores sustainability by adopting a preventive approach, demonstrated through long-term soil and climate monitoring via sensors. It integrates biofunctional product development and stakeholder participation, ensuring ethical practices and environmental integrity in organic farming for both present and future generations.

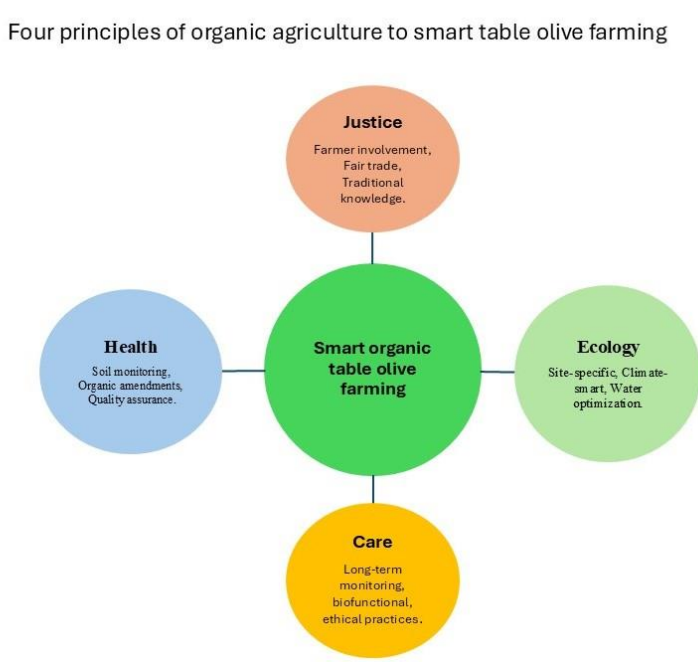

Figure 1: The Four Principles of Organic Agriculture

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3.2 Smart Soil Monitoring in Olive Farms

The integration of smart soil monitoring systems in organic olive farms (Farm A and Farm B) in Messolonghi, Greece, demonstrated significant advancements in smart agriculture. Sensor technology enabled real-time measurement of critical soil parameters-moisture, temperature, and salinity-at varying depths (5 to 55 cm), with data relayed to a cloud-based dashboard (Fig. 2). This continuous monitoring facilitated optimized irrigation and nutrient management, aligning with organic farming principles.

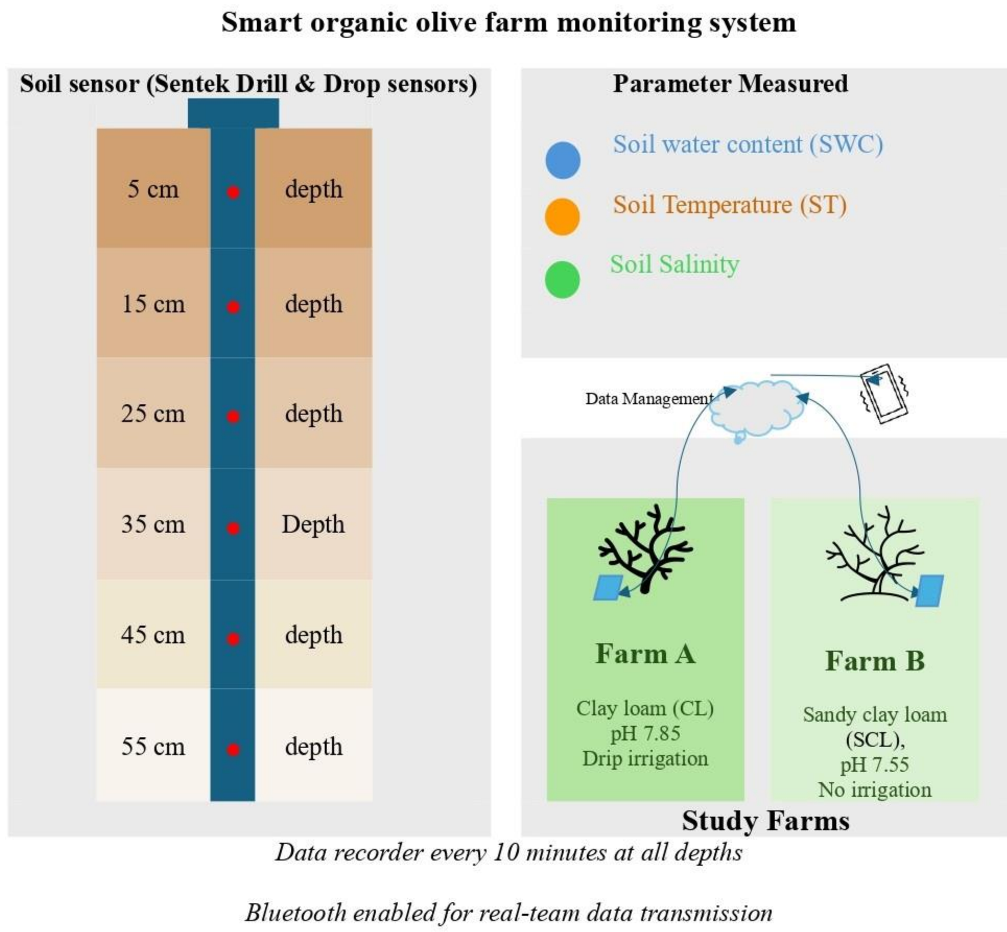

Figure 2: Smart organic olive farm monitoring system

Drone technology further complemented the soil sensors by providing high-resolution aerial data on crop health, ensuring timely interventions. These smart farming practices not only supported environmental sustainability but also contributed to the biofunctional quality of table olives. Previous studies have established that organic farming enhances phenolic content and antioxidant properties in olives (Lanza and Ninfali, 2020; Martínez et al., 2022). The precision offered by

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smart monitoring likely amplified these benefits by maintaining optimal growing conditions, thereby maximizing the accumulation of health-promoting compounds. The findings align with global trends favoring functional foods, where consumer demand is driven by health and environmental concerns (Seufert et al., 2023). By merging organic practices with smart technologies, this study presents a viable model for sustainable, high-quality olive production that meets both ecological and nutritional objectives. Future research should explore the direct correlation between sensor-driven agronomic adjustments and bioactive compound profiles in olives to further validate this approach. This work underscores the potential of smart organic olive farms to bridge the gap between sustainable agriculture and functional food production, offering a scalable solution for the evolving agri-food sector.

3.3 Integrated supply chain data system

The smart organic table olive farm was the core of the integrated supply chain, as it was implemented mechanisms for continuous monitoring of soil and climate conditions on two different farms: Farm A (clay soil, drip irrigation) and Farm B (sandy clay loam, without irrigation) (Fig. 3). Using sensors to measure temperature, humidity, and salinity, cultivation practices were adapted to the specific requirements of each area. Additionally, the systematic recording of data-including cultivation practices, meteorological conditions, and soil properties-enabled optimal resource management.

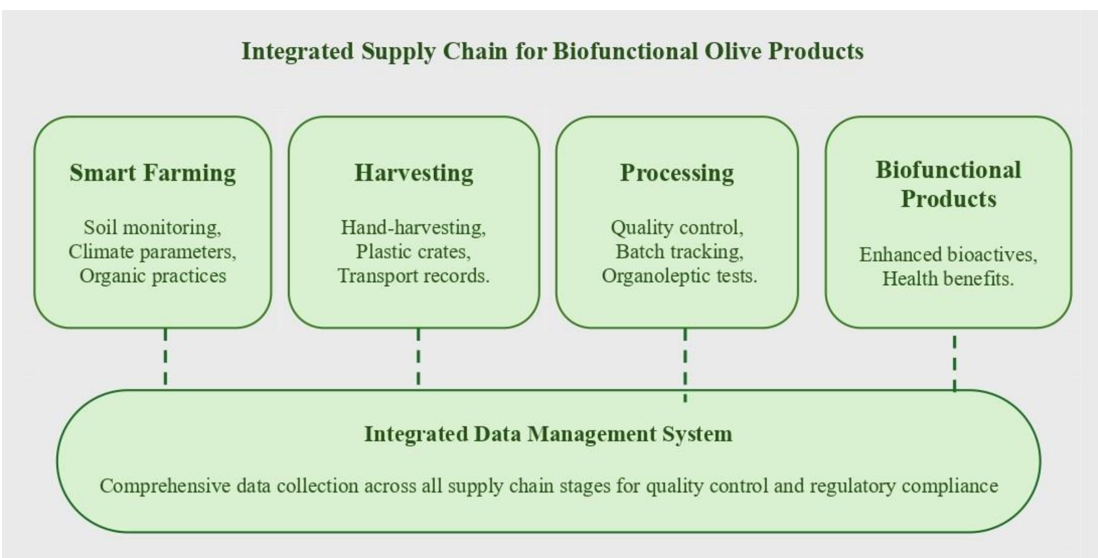

Figure 3: Integrated supply chain data management system

This technological infrastructure transforms traditional farming into a centralized process, where decisions are based on real-time data, resulting in increased productivity and reduced risks (Abiri

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et al., 2023). The application of organic practices, combined with strict quality controls, ensures that the final organic products meet the highest standards. Measures such as manual harvesting and careful transport in plastic crates, minimizing damage to the table olives and preserving their quality (Shemesh et al., 2025). Additionally, recording the characteristics of each batch (e.g., geographical origin, farming conditions) offers full transparency to the consumer, enhancing confidence in the produced biofunctional product (Nuwarapaksha et al. 2024). The system is not limited to production but covers the entire supply chain, from farm to consumer. The data flow between the stages (cultivation, harvesting, processing) ensures optimized processes and minimal losses. The emphasis on organic farming and the use of technology reduces the environmental impact, promoting a truly sustainable approach (Gamage et al., 2023).

In conclusion, the success of the proposed chain is based on the integration of smart technologies, organic methods, and strict quality controls. This model not only provides high-quality products but also sets new standards in organic agricultural production, demonstrating that modern organic agriculture can be innovative, efficient, and environmentally friendly. Future research could focus on improving the sensors for even more accurate data and on the scalability of the system to other crops.

3.4 New Product Development

The water activity of the new products was measured directly after their production as it is a determining factor for their shelf life. The recorded values were 0.542 for the “Trahanas”, 0.422 for the “soup mix” and 0.625 for the “savory bars”. Consequently, all developed products can be stored at room temperature as the, provided that the packaging material prevents moisture adsorption (Beuchat, 2013). In the following figures the nutritional value of the developed products in absolute numbers as well as in terms of % per portion and % of Daily Value (% DV).

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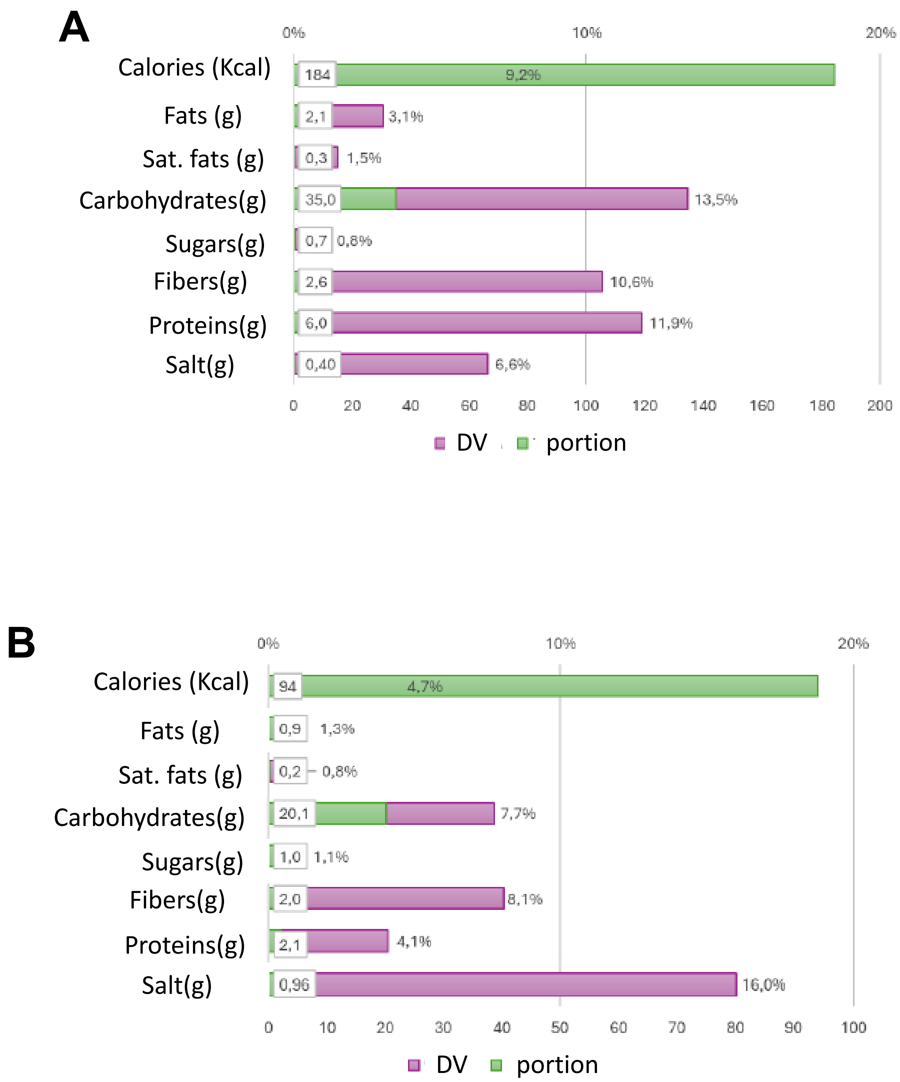

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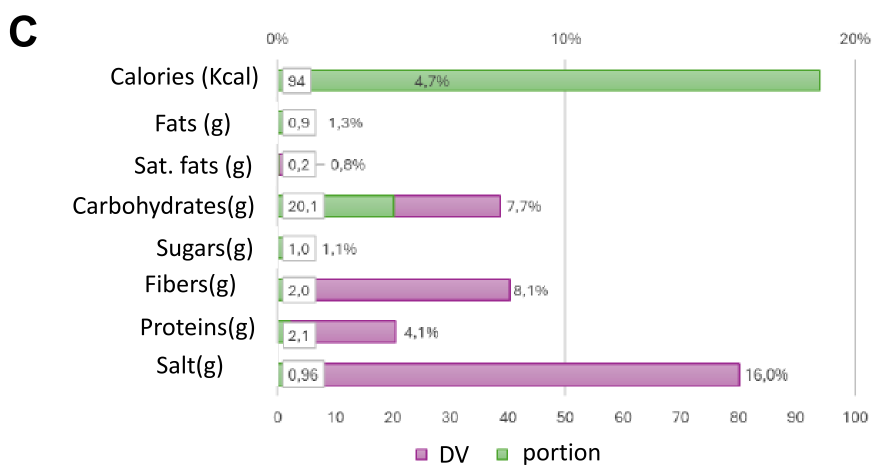

Figure 4: Absolute values and % of the indicative daily value of macronutrients in A) Trachanas with olive paste, B) instant soup mix with olive paste and C) savory bar.

The products' nutrition labels suggest that they may meet specific criteria for making nutritional claims related to certain macronutrients. These criteria are established in Regulation (EC) No. 1924/2006, which defines the threshold levels for macronutrient content required for such claims. Based on all findings, the nutrition claims presented at Table 2 can be attributed to the products.

Table 2: Various claims that can be attributed to the developed products.

Semolina-olive pasta product ('Trahanas')	Olive instant soup mix	Savory energy bar
Low in saturated fats	Low in saturated fats	Low in saturated fats
Rich in fibers	High fiber	High fiber
Source of proteins	Source of proteins	Source of proteins

More specifically, the claim that a food is low in saturated fat, and any claim likely to have the same meaning for the consumer, may only be made if the sum of saturated fatty acids and trans-fatty acids in the product does not exceed 1.5 g per 100 g for solids or 0.75 g per 100 ml for liquids. In either case, the sum of these fatty acids must not provide more than 10% of energy content. Regarding fibers, the claim "rich in fiber" is used when the product contains at least 3 g of fiber per 100 g or at least 1.5 g per 100 kcal, while the claim "high in fiber" can be used when product contains at least 6 g of fiber per 100 g or at least 3 g per 100 kcal. A product can be characterized as source of proteins when at least 12% of its energy value is provided by protein (Commission Regulation (EU) No 1047/2012).

4. CONCLUSIONS

Adopting core organic farming principles - focusing on health, ecology, fairness, and sustainability - enhances both the quality and environmental benefits of organic table olive production. By using smart soil sensors (tracking moisture, temperature, and salinity) and drone-based crop monitoring, farms in Messolonghi, Greece, have achieved smart agriculture. Combining organic practices with real-time data ensures superior olive quality while preserving ecological balance. A fully traceable, data-driven supply chain minimizes losses and maintains high standards, boosting consumer confidence in organic products.

The research presents an innovative, scalable farming model that blends traditional knowledge with cutting-edge technology. Future studies should refine sensor precision, test the system on other crops, and explore how smart farming influences bioactive compounds in olives. Using table olives and their paste for NPD can lead to the development of vegan functional food products of high nutritional value. This smart organic olive farming approach proves that sustainable agriculture can deliver high-quality, health-promoting foods while balancing ecological and economic goals. The framework sets a new standard for modern organic farming-environmentally sound, technologically advanced, and economically viable.

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