Contemporary Debates and Interdisciplinary Approaches in Agricultural, Forestry, and Aquatic Sciences

Editor: Prof. Dr. Gökhan ŞEN

DUVAR

CONTEMPORARY DEBATES AND INTERDISCIPLINARY APPROACHES IN AGRICULTURAL, FORESTRY, AND AQUATIC SCIENCES

Editor

Prof. Dr. Gökhan ŞEN

Contemporary Debates and Interdisciplinary Approaches in Agricultural, Forestry, and Aquatic Sciences
Editor
Prof. Dr. Gökhan ŞEN

Editor in chief: Berkan Balpetek
Cover and Page Design: Duvar Design
Printing : June-2026
Publisher Certificate No: 49837
E-ISBN: 978-625-8756-78-4

853 Sokak No:13 P.10 Kemeraltı-Konak/İzmir
Tel: 0 232 484 88 68
www.duvaryayinlari.com
duvarkitabevi@gmail.com

The authors bear full responsibility for the sources, opinions, findings, results, tables, figures, images, and all other content presented in the chapters of this book. They are solely accountable for any financial or legal obligations that may arise in connection with national or international copyright regulations. The publisher and editors shall not be held liable under any circumstances

TABLE OF CONTENTS

Chapter 1

Digital Transformation in Viticulture: Technological Applications, Data Governance, and Sustainability

Aysel YEŞİLYURT ER[1]

Abstract

This chapter examines the application areas of digital technologies in the viticulture sector, the advantages they provide, and the limitations encountered during their implementation processes. The study discusses the development of the precision viticulture approach and evaluates the role of remote sensing systems, sensor technologies, the Internet of Things (IoT), artificial intelligence applications, and digital farming platforms in vineyard management. In particular, multispectral imaging, sensor-based monitoring systems, and AI-supported decision support mechanisms were found to provide significant contributions to water management, disease detection, yield prediction, and quality analysis.

In addition, the study demonstrates that digital viticulture is not merely a technological transformation, but a multidimensional process that should also be evaluated in terms of data governance, data ownership, data security, applicability, and sustainability. It is observed that issues such as data integration, data standardization, big data management, and access to technology constitute major barriers to digital transformation in viticulture. Furthermore, challenges including high costs, lack of technical knowledge, and technological dependency are emphasized as factors that may limit the widespread adoption of digital technologies, particularly for small- and medium-scale enterprises.

The study concludes that digital technologies have significant potential for achieving sustainable production goals in viticulture. However, in order to effectively utilize this potential, it is necessary to develop open data policies, producer-oriented digital solutions, data security mechanisms, and sustainable digital agriculture models.

Keywords:

Precision viticulture, digital viticulture, data governance, artificial intelligence, sustainable viticulture

---

[1] Assistant Professor, Pamukkale Univercity, Çal Vocational School
Orcid ID: 0000-0003-0192-2982

1. Introduction

In recent years, the use of digital technologies in the agricultural sector has been increasing rapidly. Technologies such as sensor technologies, remote sensing systems, the Internet of Things (IoT), artificial intelligence, big data analytics, and decision support systems enable agricultural production processes to be managed in a more precise, efficient, and sustainable manner. With the widespread adoption of these technologies in the agricultural sector, concepts such as “digital agriculture,” “smart agriculture,” and “Agriculture 4.0” have increasingly begun to take place in the literature.

The main objective of digitalization in agriculture is to support production processes through data-driven decision-making mechanisms and to optimize resource use. While production decisions in traditional agricultural practices are mostly made based on experience, these decisions in digital agriculture applications are supported by sensor data, remote sensing data, and data analytics methods. In this way, production processes can be managed more precisely and production efficiency can be increased (Wolfert et al., 2017).

Viticulture is considered one of the most suitable agricultural production systems for the implementation of digital technologies. This is because vineyard areas exhibit high spatial and temporal variability. Even within the same vineyard, significant differences can be observed in terms of soil properties, microclimatic conditions, water status, and plant development. This situation causes standard practices in vineyard management not to always produce effective results. Therefore, spatial variability must be taken into consideration in order to manage production processes in viticulture more precisely. The precision viticulture approach plays an important role at this point. Precision viticulture is a modern vineyard management approach that aims to analyze variations within the vineyard through the use of technology and to apply interventions to each zone according to its specific needs. The main objectives of precision viticulture applications are as follows:

- To improve grape quality
- To ensure yield stability
- To optimize the use of water, fertilizers, and pesticides
- To reduce costs and environmental impacts

Remote sensing technologies, sensor systems, and data analytics methods are used to achieve these objectives. (Mucalo et al, 2024).

In recent years, the use of digital technologies in viticulture has increased significantly. In particular, drone-based imaging systems, multispectral sensors, and wireless sensor networks have considerably facilitated data collection processes in vineyard areas. Thanks to these technologies, parameters such as vegetative development, water stress, disease symptoms, and product quality can be analyzed at high resolution in vineyard areas (Matese and Di Gennaro, 2015).

The implementation of digital technologies in viticulture may not always achieve the expected success. It is observed that various technical, economic, and managerial problems arise during the implementation of these technologies. Among these problems, factors such as data management, data integration, cost, user adaptation, and technology adoption are prominent. In particular, the issue of data governance is one of the most important discussion areas of digital agriculture systems. Very large amounts of data are generated in digital agriculture applications. This raises important questions regarding who controls these data, how they are stored, and with whom they are shared. This situation demonstrates that digital agriculture is not only a technological transformation but also a managerial and institutional transformation (Atik, 2022).

Another important issue arising during the implementation of digital technologies in viticulture is technology adoption. Many vineyard enterprises consist of small and medium-sized enterprises. For these enterprises, investing in high-cost technologies may not always be possible. In addition, the use of digital technologies requires a certain level of technical knowledge. This situation may make technology adaptation difficult for some producers (Shang et al., 2021).

In addition, the effects of digital technologies on sustainability are also an important subject of discussion. Thanks to digital technologies, it may be possible to reduce the use of water and chemical inputs. However, new environmental problems such as energy consumption and electronic waste generation may also arise during the production and use of these technologies (Bellon-Maurel et al., 2022).

In this context, digital viticulture should be evaluated not only in terms of technological innovations but also in terms of data governance, applicability, and sustainability.

The aim of this section is to examine the use of digital technologies in viticulture and to evaluate the limitations arising during the implementation of these technologies.

2. Development of the Precision Viticulture Approach

The concept of precision viticulture first emerged in the early 2000s. The main reason for the emergence of this approach is the high spatial heterogeneity observed in vineyard areas. Even within the same vineyard, significant differences can be observed in terms of soil structure, water holding capacity, nutrient elements, and microclimatic conditions. These differences cause standard practices in vineyard management not to always produce effective results. For example, while water stress may occur in some parts of the vineyard, excessive water may be present in other parts. Similarly, while plant development is strong in some regions, weak development may be observed in others.

The precision viticulture approach aims to develop more precise practices in vineyard management by analyzing the variations occurring within the vineyard area.

The main stages of precision viticulture applications are as follows:

1. Collection of data from the vineyard area
2. Analysis of spatial variability
3. Determination of management zones
4. Implementation of targeted applications

The most important stage in this process is the data collection stage. Various technologies are used to collect data in precision viticulture applications. Remote sensing systems and sensor technologies are among the most important of these technologies.

3. Remote Sensing Technologies

Remote sensing technologies are among the most important tools of digitalization in viticulture. Thanks to remote sensing systems, parameters such as plant development, canopy structure, and water stress can be analyzed at high resolution in vineyard areas.

The main remote sensing technologies used in viticulture are as follows:

- satellite imagery
- drone imagery
- multispectral cameras
- hyperspectral sensors
- thermal cameras

Satellite imagery provides significant advantages in terms of monitoring large areas. However, the resolution of satellite imagery may not be sufficient in some cases to analyze within-vineyard variability.

Drone-based imaging systems, on the other hand, can provide data at higher resolution. Therefore, the use of drones in precision viticulture studies has increased significantly in recent years (Matese et al., 2015).

Multispectral cameras and hyperspectral sensors are advanced imaging technologies widely used in remote sensing applications in viticulture.

Multispectral cameras enable the analysis of parameters such as plant development, leaf density, chlorophyll content, and water stress by capturing images in specific bands of the electromagnetic spectrum (for example red, green, blue, and near-infrared). These systems are especially used in the calculation of vegetation indices such as NDVI and provide significant advantages in determining the spatial distribution of vegetative development in vineyard areas (Giovos et al., 2021).

(NDVI (Normalized Difference Vegetation Index) is a remote sensing index used to evaluate the health, density, and photosynthetic activity of plants. It is widely used especially in agriculture, viticulture, and environmental monitoring studies. NDVI is based on the light reflection characteristics of plants. Healthy plants largely absorb red light while strongly reflecting near-infrared (NIR) light. NDVI analyzes the plant development status by using the difference between these two bands.)

Hyperspectral sensors, on the other hand, can collect data in a much higher number of narrow spectral bands compared to multispectral systems. In this way, the physiological status of plants, nutrient deficiencies, disease symptoms, and stress factors can be analyzed in much greater detail. Hyperspectral imaging systems have high potential especially in terms of early disease detection and quality analyses. However, since these systems generate large amounts of data, they require high data processing capacity and advanced analysis methods (Matese and Di Gennaro, 2015).

Thermal cameras are used to determine plant water stress. As plant water stress increases, leaf temperature also increases. These changes can be detected through thermal imaging.

4. Sensor Technologies and Vineyard Monitoring Systems

Sensor technologies are one of the fundamental components of digital viticulture systems. Thanks to sensors, environmental and biological parameters in vineyard areas can be continuously monitored, and real-time data regarding production processes can be obtained. These data constitute an important source of information for decision support systems in vineyard management.

The sensor technologies used in viticulture can generally be divided into three main categories:

1. Environmental sensors
2. Soil sensors
3. Plant sensors

These sensors are used in applications such as monitoring microclimatic conditions in vineyard areas, determining plant stress, and irrigation management.

4.1 Environmental Sensors

Environmental sensors are used to measure parameters such as temperature, humidity, wind, and solar radiation in vineyard areas. These data provide important information especially for determining disease risk and monitoring plant development.

The environmental sensors commonly used in viticulture are as follows:

- Air temperature sensors
- Relative humidity sensors
- Wind speed sensors
- Solar radiation sensors

These sensors are generally used together with meteorological stations. Thanks to micro-meteorological stations installed in vineyard areas, microclimatic conditions in different parts of the vineyard can be analyzed.

Microclimatic conditions are of great importance in viticulture because many vineyard diseases develop under specific temperature and humidity conditions. For example, the development of diseases such as downy mildew and powdery mildew depends on temperature and humidity conditions. Therefore, microclimate sensors are used as an important component of disease early warning systems.

4.2 Soil Sensors

Soil sensors are used to measure parameters such as soil moisture, temperature, and electrical conductivity in vineyard areas. These sensors provide important information especially for irrigation management.

Soil moisture sensors are among the most commonly used sensor types in viticulture. Thanks to these sensors, soil water content in vineyard areas can be continuously monitored. These data play an important role in determining irrigation timing.

In traditional irrigation practices, irrigation decisions are mostly made based on experience. However, thanks to sensor-based irrigation systems, irrigation decisions can be supported with real-time data. This situation increases water use efficiency and reduces unnecessary water consumption.

Soil electrical conductivity sensors are used to determine the spatial variability of soil properties. Thanks to these sensors, information about soil texture and nutrient elements in vineyard areas can be obtained.

4.3 Plant Sensors

Plant sensors are used to analyze the physiological status of plants. Thanks to these sensors, it becomes possible to determine plant stress at an early stage.

The main plant sensors used in viticulture are as follows:

- Leaf temperature sensors
- Chlorophyll sensors
- Plant water potential sensors

Leaf temperature sensors are used to determine plant water stress. When the plant experiences water stress, the stomata close and leaf temperature increases. This situation can be detected through sensors.

Chlorophyll sensors are used to analyze the photosynthetic activity of plants. Thanks to these sensors, information about the nutritional status of plants can be obtained.

5. Internet of Things (IoT) and Smart Vineyard Systems

The Internet of Things (IoT) is a technology that enables physical devices to be connected to each other through the internet. IoT technologies have a wide range of applications in the agricultural sector.

In viticulture, IoT systems consist of sensors, data transmission networks, and data analysis platforms. Thanks to these systems, data collected in vineyard areas can be transferred to central data platforms through wireless networks.

The main components of IoT-based vineyard systems are as follows:

- Sensor networks
- Data transmission systems
- Data storage platforms
- Data analysis systems

Thanks to these systems, real-time data monitoring becomes possible in vineyard areas.

5.1 Wireless Sensor Networks

Wireless sensor networks are one of the fundamental components of IoT-based vineyard systems. These networks enable the transfer of data obtained from sensors to central systems.

Thanks to wireless sensor networks, data can be collected from sensors located at different points in vineyard areas. These data are transferred to central data platforms through wireless networks.

The most important advantage of wireless sensor networks is that they provide the opportunity to collect data over large areas. However, the installation and maintenance of these systems require technical knowledge.

5.2 Data Platforms

In IoT systems, data obtained from sensors are generally stored on cloud-based data platforms. Thanks to these platforms, large amounts of data can be stored and analyzed.

The main advantages of cloud-based data platforms are as follows:

- Data storage capacity
- Ease of data Access
- Data analysis capability

However, these platforms also bring some issues such as data security and data ownership.

6. Artificial Intelligence and Data Analytics Applications

Artificial intelligence and machine learning technologies are being increasingly used in the agricultural sector. These technologies enable the extraction of important information about production processes by analyzing large datasets.

In viticulture, artificial intelligence applications are used in the following areas:

- disease detection
- yield prediction
- quality analysis
- irrigation management

6.1 Disease Detection

Disease detection in viticulture is an important management problem in terms of production efficiency and grape quality. In particular, diseases such as downy mildew, powdery mildew, and botrytis can spread rapidly under suitable environmental conditions and may cause serious yield losses. Since traditional disease monitoring methods are mostly based on field observations, they can be time-consuming and disease symptoms may not be detected at an early stage. Thanks to artificial intelligence-based image analysis systems, plant diseases can be detected earlier and more precisely. By using deep learning algorithms, disease symptoms can be identified through the analysis of color changes, spots, and deformations in images of leaves, shoots, and grapes. In particular, deep learning models such as convolutional neural networks (CNNs) are widely used in image classification applications. These systems can operate in an integrated manner with images obtained from drone imagery, multispectral cameras, and mobile devices. Thus, the spatial distribution of diseases in vineyard areas can be analyzed and targeted control strategies can be developed. Artificial intelligence-supported disease detection systems provide important advantages in terms of reducing pesticide use and sustainable vineyard management (Liakos et al., 2018; Izquierdo-Bueno et al., 2024).

6.2 Yield Prediction

Yield prediction is an important decision support tool in vineyard management. Predicting production quantity in advance is of great importance in terms of harvest planning, labor management, logistics processes, and marketing strategies. Traditional yield prediction methods are mostly based on field observations and past experiences. However, more precise yield predictions can be made thanks to artificial intelligence and data analytics methods. By using artificial intelligence algorithms, highly accurate yield predictions can be performed in vineyard areas. These predictions are generally based on remote sensing data, meteorological data, soil data, and past production records. In particular, canopy density, vegetative development, and grape cluster density can be analyzed through drone imagery and multispectral sensors. Machine learning models evaluate these data and generate predictions about future production quantity. Algorithms such as Random Forest, Support Vector Machine (SVM), and artificial neural networks are widely used in yield prediction studies in viticulture. In addition, studies in which meteorological data and artificial intelligence models are used together in order to evaluate the effects of climate change on production are also increasing. These systems contribute to the reduction of economic risks by providing producers with the opportunity to make more accurate planning (Kamilaris et al., 2017; Liakos et al., 2018).

6.3 Quality Analysis

Grape quality is one of the most important production objectives in viticulture because quality parameters directly affect the economic value of the product in grape production. Traditional quality assessment methods are mostly based on laboratory analyses and expert observations. However, these methods can be time-consuming and costly. Thanks to artificial intelligence-based image analysis systems, the quality characteristics of grape clusters can be analyzed rapidly and automatically. These systems can evaluate parameters such as grape cluster size, berry density, color change, ripeness level, and surface defects. In particular, detailed information about the chemical and physiological properties of grapes can be obtained through the use of multispectral and hyperspectral imaging technologies. Artificial intelligence algorithms can analyze these image data and perform grape ripeness and quality classification. Thanks to deep learning models, the accuracy of quality analyses is increased and human-based evaluation errors are reduced. In addition, these systems provide important decision support information for determining harvest timing. Artificial intelligence applications for quality analysis provide significant advantages especially in terms of high-quality grape production and precision harvest management (Matese & Di Gennaro, 2015; Tardaguila et al., 2021).

6.4 Irrigation Management

Irrigation management is one of the important application areas of artificial intelligence and data analytics in viticulture. Artificial intelligence-based systems can determine the water requirements of vineyard areas by analyzing soil moisture sensors, meteorological data, remote sensing imagery, and plant water stress data. Thanks to machine learning algorithms, it can be predicted in which areas and at what times plants require irrigation, thus enabling irrigation decisions to be made more precisely. These systems increase water use efficiency and reduce unnecessary water consumption, especially in precision irrigation applications. In addition, artificial intelligence-supported irrigation management provides significant advantages for sustainable vineyard management under increasing water stress conditions caused by climate change (Mucalo et al., 2024; Pascoal et al., 2024).

7. Digital Vineyard Data Ecosystem

Digital viticulture is based on a complex data ecosystem formed by the integration of numerous data sources. The main components of the vineyard data ecosystem are as follows:

- sensor data
- remote sensing data
- meteorological data
- production data

The integration of these data sources is of great importance for the success of digital vineyard systems.

The data ecosystem generally consists of the following stages:

1. Data collection
2. Data storage
3. Data processing
4. Data analysis
5. Decision support

Ensuring uninterrupted data flow between these stages is critically important for the effectiveness of digital viticulture systems.

8. Data Governance in Digital Viticulture

With the development of digital agriculture systems, the amount of data generated in agricultural production processes has increased significantly. Thanks to sensor technologies, remote sensing systems, meteorological stations, and agricultural management software, very large amounts of data can be collected in production areas. These data make significant contributions to the more effective management of production processes. However, the increase in data generation has also led to the emergence of new issues related to data management. In particular, issues such as data ownership, data sharing, data security, and data access have become some of the most important discussion areas of digital agriculture systems. The concept of data governance gains importance at this point. Data governance refers to the institutional and managerial processes that determine how data are collected, how they are stored, who can use them, and under which rules they can be shared.

In digital agriculture systems, data governance is not only a technical issue. It is also a complex management process with economic, social, and political dimensions. This is because agricultural data are used by many different stakeholders. These stakeholders include producers, technology providers, research institutions, and public institutions. Therefore, the issue of data governance must be carefully addressed in order for digital viticulture systems to be implemented sustainably.

9. Data Ownership in Agriculture

Data ownership is one of the most debated issues in digital agriculture systems. Thanks to sensor technologies, remote sensing systems, IoT devices, and digital agriculture platforms, very large amounts of data are generated in agricultural production processes. These data include a wide variety of information such as soil properties, microclimatic conditions, production quantity, irrigation practices, plant development, and disease status. With the increasing economic and strategic value of agricultural data, the questions of who owns these data, who can use them, and under what conditions they can be shared have become important topics of discussion (Atik, 2022).

In digital agriculture systems, the issue of data ownership often has a complex structure. Although the data are generated by producers, the data collection, storage, and analysis processes are generally carried out through software platforms developed by technology provider companies. For example, sensor systems used in vineyard areas generate large amounts of data related to production areas, but these data are often stored on cloud-based platforms. In this case, the issue of who the actual owner of the data is may become unclear. In addition, some digital platforms may obtain broad authority regarding the processing and sharing of data through user agreements. This situation causes producers to have concerns about data control (Rijswijk et al., 2021).

The issue of agricultural data ownership is not only a technical matter. It is also a management problem with economic, ethical, and legal dimensions. Today, agricultural data are used in many areas such as production planning, insurance systems, market analyses, and the development of artificial intelligence models.

Therefore, data are increasingly becoming digital assets with high economic value. In particular, the increasing control of large technology companies over agricultural data platforms brings discussions on the data economy and data dependency to the agenda (Klerkx et al., 2019).

In general, three main data ownership models stand out in the literature:

- Producer-centered data ownership
- Platform-centered data ownership
- Shared data ownership

9.1 Producer-Centered Data Ownership

In the producer-centered data ownership model, producers are directly accepted as the owners of the data obtained from agricultural production processes. According to this approach, all data obtained from vineyard areas or agricultural enterprises should be under the control of producers. Producers should have the right to decide with whom the data will be shared and for what purposes they will be used.

This model provides important advantages especially in terms of protecting producer rights. This is because producers do not want to lose control over strategic information related to production processes. For example, the yield status, irrigation practices, or quality parameters of a vineyard enterprise may contain economically important information. The control of these data by third parties may create commercial risks for producers.

The producer-centered data ownership model is also important in terms of data trust. Studies show that producers are more reluctant to adopt digital technologies when they are concerned about losing control of their data (Rijswijk et al., 2021). Therefore, producer-centered data policies can support the widespread adoption of digital agriculture technologies.

However, this model also includes some technical and operational problems. The storage, processing, and analysis of agricultural data require advanced technical infrastructure. Small and medium-sized enterprises often do not have this infrastructure. Therefore, dependency on technology providers may arise in data management processes.

9.2 Platform-Centered Data Ownership

In the platform-centered data ownership model, data are mostly under the control of digital platform providers. Data obtained from sensors, IoT systems, and software platforms are stored in central databases and processed by platform providers. This model provides some advantages in terms of data management. In particular, centralized data management offers significant convenience in big data analytics applications. The integration of large datasets can improve the development of artificial intelligence models and increase the accuracy of decision support systems. In addition, since platform providers have high data processing capacity, they can offer advanced analysis services.

However, the platform-centered data ownership model involves various risks for producers. One of the most important issues is the concentration of data control in the hands of technology companies. Producers often may not have sufficient information about how their data are processed or with whom they are shared. In some cases, platform providers may use user data for commercial purposes or share them with third parties. This situation has brought about new discussions defined as “agricultural data capitalism.” The transformation of agricultural data into economic value by large technology companies may cause producers to become dependent on digital platforms (Klerkx et al., 2019).

In addition, the platform-centered structure also carries risks in terms of data security. Centralized data storage systems may become targets for cyberattacks. Therefore, data security and data privacy are of critical importance in platform-centered systems.

9.3 Shared Data Ownership

The shared data ownership model offers a more balanced data management approach between producers and technology providers. In this model, the rights and responsibilities related to data use are determined through agreements made between the parties. Data may be accessible to both producers and platform providers at a certain level. This approach provides important advantages especially for collaboration-based digital agriculture systems. Thanks to shared data exchange, large data pools can be created and the accuracy of artificial intelligence models can be improved. In addition, research institutions and public organizations can also perform agricultural analyses using anonymized data.

The shared data ownership model is considered a more sustainable approach in terms of data governance. This is because, in this model, the rights of producers over data are protected while also benefiting from the technological advantages provided by data sharing.

However, for this model to be successful, clear data policies, transparent user agreements, and strong data security mechanisms are required. In cases where a trust relationship cannot be established between the parties, the effectiveness of shared data exchange systems may decrease.

10. Data Sharing and Data Economy

In digital agriculture systems, data are not only used for the management of production processes. They have also become a resource with economic value.

Agricultural data can be used in the following areas:

- production planning
- risk analysis
- insurance systems
- market analyses
- agricultural research

Therefore, agricultural data are increasingly becoming an important economic resource. The concept of the data economy has emerged in this context. The data economy refers to the processes through which data generate economic value.

Digital agriculture platforms collect large amounts of agricultural data and provide various services by analyzing these data. This situation is described by some researchers as "agricultural data capitalism." One of the most important issues in this process is the extent to which producers benefit from the data economy.

11. Data Security and Privacy

Data security is an important issue in digital agriculture systems. Agricultural production data contain important information about the economic activities of enterprises. Therefore, the secure storage of these data is of great importance. The main risks related to data security are as follows:

- Data leakage
- Cyberattacks
- Unauthorized data access

In particular, the widespread use of cloud-based data platforms has led to the emergence of new risks regarding data security. Therefore, strong data security systems must be established in digital agriculture platforms.

12. Digital Agriculture Platforms

Digital agriculture platforms are software-based systems that enable the collection, storage, analysis, and transformation of data obtained from agricultural production processes into production decisions. These platforms integrate sensor systems, remote sensing technologies, meteorological data, artificial intelligence applications, and decision support mechanisms within the same digital structure. The main purpose of digital agriculture platforms is to provide producers with data-driven decision-making support and to ensure that production processes are managed more efficiently and sustainably (Fountas et al., 2015).

In viticulture, digital agriculture platforms play an important role especially in precision vineyard management applications. Data obtained from sensors, such as temperature, humidity, soil water content, and plant development, are collected in central data systems through these platforms. At the same time, satellite imagery and drone data can also be integrated into the platforms to perform spatial analysis of vineyard areas. In this way, producers can evaluate the development status of different regions within vineyard areas in detail and develop targeted management practices (Matese & Di Gennaro, 2015).

Digital agriculture platforms mostly use cloud-based data infrastructures. Thanks to cloud systems, large amounts of agricultural data can be stored and accessed through different devices. These platforms can provide producers with real-time information through mobile applications or web interfaces. For example, irrigation timing, disease risk, or meteorological warnings can be transmitted instantly to producers. Thus, faster and more data-driven decisions can be made in production processes (Wolfert et al., 2017).

The digital platforms used in viticulture generally perform the following functions:

- data collection and storage
- remote vineyard monitoring
- irrigation management
- disease risk analysis
- yield prediction
- quality analysis
- decision support systems

Thanks to these platforms, different data sources can be integrated under a single digital structure and data integration can be achieved. In particular, with the development of artificial intelligence and big data analytics applications, the importance of digital agriculture platforms has increased even further.

However, the use of digital agriculture platforms also brings some problems. One of the most important issues is data standardization. Different sensor systems and software platforms may use different data formats. This situation complicates data integration between systems. In addition, the control of data by platform providers brings discussions on data ownership and data security to the agenda (Rijswijk et al., 2021).

Another important issue is technology dependency. When producers begin to manage production processes in a way that is dependent on digital platforms, dependency on platform providers may increase. In particular, subscription-based platform systems may create economic costs in the long term. In addition, the effective use of digital platforms may become difficult in rural areas where internet infrastructure is inadequate.

Nevertheless, digital agriculture platforms offer important opportunities for sustainable viticulture. Thanks to precision irrigation applications, early disease warning systems, and data-driven production planning, resource use efficiency can be increased and environmental impacts can be reduced. Therefore, digital agriculture platforms are expected to evolve into more integrated, user-friendly, and open data-based systems in the future.

13. Data Management Problems in Viticulture

With the widespread adoption of digital technologies in viticulture, the amount of data obtained from production processes has increased significantly. Thanks to sensor systems, remote sensing technologies, meteorological stations, IoT-based devices, and digital agriculture platforms, multidimensional data production is carried out in vineyard areas. These data include many parameters such as soil properties, microclimatic conditions, plant development, water status, disease symptoms, and production performance. However, the effective operation of digital viticulture systems depends not only on data generation but also on the proper management of these data. Therefore, data management is considered one of the most critical components of digital viticulture (Wolfert et al., 2017).

Data management in viticulture is a multi-stage process that includes the collection, storage, processing, analysis, and integration of data into decision support processes. However, various technical and managerial problems may arise during this process. In the literature, issues such as data integration, data standardization, data quality, data storage capacity, and data access are stated to be among the main barriers to digital viticulture applications (Ammoniaci et al., 2021).

13.1 Data Integration Problems

One of the most important problems of data management in viticulture is the integration of different data sources. In digital vineyard systems, data are generally obtained through different devices and platforms. Sensor systems, drone imagery, satellite data, and meteorological stations may use different data formats and data processing methods. This situation complicates the integrated use of different data sources within the same system. For example, in a vineyard enterprise, data obtained from soil moisture sensors are recorded as real-time time series, while drone imagery produces high-resolution spatial image data. The analysis of these different data types within the same decision support system requires advanced data processing infrastructures (Fountas et al., 2015).

In addition, differences in the data formats used by different technology providers may lead to compatibility problems between systems. This situation is defined in the literature as the “interoperability” problem. These difficulties in data integration may reduce the effectiveness of digital viticulture systems.

13.2 Data Quality and Reliability

Data quality is of great importance in digital viticulture systems. Data obtained from sensors or remote sensing systems may in some cases be incomplete, erroneous, or inconsistent. Sensor malfunctions, data transmission interruptions, or environmental conditions may affect data accuracy.

For example, soil moisture sensors used in vineyard areas may produce inaccurate measurements due to incorrect calibration. Similarly, lighting conditions or atmospheric effects in drone imagery may reduce image quality. These problems in data quality may directly affect the accuracy of artificial intelligence and decision support systems (Giovos et al., 2021).

Therefore, data validation and data cleaning processes are of critical importance in digital viticulture systems. In order for large datasets to produce reliable analyses, data quality must be continuously monitored.

13.3 Data Storage and the Big Data Problem

Digital technologies used in viticulture generate very large amounts of data. In particular, multispectral and hyperspectral imaging systems can generate high-volume data. This situation creates important technical requirements in terms of data storage and data processing. The concept of big data gains importance at this point. The volume, variety, and generation speed of the data produced in digital viticulture systems make it difficult to manage them using traditional data management methods (Wolfert et al., 2017).

Although cloud-based data systems provide significant advantages in terms of big data management, issues such as data storage costs and data security still continue. In addition, the fact that big data analyses require high processing power may create an economic barrier for small enterprises.

13.4 Data Access and Data Sharing

One of the important issues related to data management in viticulture is data access and data sharing. Since agricultural data are often stored on different platforms, producers may not have full access to their own data. In addition, there are various concerns among producers regarding data sharing. Producers may hesitate about the use of production data for commercial purposes or access by competing enterprises. This situation may limit data sharing and complicate the creation of shared databases (Rijswijk et al., 2021).

Nevertheless, data sharing is of great importance for research and artificial intelligence applications. Thanks to large datasets, more accurate artificial intelligence models can be developed and the success of decision support systems in viticulture can be improved.

14. Digital Viticulture and Sustainability

Today, sustainability has become one of the most important concepts in the evaluation of agricultural production systems. In the agricultural sector, sustainability includes various dimensions such as the protection of natural resources, the continuity of economic production capacity, and the welfare of rural communities. The viticulture sector is also one of the agricultural areas in which sustainable production approaches are gaining increasing importance.

Digital technologies provide important tools for achieving sustainable production goals in viticulture. Thanks to sensor systems, remote sensing technologies, and data analytics methods, environmental conditions in vineyard areas can be monitored more precisely and production processes can be managed more effectively.

Digital viticulture applications can provide important contributions to sustainability especially in the following areas:

- Increasing water use efficiency
- Reducing the use of chemical inputs
- Increasing production efficiency
- Reducing environmental impacts

However, the effects of digital technologies on sustainability do not consist only of positive outcomes. The production, use, and maintenance processes of these technologies may also bring some new environmental and economic problems. Therefore, the sustainability of digital viticulture should be evaluated together in terms of environmental, economic, and social dimensions.

14.1 Environmental Sustainability

Digital technologies provide important opportunities for increasing environmental sustainability in viticulture. In particular, thanks to precision agriculture applications, it becomes possible to use natural resources more efficiently.

14.1.1 Water Management

The effective use of water resources is one of the most important components of sustainable production in viticulture. With climate change, water stress has become an important problem in many viticulture regions.

Digital technologies provide significant advantages in irrigation management. Thanks to soil moisture sensors and remote sensing systems, water status in vineyard areas can be continuously monitored. These data enable irrigation decisions to be made more accurately. Thanks to precision irrigation systems, irrigation can be applied only in the areas where it is needed. This situation contributes to the reduction of water consumption.

14.1.2 Pesticide Use

Disease and pest management is an important production problem in viticulture. In traditional production systems, large-scale pesticide applications may be carried out to reduce disease risk.

Thanks to digital technologies, it becomes possible to determine disease risk at an early stage. Disease risk prediction systems can be developed using sensor data and meteorological models. Thanks to these systems, pesticide applications can be carried out only when necessary. This situation contributes to the reduction of chemical input use and environmental impacts.

14.1.3 Soil Management

Soil health is one of the important components of sustainable viticulture. Thanks to digital technologies, the spatial variability of soil properties in vineyard areas can be analyzed.

Information about soil moisture, temperature, and nutrient elements can be obtained using soil sensors and remote sensing systems. These data enable the optimization of fertilization management. Thanks to variable-rate fertilization applications, fertilizer use can be reduced and the risk of soil pollution can be lowered.

14.2 Economic Sustainability

The economic sustainability of digital viticulture systems is an important subject of discussion. Although digital technologies have the potential to increase production efficiency, the implementation of these technologies requires certain costs.

The economic sustainability of digital viticulture systems depends on the following factors:

- Technology investment costs
- Enterprise scale
- Production efficiency
- Product quality

14.2.1 Investment Costs

Sensor systems, drone technologies, and data analysis platforms require a certain level of investment cost. These costs may constitute a significant barrier especially for small and medium-sized vineyard enterprises. Therefore, the economic sustainability of digital technologies is closely related to enterprise scale.

14.2.2 Yield and Quality Increase

Digital technologies can provide increases in yield and quality by enabling production processes to be managed more effectively. In particular, improving grape quality can provide significant economic advantages in the viticulture sector. High-quality grapes can create higher market value in the sector.

14.3 Social Dimension

The social dimension of digital viticulture is also an important issue in terms of sustainability. The widespread adoption of digital technologies in the agricultural sector leads to significant changes in production processes. The use of digital technologies requires the development of certain new skills. This situation causes new training needs to emerge in terms of producers' technology adaptation.

In addition, the widespread adoption of digital technologies may also bring digital inequality issues in rural areas to the agenda. In regions where internet infrastructure is insufficient, the widespread adoption of digital agriculture applications may become difficult. Therefore, it is important to develop policies by taking the social dimension of digital viticulture systems into consideration.

15. Conclusion and General Evaluation

The use of digital technologies in viticulture has increased significantly in recent years and has created new opportunities for managing production processes in a more precise, data-driven, and sustainable manner. Digital tools such as sensor technologies, remote sensing systems, the Internet of Things (IoT), artificial intelligence applications, and big data analytics provide important advantages in terms of monitoring environmental conditions in vineyard areas, evaluating plant development, determining disease risks, and optimizing production decisions. In particular, the precision viticulture approach contributes to increasing production efficiency and product quality by enabling a more detailed analysis of spatial and temporal variability in vineyard areas.

However, when the literature is examined, it is seen that digital viticulture is not only a technological transformation but also a complex process with economic, managerial, and social dimensions. During the integration of digital technologies into production systems, various issues such as data management, data ownership, data security, interoperability between systems, and technology adoption may arise. In particular, the issue of data governance is of critical importance for the sustainability of digital agriculture systems. Uncertainties regarding who controls agricultural data, under which conditions they are shared, and how they are used may directly affect producers' trust in digital systems. Therefore, the development of open, transparent, and producer-rights-oriented data governance policies is of great importance for the future of digital viticulture systems.

Another important issue evaluated within the scope of this study is the applicability of digital technologies. Although sensor systems, drone technologies, data analysis platforms, and artificial intelligence applications provide important advantages in production processes, the use of these technologies requires a certain level of technical knowledge, infrastructure, and economic investment. Especially for small and medium-sized vineyard enterprises, high investment costs and technical expertise requirements may limit the widespread adoption of digital technologies. Therefore, digital viticulture applications should be developed not only for large-scale enterprises but also in a way that is suitable for different producer profiles.

The sustainability dimension of digital viticulture systems has also constituted one of the main discussion areas of this study. Thanks to digital technologies, it may be possible to increase water use efficiency, optimize pesticide and fertilizer use, and reduce environmental impacts. In particular, precision irrigation applications and early disease warning systems provide important advantages for sustainable vineyard management. However, it should also be considered that digital systems may bring new environmental problems such as energy consumption, dependency on data infrastructure, and electronic waste generation. Therefore, sustainability assessments of digital agriculture technologies should be addressed not only in terms of production efficiency but also in terms of environmental and socio-economic impacts.

As a result of this study, it is predicted that digital viticulture systems will become more integrated, data-driven, and sustainable structures in the future. However, technological developments alone are not sufficient for this transformation to be successfully achieved. Ensuring data integration and data standardization, developing open data platforms, expanding producer-oriented digital solutions, and increasing the accessibility of digital technologies are of great importance. In addition, interdisciplinary research should be increased and cooperation among technology developers, producers, research institutions, and policy makers should be strengthened.

As a result, digital technologies offer significant potential for achieving sustainable production goals in the viticulture sector. However, in order for this potential to be effectively utilized, technological innovations must be addressed together with the dimensions of data governance, applicability, and sustainability. In this direction, holistic digital viticulture systems to be developed will make important contributions to the establishment of more efficient, environmentally friendly, and sustainable production models in vineyard management in the future.

REFERENCES

Ammoniaci, M., Kartsiotis, S.P., Perria, R., Storchi, P., 2021. State of the Art of Monitoring Technologies and Data Processing for Precision Viticulture. *Agriculture, 11*(3), 201. https://doi.org/10.3390/agriculture11030201

Atik, C., 2022. Towards Comprehensive European Agricultural Data Governance: Moving Beyond the "Data Ownership" Debate. *International Review of Intellectual Property and Competition Law, 53*, 1169–1199. https://doi.org/10.1007/s40319-022-01191-w

Bellon-Maurel, V., Lutton, E., Bisquert, P., Brossard, L., et al., 2022. Digital Revolution for the Agroecological Transition of Food Systems a Responsible Research and Innovation Perspective. *Agricultural Systems, 203*, 103524. Published by Elsevier. https://doi.org/10.1016/j.agsy.2022.103524

Fountas, S., Carli, G., Sørensen, C. G., Tsiropoulos, Z., Cavalaris, C., et al., 2015. Farm management information systems: Current situation and future perspectives. *Computers and Electronics in Agriculture, 115*, 40–50. https://doi.org/10.1016/j.compag.2015.05.011

Giovos, R., Tassopoulos, D., Kalivas, D., Lougkos, N., Priovolou, A., 2021. Remote Sensing Vegetation Indices in Viticulture: A Critical Review. *Agriculture, 11*(5), 457. https://doi.org/10.3390/agriculture11050457

Izquierdo-Bueno, I., Moraga, J., Cantoral, J.M., Carbu, M., Garrido, C., Gonzalez-Rodriguez, V.E., 2024. Smart viniculture: Applying Artificial Intelligence for Improved Winemaking and Risk Management. *Applied Sciences, 14*(22), 10277. https://doi.org/10.3390/app142210277

Kamilaris, A., Kartakoullis, A., Prenafeta-Boldú, F. X., 2017. A Review on the Practice of Big Data Analysis in Agriculture. *Computers and Electronics in Agriculture, 143*, 23–37. https://doi.org/10.1016/j.compag.2017.09.037

Klerkx, L., Jakku, E., Labarthe, P., 2019. A review of social science on digital agriculture, smart farming and agriculture 4.0: New contributions and a future research agenda . *NJAS: Wageningen Journal of Life Sciences, 90–91*, 100315. https://doi.org/10.1016/j.njas.2019.100315

Liakos, K.G., Busato, P., Moshou, D., Pearson, S., Bochtis, D., 2018. Machine Learning in Agriculture: A Review. *Sensors, 18*(8), 2674. https://doi.org/10.3390/s18082674

Matese, A., Di Gennaro, S. F., 2015. Technology in precision viticulture: A state of the art review. *International Journal of Wine Research, 7*, 69–81. https://doi.org/10.2147/IJWR.S69405

Mucalo, A., Matic, D., Moric-Spanic, A., Cagalj, M., 2024. Satellite Solutions for Precision Viticulture: Enhancing Sustainability and Efficiency in Vineyard

Management. Agronomy, 14(8), 1862. https://doi.org/10.3390/agronomy14081862

Pascoal, D., Silva, N., Adao, T., Lopes, R.D., Peres, E., Morais, R., 2024. A Technical Survey on Practical Applications and Guidelines for IoT Sensors in Precision Agriculture and Viticulture. *Scientific Reports, 14*, 29793. https://doi.org/10.1038/s41598-024-80924-y

Rijswijk, K., Klerkx, L., Bacco, M., Bartolini, F., Bulten, E., Debruyne, L., Dessein, J., Scotti, I., & Brunori, G., 2021. Digital transformation of agriculture and rural areas: A socio-cyber-physical system framework to support responsibilisation. *Journal of Rural Studies, 85*, 79–90. https://doi.org/10.1016/j.jrurstud.2021.05.003

Shang, L., Heckelei, T., Gerullis, M. K., Börner, J., Rasch, S., 2021. Adoption and Diffusion of Digital Farming Technologies - Integrating Farm-Level Evidence and System Interaction. *Agricultural Systems, 190*, 103074. https://doi.org/10.1016/j.agsy.2021.103074

Tardaguila, J., Stoll, M., Gutiérrez, S., Proffitt, T., Diago, M. P., 2021. Smart Applications and Digital Technologies in Viticulture. *Smart Agricultural Technology, 1*, 100005. https://doi.org/10.1016/j.atech.2021.100005

Wolfert, S., Ge, L., Verdouw, C., Bogaardt, M.J., 2017. Big Data in Smart Farming: A Review. *Agricultural Systems, 153*, 69–80. Elsevier.https://doi.org/10.1016/j.agsy.2017.01.023

Chapter 2

Aquaculture's Sustainable Development Practices

Funda TURAN[1],Cemal TURAN[2]

ABSTRACT

Aquaculture, defined as the controlled cultivation of aquatic organisms such as fish and shellfish, is crucial in addressing global food security challenges exacerbated by climate change, population growth, and resource scarcity. With the world population projected to reach 9.7 billion by 2050, food production needs to increase by 25% to 70%, making aquaculture a critical contributor to providing nutritious diets. Reaching a production volume of approximately 130.9 million tons, this rapidly growing sector significantly supports nutrition and economic sustainability, particularly in developing countries, and offers a pathway to poverty alleviation.However, aquaculture faces sustainability challenges. Traditional practices often exacerbate environmental problems such as biodiversity loss and habitat degradation. Innovative strategies are essential to align environmental sustainability with production efficiency, as highlighted by cutting-edge technologies such as recirculating aquaculture systems (RAS) that improve water management and wastewater recycling.Furthermore, integrating ecological principles through methods such as aquaponics and integrated multitrophic aquaculture (IMTA) promotes resource utilization by mimicking natural ecosystems. Artificial intelligence (AI) enables real-time monitoring and optimizes feeding strategies. The use of technological, ecological, and socio-economic strategies such as digital monitoring and nutrient recycling is crucial for strengthening the sector's environmentally conscious and economically viable production capacity while overcoming sustainability challenges. The aim of this study is to provide information on good and next-generation practices in sustainable aquaculture.

Key Words: Sustainability, RAS, IMAT, AI

---

[1] Prof. Dr., Faculty of Marine Science and Technology, Iskenderun Technical University, Hatay, Türkiye ORCID ID: https://orcid.org/0000-0002-0257-6009, funda.turan@iste.edu.tr

[2] Prof. Dr., Faculty of Engineering and Natural Sciences, Istanbul Atlas University, İstanbul, Türkiye ORCID ID: https://orcid.org/0000-0000-0000-0000, cemal.turan@atlas.edu.tr

INTRODUCTION

Aquaculture is one of the leading sectors in the global food supply, addressing global food security concerns stemming from global climate change, population growth, and resource scarcity. Furthermore, the world population is projected to reach 9.7 billion by 2050, requiring a 25% to 70% increase in food production. Providing a rich and healthy diet is essential to overcoming these challenges, and aquaculture plays a crucial role here. Defined as the controlled cultivation of aquatic organisms such as fish, shellfish, mollusks, and aquatic plants, aquaculture has emerged as a rapidly growing global food production industry. Thanks to increasing demand for high-protein foods and advancements in agricultural technologies, its production has reached approximately 130.9 million tons. Aquaculture plays a critical role in global food security, nutrition, and economic sustainability, particularly in developing countries, as it is seen as a sustainable alternative that can alleviate poverty (Bayır et al. 2025; Ranjan et al ., 2026).

However, aquaculture faces significant sustainability challenges such as poor water quality, dependence on fishmeal and fish oil, and high susceptibility to diseases in intensive farming environments. Furthermore, traditional aquaculture practices can exacerbate environmental problems such as biodiversity loss, habitat degradation, and food pollution. Addressing these issues requires innovative strategies that align environmental sustainability with production efficiency (Serra et al ., 2024).

Recent advancements in sustainability in aquaculture include the development of technologies such as recirculating aquaculture systems (RAS) aimed at improving water management and wastewater recycling. Furthermore, methods integrating ecological principles such as aquaponics and integrated multitrophic aquaculture (IMTA) have been adopted to increase resource utilization by mimicking natural food webs (Stoyanova et al ., 2024).

Furthermore, the integration of artificial intelligence (AI), the Internet of Things (IoT), and automated systems facilitates real-time monitoring of water quality and optimizes feeding strategies . Innovations in biotechnology and genetic enhancements, along with the exploration of alternative feed components, aim to increase the resilience and efficiency of aquaculture systems. Technological, ecological, and socio -economic strategies, including digital monitoring, nutrient recycling, and ecosystem-based agriculture practices , are crucial in overcoming sustainability challenges while strengthening the sector's environmentally conscious and economically viable production capacity (Bayır et al ., 2025; Ranjan et al., 2026). The aim of this article is to provide general information about next-generation concepts applied in good and sustainable aquaculture.

RECIRCULATING AQUACULTURE SYSTEMS (RAS)

As aquaculture expands, it increasingly impacts the environment through nutrient contamination from uneaten feed and waste, chemical pollution from production materials such as antibiotics, and the transmission of genes, diseases, and parasites from farmed fish to wild populations . Indirect impacts include ecological damage from the use of wild fish to feed carnivorous farmed species. Direct impacts include visual and auditory disturbances, odors, and marine pollution from farm operations. Untreated fish farm wastewater, rich in nutrients and chemicals, poses significant pollution risks, particularly in open net cage systems where pollution control is limited (Carballeira) . Braña et al ., 2021).

The biological characteristics of the species used in aquaculture primarily shape nitrogen (N) and phosphorus (P) discharge levels, but specific discharge rates are significantly influenced by the engineering design of aquaculture systems. Various system characteristics, including hydraulic exchange frequency and waste holding capacity , determine nutrient migration and environmental impacts. Intensive aquaculture systems, such as net cages and flow-through systems, rely on continuous water exchange, leading to the direct release of untreated wastewater; despite low N and P concentrations , large-scale operations result in significant total discharges. For example, net cage systems are reported to release approximately 132.5 kg N and 25.0 kg P per ton of fish produced, impacting local environments, particularly in fjords and shallow lakes, by increasing nutrient concentrations and accelerating eutrophication . Innovative aquaculture models such as recirculating aquaculture systems (RAS) and integrated multitrophic aquaculture (IMTA) are being investigated as solutions to manage discharge limitations. One of the biggest advantages of the RAS system is the reduction in operating costs related to feed, predator control, and parasites; this can potentially lead to the elimination of parasites released into receiving waters. RAS also minimizes reliance on antibiotics and therapeutics , thus offering a marketing advantage for the production of high-quality, 'safe' seafood. These systems allow for versatile breeding sites, proximity to markets, and facility construction on former industrial sites, but still require close access to quality water sources. Flexibility in species farming regardless of temperature requirements and safe production of non-endemic species are additional benefits. Optimized environmental conditions ensure excellent Feed Conversion Ratios (FCRs), allowing high-value marine species to reach market size significantly faster than in traditional sea cages. Intensive control within RAS regulates water flow, stock density, and physiological balance, maintaining optimal fish health while efficiently removing metabolic waste and preserving acceptable water chemistry . However, the document also addresses the significant challenges facing RAS technology. A major concern is the lack of experienced specialists in RAS culture; former cage or hatchery managers often lack the skills necessary for commercial-scale operations requiring 24-hour monitoring of water quality variables. Economic viability generally depends on assumptions about market prices, waste stream utilization, product quality, and operating costs, including energy and loan interest . Choosing the right type for RAS production is crucial, as competition with lower-cost alternatives on the market poses a risk. While it is possible to utilize farm waste for value-added products and on-site energy production, such innovations are still in their infancy (Boyd et al ., 2020; Aich et al., 2020). Esmaeili et al., 2026).

Biosecurity plays a critical role in RAS , encompassing policies aimed at minimizing pathogen entry and spread . RAS technology can reduce the frequency of disease outbreaks, but poorly designed systems can inadvertently promote conditions that foster pathogen proliferation. Therefore, the experience and knowledge of RAS managers are crucial for mitigating health risks within the system. Studies highlighting the efficiency of biofilters and sedimentation systems show variability in waste removal, which can degrade water quality, leading to nitrite poisoning and fish mortality. The accumulation of nutrients and organic matter can create favorable environments for harmful microorganisms, hindering the overall effectiveness of RAS in protecting fish health (Aich et al ., 2020). Furthermore, it leads to the accumulation of high amounts of dissolved N and P, which can have detrimental effects on local environments. On the other hand, IMTA (Integrated Irrigation System) systems, which integrate species at different trophic levels, utilize waste produced by higher trophic level organisms to benefit lower trophic level species, thereby increasing nutrient utilization and reducing overall discharges (Islam et al ., 2005; Martin et al., 2010; Luo et al., 2023; Choudhury et al. , 2026).

Emissions of these systems Despite the advantages it offers in reducing nutrient discharge , its widespread adoption is hampered by associated costs and adaptability issues across different regions. Current global practices in aquaculture are still insufficient to deliver significant reductions in nutrient discharge, and there is an urgent need for continued research and policy support to facilitate the transition to more sustainable practices in aquaculture (Choudhury et al . , 2026).

Chemical treatments in aquaculture are affected by factors such as disease prevalence, facility location, system parameters, type of treatment, and varying legislation across countries. Regulatory frameworks determine the evaluation and authorization of substances, but monitoring of chemical accumulation remains limited. Current authorities introduce regulations regarding permitted substances, application methods, and dosage guidelines, particularly because fish poorly metabolize antibiotics , resulting in significant chemical releases into the environment (Dawood et al ., 2018).

Although advances in aquaculture practices, hygiene measures, and vaccine development have led to a decrease in the use of antimicrobials , the cultivation of some fish species, such as Atlantic salmon (S. salar), faces strict reporting requirements for diseases and chemicals used, as well as regular monitoring to reduce chemical treatments (Hjeltnes et al ., 2018). Aquaculture is largely water-dependent, and mismanagement of this resource poses ecological risks, particularly through nutrient waste leading to eutrophication , hypoxia , and associated water quality degradation . Climate change exacerbates these risks by affecting aquatic conditions, impacting species health and resilience. Water scarcity limits the development of fisheries and necessitates better water use technologies; challenges posed by saltwater intrusions affect growth and survival, requiring changes in fish species or aquaculture techniques (Khalili and Moridi , 2025).

Rising feed costs, driven by increasing demand from the expanding aquaculture sector, further challenge economic sustainability, while conventional feeds may also contain anti-nutritional factors. Aquatic animal diseases pose a significant threat to the sustainability of aquaculture. High stocking densities contribute to chronic stress and a weakened immune response in fish, increasing disease susceptibility and outbreaks due to various physiological stressors. The complexity of disease management is further exacerbated by antimicrobial resistance (AMR) , which jeopardizes public health and aquaculture systems due to uncontrolled antibiotic use (Bueno et al ., 2017; Mohan et al., 2022).

Improper aquaculture management can severely impact ecosystems by destroying critical habitats such as mangroves and wetlands. The socio -economic environment reveals that small-scale farmers face significant barriers due to limited access to finance, markets, and technology, affecting their ability to adopt sustainable practices (Haryanto , 2023). A National Fisheries Policy, while acknowledging these issues and highlighting public concerns regarding food security, poses a challenge to the growth and sustainability of the aquaculture sector (Ranjan et al ., 2026).

INTEGRATED MULTI-TROPHIC AQUACULTURE (IMTA)

The Integrated Multitrophic Aquaculture (IMTA) strategy aims to utilize surplus nutrients from higher -trophic organisms (such as fish and shrimp) to cultivate lower -trophic species (such as bivalves and aquatic plants), thereby addressing key challenges in aquaculture, including environmental pollution and resource inefficiency. IMTA systems are proposed as a viable solution to improve aquaculture practices by minimizing ecological impact and maximizing economic returns. However, the optimization and widespread implementation of IMTA designs are limited by multiple challenges, particularly in pond aquaculture settings. These include the difficulty of selecting species combinations that utilize resources efficiently, maintain nutrient dynamics, and ensure economic viability while reducing competition . Consequently, species-specific designs adapted to local conditions such as climate and water quality are necessary. Overall, IMTA systems not only improve environmental health and resource sustainability but also significantly increase the growth, feed utilization, productivity, and immunity of aquaculture species (Tang et al ., 2024; Huanacuni et al., 2026).

IMTA operates based on the principles of cultivating organisms according to their trophic levels and using the by-products of one species as input for another, thus promoting a balanced ecosystem in aquaculture environments. Effective IMTA relies on both extractive species , such as bivalves and aquatic plants, that consume organic/inorganic waste, and feeder species that require supplemental nutrition. Furthermore, filter-fed organisms in IMTA systems can significantly reduce microbial loads by filtering suspended particles from the environment, thereby improving system health. For example, seaweed can absorb excess nutrients and support beneficial microbial communities that remove harmful pathogens. The adaptability of the IMTA concept facilitates its application in diverse environments globally, making it an indispensable approach for sustainable aquaculture practices (Ghosh et al ., 2025; Huanacuni et al., 2026).

ARTIFICIAL INTELLIGENCE AND AQUACULTURE

Artificial intelligence (AI) represents the ability to mimic human intelligence through methods such as machine learning (ML), deep learning (DL), and computer vision (CV). In the field of aquaculture, AI is uniquely applied to address the challenges posed by dynamic biological systems, changing water qualities, and species-specific behaviors. Unlike its industrial counterparts, which focus on automation and logistics, AI in aquaculture emphasizes adapting to complex ecological contexts. This application encompasses numerous technologies, including ML, CV, and data-driven decision-making systems, which can increase operational efficiency, reduce production costs, and enhance sustainability in aquaculture practices. By analyzing comprehensive data from aquaculture environments, AI systems provide critical insights for water quality management, fish health monitoring, feed optimization , and other vital aspects of aquaculture operations. The integration of AI technologies enhances the precision and efficiency of various processes, as well as enabling real-time monitoring and proactive measures necessary to maximize productivity and protect the health of cultivated species Fig 1. (Gokunalth et al., 2024; Rather et al ., 2024).

Figure 1: Feeding by the deep sea thanks to the AI application (modified to Gokulnath et al., 2024).

Significant gap in studies that comprehensively address the role of AI in aquaculture. Much of the existing research focuses on isolated elements such as feed optimization or disease detection, neglecting a holistic view of technological advancements across the sector. This article aims to address this gap by providing an integrated review of AI applications related to key areas such as water quality management, disease prevention, feed automation, cultivation strategies, and product traceability. Through bibliometric analysis, it highlights trends by time and geography, identifies key research areas, and examines significant contributions of AI- driven aquaculture. The results not only help to increase knowledge in the field but also underscore the important role AI plays in addressing environmental, operational , and socioeconomic challenges affecting aquaculture (Yang et al ., 2025). Furthermore, recent developments in the aquaculture sector highlight a shift towards digital transformation, climate resilience, and models supporting a circular bioeconomy. Particularly since 2020, the use of artificial intelligence and digital technologies has increased significantly in large-scale operations, especially for valuable species such as shrimp and salmon. The integration of predictive analytics, real-time monitoring, and automated control systems has significantly improved environmental performance and biosafety (Gupta et al ., 2024). Research studies have focused on integrating microalgae- based systems into recirculating aquaculture systems (RAS) to improve nutrient cycling and reduce energy costs (Ende et al ., 2024). Notable advancements in sustainable alternative feeds such as single-cell protein, algal oil, and insect meal are helping to reduce reliance on traditional fishmeal and fish oil and support circular production strategies. Overall, these innovations represent a sophisticated evolution in aquaculture that combines ecological sustainability with advanced technological applications (Ranjan et al ., 2024).

CONCLUSIONS

For sustainable, resilient, and innovative aquaculture, next-generation applications such as RAS, IMAT, and AI play a critical role in the development of this sector. Comprehensive training in these applications enables the sector to overcome various challenges related to health reproduction, environment, and technology, and advances sectoral development in terms of sustainability. their contributions are vital at all stages, from laboratory settings to field applications and from basic research to public policy formulation. The future success of the aquaculture sector will largely depend on its integration with social, economic, and environmental demands. Therefore, it is necessary to support sustainability in good aquaculture practices and encourage applied research.

REFERENCES

Aich , N ., Nama, S., Biswal , A., & Paul, T. (2020). A review on recirculating aquaculture systems : Challenges and opportunities for sustainable Aquaculture . *Innovative . Farming* , *5* (1), 17-24.

Bayır, A. , Saoula , S., Almansour , A., Wang , D., Bayır, M., Uzun, BN, ... & Arslan, G. (2025). CRISPR- Based genetic improvement of aquaculture species . *Fishes* , *10* (2), 84.

Boyd , C. E. , D'Abramo , LR, Glencross , BD, Huyben , DC, Juarez , LM, Lockwood , GS, ... & Valenti , WC (2020). Achieving sustainable Aquaculture : Historical and current perspectives and future needs and challenges . *Journal of the world aquaculture society* , *51* (3), 578-633.

Bueno , G. W. , Bureau , D., Skipper -Norton, J. O. Roubach , R., Tavares de Mattos , F., and Bernal , FEM (2017). Mathematical modeling for the management of the carrying capacity of aquaculture enterprises in lakes and reservoirs pesq . Agropec . brass . 52, 695–706.

Burridge , L. , Weis , J.S., Cabello , F., Pizarro , J., and Bostick , K. (2010). Chemical use in salmon aquaculture : a review of current practices and possible environmental effects . Aquaculture 306, 7–23.

Carballeira Braña , C. B. , Cerbule , K., Senff , P., & Stolz , I.K. (2021). Towards environmental sustainability in marine finfish aquaculture *Frontiers in Marine Science* , *8* , 666662.

Choudhury , A. , Lepine , C., Witarsa , F., & Good , C. (2022). anaerobic digestion challenges and resource recovery opportunities from land-based aquaculture waste and seafood processing byproducts : A review . *bioresource Technology* , *354* , 127144.

Dawood , M.A. , Koshio , S., & Esteban , M. Á. (2018). Beneficial roles of feed additives as immunostimulants in aquaculture : a review . *Reviews in Aquaculture* , *10* (4), 950-974.

Ende, S. , Henjes , J., Spiller , M., Elshobary , M., Hanelt , D., and Abomohra , A. (2024). Recent advances in recirculating aquaculture systems and the role of microalgae to close system loop.bioresource Technol . 407, 131107. doi : 10.1016/j.biortech.2024.131107.

Esmaeili , H. R. (2026). sustainable Aquaculture , Fish Diversity , and Fish Conservation . *Biotechnology Innovations for a sustainable Future : Integrating Clean Energy , Life on the Planet, Clean Water , and Climate Action* , 549-574.

Ghosh , A.K. Hasanuzzaman , AFM, Islam , SS, Sarower , MG, Mistry , SK, Arafat, ST, & Huq , KA (2025). integrated multi-trophic Aquaculture (IMTA): Enhancing growth , production , immunological responses , and environmental management in aquaculture . *Aquaculture International* , *33* (5), 336.

Gokulnath, S. R., Vasanthakumaran, K., Thanga, A., Naveen, S. K., Iburahim, A., & Paul, N. T. (2024). Precision aquaculture: Empowering fish farming with AI and IoT. *Aquac. Rep*, *42*, 102625.

Gupta , S. , Makridis , P., Henry, I., Velle -George, M., Ribicic , D., Bhatnagar , A., et al. (2024). Recent developments in recirculating aquaculture systems : a review . Aquac . Pic . 2024, 6096671. doi : 10.1155/ are /6096671

Haryanto , T. , Wardana , WW, Jamil , IR, Brintanti , ARD, & Ibrahim , KH *Impact of credit access on farm performance : Does source of credit matter ?. Helion . 2023; 9(9):e19720 .*

Huanacuni , J. I. , Pepe- Victoriano , R., Resurrección-Huertas , J.Z., Acosta-Angulo , O., & Espinoza Ramos , L.A. (2026). The Role of the Biologist in Sustainable Aquaculture : Review of Contributions , Technologies and Emerging Challenges . *Sustainability* , *18* (3), 1165.

Islam , MS (2005). Nitrogen and phosphorus budget in coastal and marine cage aquaculture and impacts of effluent loading on ecosystem : review and analysis towards model development . *marine pollution bulletin* , *50* (1), 48-61.

Khalili , R ., & Moridi , A. (2025). A comprehensive review of eutrophication in water resources : from identifying contributing factors to proposing management strategies . *interdisciplinary Journal of Civil Engineering* , *1* (1), 38-52.

Li , Z. , Deng , Y., Zheng , M., Yang , L., He, C., Yang , C., ... & Liu , B. (2026). A review of global aquaculture wastewater treatment and Management : Sustainable pathways through technological innovations and policy coordination . *Journal of Hazardous Materials* , 141235.

Luo , G. (2023). Review of waste phosphorus from aquaculture : Source, removal and recovery . *Reviews in Aquaculture* , *15* (3), 1058-1082.

Martins , CI M. , Eding , EH, Verdegem , MC, Heinsbroek , LT, Schneider , O., Blancheton , JP, ... & Verreth , JAJ (2010). New developments in recirculating aquaculture systems in Europe: A perspective on environmental sustainability . *Aquacultural engineering* , *43* (3), 83-93.

Mohan , K. Rajan , D.K., Muralisankar , T., Ganesan , A.R., Sathishkumar , P., & Revathi , N. (2022). Use of black soldier fly (Hermetia) illucens L.) larvae meal in aquafeeds for a sustainable aquaculture Industry : A Review of Past and future needs . *Aquaculture* , *553* , 738095.

Ranjan , D ., Singh, S., Singh, A., Misra , V. K., Singh, C. P., & Kumar, D. (2026). Recent advancements in sustainable aquaculture : innovative techniques and future prospects . *Frontiers in Aquaculture* , *5* , 1770106.

Rather , M. A. , Ahmad , I., Shah , A., Hajam , Y.A., Amin, A., Khursheed , S., ... & Rasool , S. (2024). exploring Opportunities of Artificial Intelligence Intelligence in aquaculture to meet increasing food demand . *Food Chemistry : X* , *22* , 101309.

SerraV.PastorelliG .TedescoD . E. A. Turin L. Guerrini A . (2024). Alternative protein sources in aquafeed : Current scenario and future perspectives . *Vet. Anim. Sci.* 25, 100381. doi : 10.1016/j.vas.2024.100381.

Stoyanova , S. , Sirakov , I., & Velichkova , K. (2024). Sustainable production : integrating medicinal plants with fish farming in aquaponics —a mini review . *Sustainability* , *16* (15), 6337.

Yang , H ., Feng , Q., Xia , S., Wu , Z., & Zhang , Y. (2025). AI- driven aquaculture : A review of technological innovations and their sustainable impacts . *Artificial Intelligence in Agriculture* , *15* (3), 508-525.

Chapter 3

Approaches to Aquaculture within the Framework of One Health

Funda TURAN[1],Cemal TURAN[2]

Abstract

The One Health concept encourages a holistic approach to various health issues by acknowledging the interconnectedness of human, animal, and environmental health. Initially focused on medicine and veterinary sciences, the One Health approach now encompasses zoonotic diseases, antimicrobial resistance, food safety, vector-borne diseases, and environmental pollution. The One Health Aquaculture approach addresses the need for sustainable food supply from aquaculture, linking the roles of food systems in biodiversity, climate change, and nutrition. It emphasizes that sustainability should be considered within the context of terrestrial and aquatic food sectors, along with cultural values and perceptions. Overall, this study aims to analyze the role of aquaculture within the Framework of One Health framework to better align sustainability goals under the One Health concept.

Key Words : One Health , Aquaculture , Sustainable

---

[1] Prof. Dr., Faculty of Marine Science and Technology, Iskenderun Technical University, Hatay, Türkiye
ORCID ID: https://orcid.org/0000-0002-0257-6009, funda.turan@iste.edu.tr
[2] Prof. Dr., Faculty of Engineering and Natural Sciences, Istanbul Atlas University, İstanbul, Türkiye
ORCID ID: https://orcid.org/0000-0000-0000-0000, cemal.turan@atlas.edu.tr

INTRODUCTION

The One Health concept, which acknowledges the interdependence of human, animal, and environmental health, emerged to address these interwoven issues with a holistic approach. In recent years, the One Health approach has expanded from medicine and veterinary sciences to encompass a rapidly growing range of coordinated areas, including zoonotic diseases, antimicrobial resistance, food safety and security, vector-borne diseases, environmental pollution, and other health hazards shared by humans, animals, and the environment (Bronzwaer et al ., 2021). Furthermore, the One Health approach has gained widespread support globally and has led to the establishment of numerous international initiatives. For example, in the US, the National Park Service, the Centers for Disease Control and Prevention, and the Department of Agriculture have created One Health initiatives; countries like Bangladesh and Liberia have also established their own coordination platforms. Additionally, international networks and consortia have been developed, such as the FAO/OIE/WHO collaboration. Launched in 2014, the Global Health Security Agenda (GHSA) brought together approximately 50 countries to enhance their capacity to prevent, detect, and respond to disease threats. One Health offers a holistic approach based on the interaction between human, animal, and environmental health. This approach encourages collaborative efforts among various actors at the government, sectoral , and societal levels to prepare for global threats such as pandemics and climate change. It also increases societal awareness and participation to ensure the sustainable development of human-animal-environment systems (Zhang et al ., 2022).

To reduce disease risks, One Health practices expand the scope of comparative medicine for early detection and a better understanding of hazards. For example, monkey deaths related to the Ebola virus can be used as an indicator to predict potential outbreaks in humans. Similarly, weather assessments can predict the impact of outbreaks such as Rift Valley fever. In this context, vaccination and mosquito control efforts contribute to mitigating health and economic consequences . Integrated human, animal, and environmental surveillance helps to elucidate pathogen transmission pathways and develop solutions to prevent disease at its source (Kelly et al., 2021).

Further more Infectious diseases in humans, farm animals (including fish and crustaceans), and plants were successfully controlled through new drugs, pesticides, food hygiene , health advances, and improved nutritional status. OECD countries benefited most from these developments, while poorer countries suffered from a lack of clean drinking water and effective infectious disease control. Although the Green Revolution increased agricultural production worldwide, health inequalities became visible. Non-communicable diseases remain a problem in developed countries, while infectious diseases remain a problem in less developed countries. Pandemics at the human-animal interface pose a threat to health security and economic stability. Population growth and changes in the interactions between humans, animals, and wildlife are increasing the risk of pandemics. It increases infectious diseases. Diseases such as HIV/AIDS, SARS, H5N1, and H1N1 have had serious economic impacts. The World Bank estimates that the direct cost of infectious diseases transmitted from animals to humans in the last decade is approximately $20 billion, and the indirect cost is more than $200 billion. The economic impact of diseases always stems more from how they are managed than from the disease itself (Chatham House, 2010).

The One Health Aquaculture approach is a first step toward developing societal discussions on aquaculture food supply, acknowledging that food systems (including aquatic environments) play a critical role in biodiversity , climate change mitigation, and human nutrition. It emphasizes that the sustainability of aquaculture should be assessed in relation to other terrestrial and aquatic food sectors. The integration of cultural values and perceptions of land and water, along with historical food supply experiences , complicates defining the sustainability of aquaculture within the broader food system. While there is a growing technical literature supporting the environmental benefits of aquaculture, particularly for non-farmed and preyed species , a significant cultural shift may be needed for these advantages to be fully appreciated and accepted. The One Health Aquaculture approach aims to guide this process, albeit over a long period (Carboni et al ., 2019; Steinford et al., 2020).

It proposes 15 success criteria covering the environment, organisms, and human health; fulfillment of these is supported by the availability and implementation of research, evidence, policies, and legislation. While some success criteria can be incorporated into existing industry accreditation schemes for the aquaculture sector , others fall within the purview of the State and require provision as a public benefit. Figure reproduced with permission from Stentiford et al. 2020. The aim of this study is to examine the general situation in aquaculture within the scope of One Health(Figure 1)

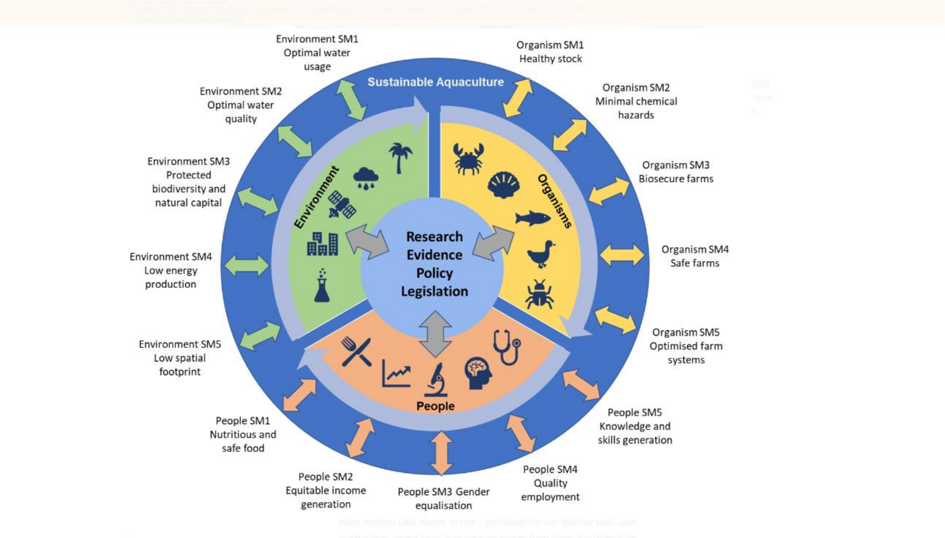

Figure 1. The One Health Aquaculture approach to designing a sustainable aquaculture sector. This figure is modified from Steinford 2020.

One Health and Zoonotic Diseases

According to the World Health Organization (WHO), the "One Health" approach is a method where various scientific fields collaborate, communicate, and develop common policies and programs to improve public health. This approach is situated at the intersection of health and the environment, addressing environmental issues such as zoonotic diseases, antimicrobial resistance, food security, biodiversity loss, and climate change. Zoonotic diseases are infections that can be transmitted from animals to humans or from humans to animals, usually caused by bacterial, viral , fungal , or parasitic agents . Approximately two-thirds of infectious diseases are caused by such pathogens, and their transmission occurs through a series of interactions. Zoonoses , which are not limited to developing countries , are spreading with increasing global trade and travel, creating concern. In addition, climate change, biodiversity loss, and human activities increase the risk of zoonotic spread. As of 2018, 107 different zoonotic diseases have been recorded in Turkey, 37 of which are bacterial, 13 fungal , 29 viral , and 28 parasitic infections. Due to animal mobility, migrations, and geographical conditions, there is a significant risk of zoonoses in our country. The relationship between zoonotic diseases and human health, and ecosystem changes, is directly affected by climate change and human activities. Close contact between humans and nature, and changes in habitats, lead to the emergence of new zoonotic diseases. Biodiversity loss resulting from ecosystem destruction and human population growth accelerate the spread of zoonotic diseases. The threat posed by these diseases is particularly exacerbated in low- and middle-income countries due to weak health systems. Climate change, by increasing the amount of CO2 in the atmosphere, facilitates the emergence of new diseases along with its effects on health. According to the IPCC , the expected increase in global temperatures by 2100 and its negative impacts on health present an alarming series of situations regarding the spread of zoonotic diseases (Türkeş, 2020; IPCC, 2021; Işık et al ., 2025).

Animal-derived foods such as meat, milk, eggs, and fish can harbor microbes, primarily bacterial agents and toxins, that can cause foodborne illnesses. While viruses are responsible for the vast majority of foodborne illnesses, hospitalization and mortality rates are often associated with Staphylococcus. aureus , Escherichia coli and salmonella It is associated with bacteria such as spp . In aquaculture, biological hazards include bacteria, viruses, and trematodes , and significant public health threats from both local and foreign bacteria can be exacerbated by increased antimicrobial use resulting from intensive agricultural practices . This use, combined with antibiotic resistance, raises concerns that drug-resistant pathogens could enter the human food chain through direct contact or contaminated seafood. Furthermore, antibiotic residues can accumulate in aquatic species, leading to public health concerns regarding drug resistance and potential harmful effects. Parasitic infections are common in various fish species, particularly for those consuming raw or undercooked fish, with important genera such as Chlonorchis and Opisthorchis being of medical importance. Additionally, viral infections such as norovirus and hepatitis A and E are also prevalent. Contaminants pose additional risks , largely stemming from environmental pollutants entering aquaculture. Current risk assessments focus predominantly on bacterial indicators, which may not accurately reflect the public health risks associated with viral pathogens in aquaculture (Vergis et al ., 2021; Onmaz et al., 2020).

One Health and Chemicals

Heavy metals, pesticides, and biotoxins are prevalent in food systems, particularly in aquaculture, where numerous chemicals are used in production. These substances not only contribute to antimicrobial resistance but also pose risks to non-target species and the wider ecosystem; for example, problems such as microplastics that can be ingested by humans via seafood arise. Environmental hygiene is crucial in aquaculture , as improper waste management can lead to spoilage and microbial growth due to nutrient-rich conditions in water bodies. Personal hygiene of food processors is equally important, as inadequate practices can increase the risk of foodborne illness. Implementing quantitative risk assessment can help identify pathogens and implement effective safety measures throughout the food supply chain (Hook et al ., 2018; Hidayatai et al., 2021).

The One Health approach is essential to address the interconnected issues of food safety and security and to promote sustainable aquaculture practices that meet socio -economic demands. Aquaculture can promote employment and improve public health by providing nutritious food options, especially in low- and middle-income countries. Furthermore, understanding the complexity of organism health in aquaculture environments is crucial for managing biosecurity risks and preventing disease outbreaks, which necessitates the use of modern technologies for microbial hazard profiling (Işık et al ., 2025).

Environmental health issues stemming from climate change necessitate attention to pollution, wastewater discharge, and aquaculture practices with varying levels of ecological impact. For effective food safety and prevention of foodborne illnesses, rapid detection of contaminants is essential, and there are shared responsibilities among producers, regulators, and consumers to enforce safety standards and promote public health. Collaboration among stakeholders, including medical professionals and veterinarians, is vital to ensure food safety and comprehensively address concerns about chemical and pathogen contamination (Tsygankov et al ., 2016).

Heavy metals, pesticides, and biotoxins are prevalent in food systems, particularly in aquaculture, where numerous chemicals are used in production. These substances not only contribute to antimicrobial resistance but also pose risks to non-target species and the wider ecosystem; for example, problems such as microplastics that can be ingested by humans through seafood arise. Environmental hygiene is crucial in aquaculture , as improper waste management can lead to spoilage and microbial growth due to nutrient-rich conditions in water bodies. Personal hygiene of food processors is equally important, as inadequate practices can increase the risk of foodborne illness. Implementing quantitative risk assessment can help identify pathogens and implement effective safety measures throughout the food supply chain . The One Health approach is essential to address the interconnected issues of food safety and security and to promote sustainable aquaculture practices that meet socio -economic demands. Aquaculture can promote employment and improve public health by providing nutritious food options, especially in low- and middle-income countries. Furthermore, understanding the complexity of organism health in aquaculture environments is crucial for managing biosecurity risks and preventing disease outbreaks, which necessitates the use of modern technologies for microbial hazard profiling (Jacobs et al ., 2002; Hook et al., 2018). Additionally, environmental health issues stemming from climate change require attention to pollution, wastewater discharge, and aquaculture practices with varying levels of ecological impact. For effective food safety and prevention of foodborne illnesses, rapid detection of contaminants is essential, and there are shared responsibilities among producers, regulators, and consumers to enforce safety standards and promote public health. Collaboration among stakeholders, including medical professionals and veterinarians, is vital to ensure food safety and comprehensively address concerns about chemical and pathogen contamination (Hidayati et al ., 2021).

Conclusions

The What's that One Health perspective has been developed to manage the health of aquaculture and in particular , successful industry outcomes in the field of aquaculture . One Health approaches can be made applicable to aquaculture. Given the expansion and intensification of aquaculture climate change , and environmental degradation , this will likely broaden the scope of these risks and amplify their impacts and consequences . One Health approach is essential to address the interconnected issues of food safety and security and to promote sustainable aquaculture practices that meet socio-economic demands. Aquaculture can promote employment and improve public health by providing nutritious food options , especially in low - and middle-income countries . Furthermore , understanding the complexity of organism health in aquaculture Environments are crucial . for managing biosecurity risks and preventing disease outbreaks , necessitating the use of modern technologies for microbial hazard profiling .

REFERENCES

Bronzwaer , S. , Geervliet , M., Hugas , M. & Url , B. (2021). EFSA's expertise supports What's that Health policy needs . EFSA Journal , 19(5), e190501. https://doi.org/10.2903/j.efsa.2021.e190501 .

Carboni , S. , Kaur , G., Pryce , A., McKee , K., Desbois , A.P., Dick , J.R., ... & Hamilton, D.L. (2019). mussel consumption as a " food" first " approach to improve omega-3 status . *Nutrients* , *11* (6), 1381.

Chatham House. (2010). Shifting from emergency response to prevention of pandemic disease threats at source . London : Meeting report .

Hidayati , N.V. , Asia , L., Khabouchi , I., Torre , F., Widowati , I., Sabdono , A., ... & Syakti , A.D. (2021). Ecological risk assessment of persistent organic pollutants (POPs) in surface sediments from aquaculture system . *Chemosphere* , *263* , 128372.

Hook , S. E. , Doan , H., Gonzago , D., Musson , D., Du , J., Kookana , R., ... & Kumar, A. (2018). the impacts of modern- use pesticides on shrimp Aquaculture : An assessment for north eastern Australia . *Ecotoxicology and environmental safety* , *148* , 770-780.

IPCC, (2021). (Intergovernmental Panel on Climate Change). Climate change 2021: The physical science basis . Working Group I contribution to the IPCC Sixth Assessment Report. CambridgeUniversity Press ,

Işik, Ö. G. Y. , Babacan, O., & Taş, T. (2025) The Impact Of Global Warming And Climate Change On Agriculture And Livestock Farming From A One Health Perspective., Iksad Publishing Agriculture Forestry Farming Aquaculture Book

Jacobs , M. N. , Covaci , A., & Schepens , P. (2002). Investigation of selected persistent organic pollutants in farmed Atlantic salmon (Salmo salar), salmon aquaculture feed , and fish oil components of the feed . *Environmental science & technology* , *36* (13), 2797-2805.

Kelly , T.R. Machalaba , C., Karesh , WB, Crook , PZ, Gilardi , K., Nziza , J., Uhart , MM, Robles , EA, Saylors , K., Joly , DO, Monagin , C., Mangombo , PM, Kingebeni , PM, Kazwala , R., Wolking , D., Smith , W. & Mazet , JAK (2020). implementation What's that Health approaches to confront emerging and reemerging zoonotic disease threats : lessons from PREDIC. One Health Outlook, 2:1. https://doi.org/10.1186/s42522-019-0007-9 .

Onmaz, N. E. , Yildirim , Y., Karadal , F., Hizlisoy , H., Al, S., Gungor , C., ... & Simsek, E. (2020). Escherichia coli O157 in fish : Prevalence , antimicrobial resistance , biofilm formation capacity , and molecular characterization . *Lwt* , *133* , 109940.

Stentiford , G. D. , Bateman , I.J., Hinchliffe , S.J., Bass , D. 1., Hartnell , R., Santos , EM, ... & Tyler, C.R. (2020). sustainable aquaculture through the What's that Health lens. *Nature Food* , *1* (8), 468-474.

Tsygankov , V. Y. , Lukyanova , ON, & Khristoforova , N.K. (2016). the Sea of Okhotsk and the Bering Sea as the region of natural Aquaculture : Organochlorine pesticides in Pacific salmon . *Marine Pollution Bulletin* , *113* (1-2), 69-74.

Türkeş M. (2020). Effects of climate change on agricultural production and food security. Aegean Geographical Journal , 29(1): 125–14

Uzair, M. , Abid , A., Abid , MA, Sarfraz , MS, Badshah , T., Prince , K., ... & Mughal , MAS (2023). Zoonosis : an emerging link to antibiotic resistance under " one health approach ". *Zoonosis , Unique Scientific Publishers , Faisalabad , Pakistan* , *4* , 251-263.

Vergis , J. , Rawool , D.B., Malik, SVS, & Barbuddhe , S.B. (2021). food safety in fisheries : Application of One Health approach . *Indian Journal of Medical Research* , *153* (3), 348-357.

Zhang , X. X. , Liu , JS, Han, LF, Xia , S., Li , SZ, Li , OY, Kassegne , K., Li , M., Yin , K., Hu, QQ, Xiu , LS, Zhu , YZ, Huang , LY, Wang , XC, Zhang , Y., Zhao , HQ, Yin , JX, Jiang , TG, Li , Q., Fei , SW, Gu , SY, Chen , FM, Zhou , N., Cheng , ZL, Xie , Y., Li , HM, Chen , J., Guo , ZY, Feng, JX, Ai , L., Xue , JB, Ye, Q., Grant, L., Song , JX, Simm , G., Utzinger , J., Guo , XK & Zhou , XN (2022). Towards a global What's that Health index : a potential assessment tool for What's that Health performance . Infectious Diseases of Poverty , 11, 57. https://doi.org/10.1186/s40249-022-00979-9 .