BURSA ULUDAĞ ÜNİVERSİTESİ ZİRAAT FAKÜLTESİ DERGİSİ
Journal of Agricultural Faculty of Bursa Uludag University
e-ISSN 2651-4044
https://dergipark.org.tr/tr/pub/bursauludagziraat
http://www.uludag.edu.tr/ziraatdergi
Aralık/2025, 39(2), s. 453-469

DERLEME REVIEW

Geliş Tarihi (Received): 05.12.2024
Kabul Tarihi (Accepted): 02.06.2025

Use of Machine Learning in Olive Cultivation: A Review [A]

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Abstract: Together with the globalization and climate change, rapid technological developments are also driving research into agriculture. Considering the current state of the world's population, agricultural sustainability is one of the key factors for minimizing food waste and shortages. Thanks to technology improvements, smart agricultural practices can produce a range of chances in this context, promoting the notion of regional goods being producible in different regions. In this study, studies were carried out in the field of machine learning of the cultivation of olive fruit. There are detailed analyses of the existing studies based on the year, region and methodologies used. While commonly referred to be a Mediterranean product in literature, it may flourish with the same quality anywhere with a technological tweak. Furthermore, apart from emphasizing the significance of machine learning in optimizing product quality, it is anticipated that various forms of learning will be more effectively controlled with social and governmental support.

Keywords: Machine learning, Olive cultivation, Olive yield, Smart agriculture.

[A] This study was supported by Scientific and Technological Research Council of Türkiye (TUBITAK) under Grant Number 123N549. The article has been prepared in accordance with research and publication ethics.

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Atıf/Citation: Sarpkaya, D., Kesici, M., Tacer-Caba, Zeynep., Kahraman, F., Temur, G.T. 2024. Use Of Machine Learning for Olive Cultivation: A Review. *Bursa Uludag Üniv. Ziraat Fak. Derg.*, 39(2), 453-469. https://doi.org/ 10.20479/bursauludagziraat.1589035.

Zeytin Yetiştiriciliğinde Makine Öğrenmesi Kullanımı: Derleme

Öz: Küreselleşme ve iklim değişikliğiyle birlikte, hızlı teknolojik gelişmeler de tarıma yönelik araştırmaları yönlendirmektedir. Dünya nüfusunun mevcut durumu göz önüne alındığında, tarımsal sürdürülebilirlik gıdaisrafını ve kıtlığını en aza indirmek için temel faktörlerden biridir. Teknolojik gelişmeler sayesinde, akıllı tarım uygulamaları bu bağlamda çeşitli fırsatlar üretebilir ve bölgesel olarak anılan ürünlerin farklı bölgelerde üretilebilmesi kavramını teşvik edebilir. Bu çalışmada, zeytin meyvesinin yetiştirilmesinin makine öğrenimi alanında çalışmalarına odaklanılmıştır. Mevcut çalışmaların yıl, bölge ve kullanılan metodolojilere göre ayrıntılı analizleri bulunmaktadır. Literatürde genellikle Akdeniz ürünü olarak anılsa da teknolojik gelişmeler ile her yerde aynı kalitede ulaşılabilir. Ayrıca, ürün kalitesini optimize etmede makine öğreniminin önemini vurgulamanın yanı sıra, çeşitli öğrenme biçimlerinin sosyal ve hükümet desteğiyle daha etkili bir şekilde kontrol edileceği öngörülmektedir.

Anahtar Kelimeler: Makine öğrenmesi, Zeytin yetiştiriciliği, Zeytin verimi, Akıllı tarım.

Introduction

Farming plays a critical role in ensuring worldwide food security and economic stability, making substantial contributions to the well-being of people by supplying energy and food. The fact that family farms account for more than 98 percent of all farms on a global scale, cultivating more than half of all agricultural land, and making a significant contribution to the production of food is evidence of the relevance of agriculture (Graeub et al., 2016).

More particularly, olive production, a technique that is strongly placed in the heritage of the Mediterranean. Olive trees and their products possess significant historical and cultural origins within the civilizations of the Mediterranean. Olive and olive oil have been symbolic of prosperity, wisdom, and harmony for millennia, according to ancient texts. Olive, which is also called as *Olea europaea* has been crucial in influencing the economics, environments, and cultures of several regions, especially in this particular region. Olive cultivation shows its importance in environmental, economic, health and cultural areas. In terms of environmental benefit, since they are drought-resistant, helping to prevent desertification and soil erosion in arid areas (Mezghani et al., 2021). Significant economic contributions are made to these regions by the olive oil industry, which provides a livelihood for millions of individuals by way of international trade and domestic consumption. Olive oil consumption has been correlated with reduced risks from cardiovascular diseases and specific forms of cancer thanks to its substantial monounsaturated fat and antioxidant content. (Marcelino et al., 2019).

Together with the technological innovations in the world, it is inevitable that there will be developments in the field of agriculture. Consecutively, opportunities and challenges will follow these developments. Considering climate change adaptability, the compatibility of olive trees can be at a relatively good level. Resilience to changing climatic scenarios makes them an essential crop for global agriculture in response to climate change. Changing patterns of rainfall and rising temperatures, according to studies, may limit the suitability of traditional olive-growing regions, which in turn may have an effect on the output of olive oil as well as its quality. Benlloch-González (2019) brought attention to the olive fruiting cycle, which occurs at greater temperatures when global warming circumstances are simulated. The outcome includes reduced fruit size, decreased pulp/stone ratio, lower oil yield, and anthocyanin content. A similar result was found in another study in terms of water supply. Total amount of oil in the olive product, together with the size of the olive will be affected by insufficient available water (Beltran et al., 2004).

It is possible that it is of vital importance to conduct research into the factors that influence the yield of agricultural products and agricultural production. In addition, there is a possibility that agricultural techniques will go through a change in the very near future. Changes in the agricultural technologies will also change the direction of agricultural trends (Dhanaraju et al., 2022). These changes consist of the application of a wide variety of machinery and equipment, the utilization of inorganic fertilizers, and the reduction of the application of pesticides. In order to achieve the goal of increasing agricultural production levels while simultaneously lowering expenditures, this development represents a transition toward methods that are more resource efficient. As a consequence of this, environmental friendly agricultural solutions are expecting to be increased (Dhanaraju et al., 2022), which in turn encourages the expansion of the economy.

Machine learning (ML) is a branch of the field of artificial intelligence (AI) that allows computers to have the ability to learn and improve themselves without human intervention. The implementation of machine learning techniques has made it possible to make decisions that are more evidence-based in a variety of domains, including but not limited to the fields of health care, manufacturing, education, financial modelling, policing, and marketing (Jordan and Mitchell 2015). The convergence of machine learning and agriculture has presented an original and revolutionary strategy to transform conventional farming methods, elevating the efficiency and environmental impact of various crop production. ML is transforming agriculture by improving the management of crops, livestock, and resources.

The quality of agricultural products as well as food safety are the main factors determining the sustainability of agricultural production (Tüccar et al., 2022). Enhancing quality and productivity of the crop is conceivable with accurate forecasting of agricultural production, disease detection and categorization thanks to ML (Liakos et al., 2018). ML also enables quantifying animals' health and productivity of livestock management (Liakos et al., 2018). These techniques are used in water and soil management to encourage the adoption of sustainable farming methods, while attempting to improve the prediction of irrigation and soil moisture levels. (Sadiku et al., 2018). By analyzing data collected from sensors and satellite photos, precision agriculture leverages machine learning to enhance farming techniques, such as irrigation and fertilization (Sharma and Abrol 2024). Because of data content and necessity of huge datasets, ML algorithms continue to face challenges besides its great potential. Therefore, integration of ML and agriculture related studies are proceeding importance (Condran et al., 2022)

One of the motivations of this study is that olive cultivation is an important agricultural activity that contributes to both economic and cultural heritage, especially in the Mediterranean region (Muzzalupo et al., 2009). Climate change significantly impacts olive phenology, yield, and pest dynamics, necessitating advanced monitoring and predictive tools (Milicevic et al., 2020, Fraga et al., 2020). European olive-growing regions have tendency to adapt globalization, focusing on technological changes and professional management (Rodriguez-Cohard et al., 2020). Technologies enable precise monitoring and management of crops, optimizing resource use and reducing environmental impact (Messina and Modica, 2022). In addition, aligning with EU regulations, such as the Protected Designation of Origin (PDO) framework, can improve the competitiveness and quality of olive products which helps to promote sustainable practices and meet consumer expectations for traceability and authenticity (Hinojosa-Rodriguez et al., 2014). As another motivation, in order to assure accurate management and prompt interventions of olive trees, machine learning can enhance the authentication of phenophases and stressors (Navrozidis et al., 2023). ML optimizations can also make possible phenological projections and base temperature settings which is very important role during climate change context (Oses et al., 2020). Considering the importance of olive farming's economic and cultural situation in Mediterranean, studies related to creation of adjustment and reduction policies to assure the sector's resilience to climate change is very vital (Villalobos et al., 2023).

Material and Methodology

Definition of review scope

This study will focus on studies that have been conducted with a view of increasing yield in fields that are associated with olive trees, olive fruit, and olive oil. Artificial neural network (ANN) applications that are based on machine learning and multi-criteria decision-making approaches are taken into consideration in the analysis of strategic decisions for the purpose of studying the factors that affect productivity. This is carried out for the purpose of achieving the previously stated objective.

Literature search

Prior to moving on to the phase of the literature review process that deals with the processing of data, keywords were identified, and the time interval that was going to be included was chosen. Throughout each phase of the research, the concepts of "olive cultivation" and "machine learning" have been used as keywords. Not only olive cultivation, but also studies on olive oil production and procedures, olive mill, and machine learning for other fruit and vegetable products were put into use during the screening process. Figure 1 indicates the flow of the literature search.

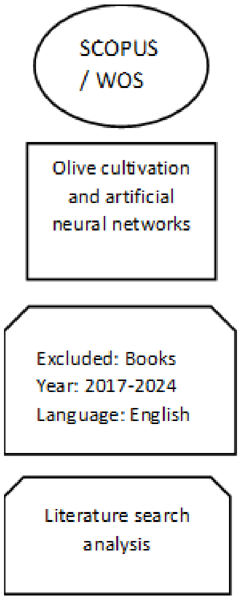


Figure 1: *Flow of the methodology*

The process of evaluation included not just olive cultivation but also studies on olive oil production and procedures, olive mills, and machine learning research for other fruits and vegetables products. This was done in order to have a more comprehensive understanding of the topic.

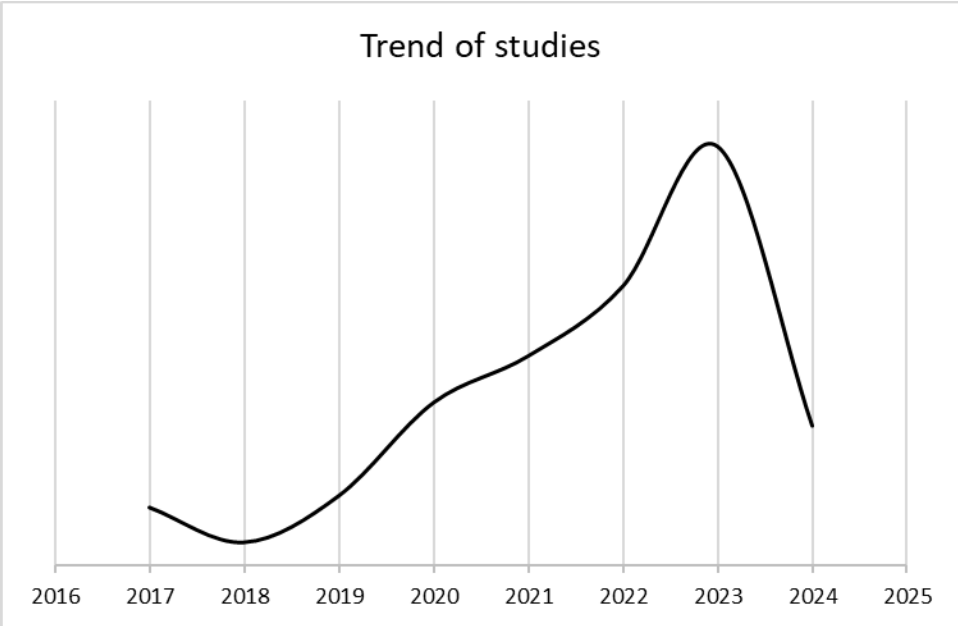
As mentioned earlier, it was noted that processes were carried out on the Scopus and WOS databases. The time period covered by the reviews is from 2018 to 2024; books and studies in the literature written in languages other than English are not included. During the Scopus research as a first stage, a total of 779 results were retrieved by using only keywords without any filtering being carried out. Among these, there was one publication that was released in French. Following that, time interval filtering was implemented, and 401 studies were obtained pursuing this process. However, due to the fact that certain studies were not subscribed to, a total of 284 articles were reached out of 401 studies. Studies other than those mentioned in the preceding paragraphs, which are not related to the field of reviewing, are also not included. 259 papers were initially discovered through the use of the web of science search. In a similar manner, the number of publications dropped to 220 after the time interval was filtered. After the two papers that were published in Chinese and unrelated studies which are not related to agriculture or machine learning were excluded, the process of analysis began with 126 articles on the basis of open access studies.

Table 1. List of journals

Scopus	Number of articles	Wos	Number of articles
Agricultural Water Management	1	8th Pemwn Conference	1
Agriculture, Ecosystems and Environment	1	Acta Technologica Agriculturae – Sciendo	1
Alexandria Engineering Journal	3	Agricultural and Forest Meteorology	1
Analytica Chimica Acta	1	Agriculture-Basel	1
Biocatalysis and Agricultural Biotechnology	2	Agriengineering	1
Biochemical Engineering Journal	1	Agronomy-Basel	2
Bioresource Technology	3	Alzheimers Research and Therapy	1
Biosystems Engineering	2	Antioxidants	1
Chemosphere	1	Applied Science	1
Computers & Industrial Engineering	1	Communications Biology	2
Computers and Electronics in Agriculture	12	Computers and Electronics in Agriculture	1
Computers, Environment and Urban Systems	1	Ecosphere	1
Construction and Building Materials	1	European Food Research and Technology	1
Current Research in Green and Sustainable Chemistry	1	Fermentation-Basel	1
Ecological Modelling	1	Foods	4
Energy	1	Frontiers in Chemistry	1
Engineering Applications of Artificial Intelligence	1	Frontiers in Plant Science	3
Environmental Technology & Innovation	1	Human Genomics	2
European Journal of Operational Research	1	IEEE Access	2
Expert Systems with Applications	1	Insects	1
Food Chemistry	5	International Agrophysics	1
Food Control	2	I2CNP Conference	0
Information Processing and Management	1	International Research and Innovation Summit	1
International Journal of Applied Earth Observation and Geoinformation	1	Journal of Consumer Protection and Food Safety	1
Internet of Things	1	Journal of Food Quality	1
Journal of Agriculture and Food Research	1	Journal of Sensor and Actuator Networks	1
Journal of Contaminant Hydrology	1	Journal of Universal Computer Science	1
Journal of Drug Delivery Science & Technology	1	Land Degradation and Development	1
Journal of Environmental Management	1	Molecules	2
Journal of Food Composition and Analysis	2	Optical Sensing and Detection VII	2
Journal of Hydrology	1	Pest Management Science	1
LWT - Food Science and Technology	2	Phytochemical Analysis	1
Measurement	1	Processes	1
Measurement: Sensors	1	Remote Sensing	5
Microchemical Journal	1	Scientific Reports	1
Pharmacology & Therapeutics	1	Sensors	6
Procedia Computer Science	1	Water	1
Remote Sensing Applications: Society&Environment	1	Wireless Communications &Mobile Computing	1
Remote Sensing of Environment	1		
Renewable Energy	1		
Science of the Total Environment	2		
Scientia Horticulturae	1		
Sensors and Actuators: B. Chemical	1		
Sustainable Computing: Informatics&Systems	1		

Data processing

The application of artificial neural networks/machine learning in olive cultivation is the primary emphasis of the study that is being conducted. Publications written in languages other than English were not considered. A particular emphasis was placed on papers that were published between the years 2018 and 2024. These publications included not just those that dealt with artificial neural networks but also those that examined machine learning. In addition, articles and review publications on fruits and vegetables other than olives that are notable within the area of the research were included. These publications and review publications covered similar subjects linked to olives.



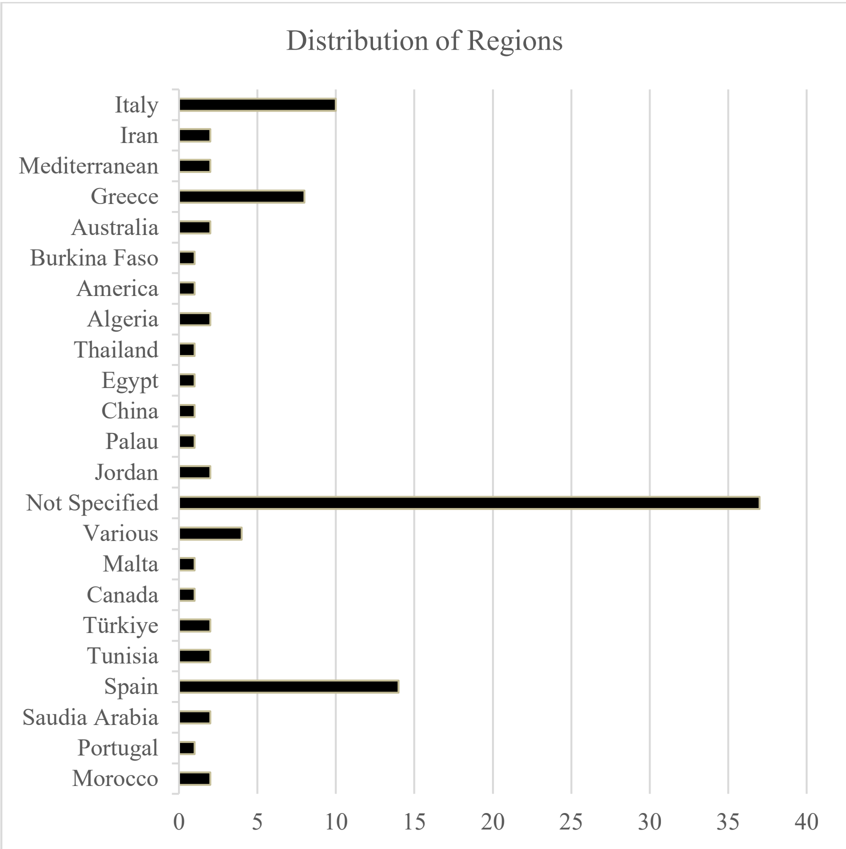
Graph 1. *Yearly trend of literature*

The titles of the publications, the years in which they were published, the artificial neural network or machine learning design that was utilized, the parameters that were working, the standards for performance, the field in which the study was carried out, the purpose of the study (the classification was made in ten categories; classification, efficiency, content quality, cultivation, disease detection, habitat suitability, pollution, prediction and yield estimation), the stages of the plant (olive, olive oil, olive mill and other), and a brief summary of the results are the primary areas of focus during the reviewing process.

Findindg and Discussion

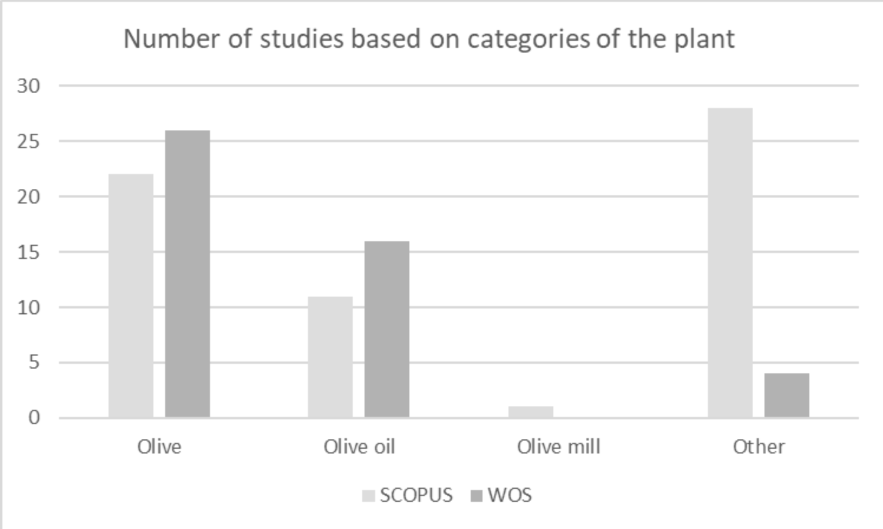
Use of Artificial Neural Networks in olive cultivation

Olive tree farming, oil extraction, disease diagnosis, and environmental sustainability are covered in research papers. The papers mostly use AI, machine learning, and advanced modelling for agricultural and environmental applications. Important topics include neural network-based olive fruit and olive oil identification in terms of different aspects (Aquino et al., 2020; Dumenci et al., 2021; Rajković et al., 2023; Senizza et al., 2023 Issaad et al., 2024; Miho et al., 2024), olive tree environment suitability modelling for optimal lipase production (Menezes et al., 2021), olive leaf disease identification (Noon et al., 2020; Alshammari and Alzahrani 2023; Alshammari et al., 2023), extra-virgin olive oil authentication, olive cultivar classification (Skiada et al., 2023), olive oil adulteration detection and quantification (Pradana-Lopez et al., 2022), and olive disease detection (Zhang et al., 2019; Alshammari and Alkhiri 2023; Poblete et al., 2023).



Graph 2. *Distribution of studies by country*

These studies demonstrate the importance of data-driven strategies, environmentally responsible agricultural methods, and sustainable agricultural practices considering use of sources such as water and soil, as well as improvements in olive fruit yield estimation (He et al., 2022; Aquino et al., 2023), anthracnose detection (Fazari et al., 2021), and chlorophyll accumulation optimization (Guendouzi et al., 2024). Machine learning, artificial intelligence, and advanced modelling can be done by using different techniques like sensors. Researches indicated that image-based applications are used widely (Fazari et al., 2021; Azgomi et al., 2023; Poblete et al., 2023; Miho et al., 2024) through machine learning applications. As seen in Graph 2, around 40% of these studies did not indicate the location of the study that conducted. Remaining studies have belonged to variety of countries like Morocco, Saudia Arabia as indicated in Graph 2. Spain, Italy and Greece are the most studies are done.



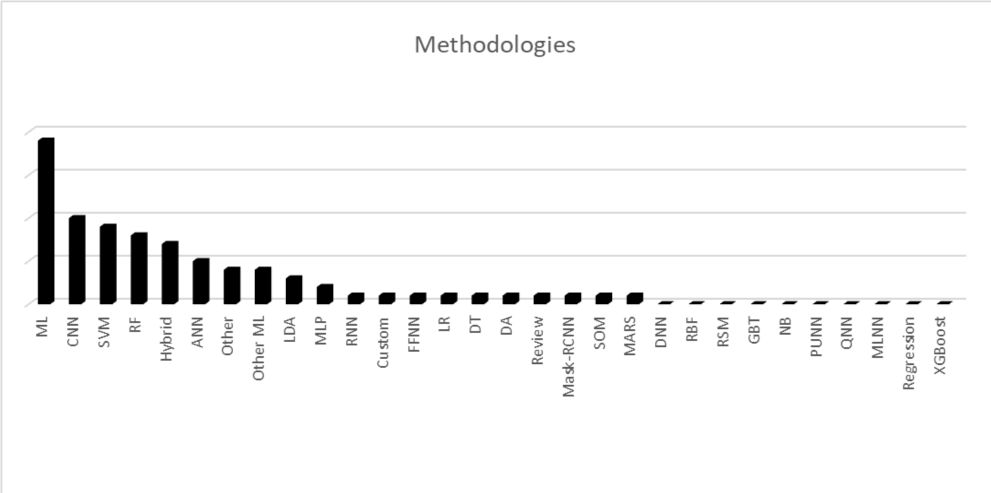
Graph 3. *Distribution of studies according to different categories of olives*

When examining the research on these specific topics each year, it becomes evident that there is a consistent upward tendency throughout time. Graph 3 illustrates the specific category of fruit at which the studies were conducted. The categories are classified as olive, olive oil, olive mill and other and not mentioned. The term "other" denotes that it corresponds to a product other than olive related.

Table 2. Distribution of studies' categories based on database

Category	Scopus	Wos	Total
Olive	22	26	48
Olive Oil	11	16	27
Olive Mill	1	0	1
Other	28	4	32

Based on the available literature, it is obvious that different machine learning algorithms have been used in a variety of studies. Although the vast majority of research do not include any specific details regarding the technique that was employed, convolutional neural networks (CNN), support vector machines (SVM), random forest (RF) are implemented. In recent years, CNN have become popular in the image processing domain. With its layered structure, this deep learning architecture is able to understand spatial correlations in data with high accuracy rates.



Graph 4. *Distribution of methodologies*

However, the SVM algorithm is also widely applied in classification tasks, attempting to determine the optimal line of separation by transforming data into a high-dimensional space. Additionally, the RF technique enhances the overall performance of the model while lowering the danger of over-adaptation by combining a number of decision trees. Consequently, every approach in machine learning applications including CNN, SVM, and RF has a specific function for a variety of data sources and goals. In the graph4, "hybrid" point that is shown the high concentration of these kind of studies, which is another point of interest. The research approaches that were classified as hybrid used a combination of more than one algorithm during the duration of the research and occasionally conducted comparisons. An example of this would be the combination of SVM and RF.

As mentioned in the previous sections; while performing the reviewing analysis, the studies were divided into 10 categories based on their objectives. One of these categories is classification. An olive classification model by Skiada et al. (2023) can accurately distinguish between different olive variables based on their oil's chemical composition. The need for measures to ensure the authenticity and traceability of extra virgin olive oil drove this development. The objective of this study was to precisely determine the olive cultivars and their geographical origins by employing sophisticated artificial intelligence (AI) techniques. A total of 385 olive oil samples from Greece and Italy were collected over a span of two harvest years. The sterol and fatty acid content was analyzed by chemical analysis. The model achieved an accuracy of 81% in distinguishing between Greek and Italian cultivars. The classification of the two Greek cultivars was completely accurate. In terms of geography, the model achieved a 99% accuracy rate, with only one instance of misidentifying Greek and Italian data. Based on study of AI, particularly XGBoost is highly preferrable. In order to enhance and broaden the applicability of the model, it is necessary to increase the number of cultivars and sample sizes.

The second category of analysis focuses on the development of methodologies for olive yield estimation. This approach uses computer vision to examine the visual characteristics of olive trees, rather than relying on indirect variables. Precise estimations of crop output enhance the profitability and sustainability of olive cultivation. Number of images with sample points selected and every image has a total of eight visual characteristics such as fruit number, area. The neural network is a fully connected feedforward multilayer perceptron with 16 neurons with 1 output layer which predicts the yield. The training set consists of 37 sample points, which corresponds to a total of 74 photos. The validation set, on the other hand, contains 10 sample points, equivalent to 20 images. The findings demonstrate that this approach has the ability to meet the standards set by the industry and enhance the efficiency and profitability of olive production. Subsequent research will confirm the accuracy and reliability of the findings by doing experiments in various orchards and during different seasons. Additionally, the study will incorporate fully automated techniques for capturing images.

The applications of smart farming are still in their infancy from a theoretical standpoint, and they need to undergo a number of different kinds of innovations. The gradient-boosting tree, neural networks, linear regression, and random forest models are thought to be the most often used models, according to Castro et al. (2020). In addition, there is a significant need for advancements in the field of disease detection approaches that involve computer imagery, drones, and automated machines. Artificial intelligence (AI) models that are more advanced deserve to be the focus of future research (He et al., 2022). Deep learning techniques and reinforcement learning are two examples of AI models that might be developed and integrated into AI systems. Since machine learning and deep learning technologies provide raised accuracy and speed (Louppis and Kontominas, 2024) in fruit detection, yield prediction can benefit from their application.

Integrating information technologies into the agriculture industry has the capacity to facilitate the sector's progress. The industry must find a middle ground between technological advancement and economic viability, as demonstrated by the use of affordable technologies like cellphones for small orchards and agricultural vehicles with reduced costs for predicting crop yields. According to He et al., (2022), commercial feasibility and adoption of the product in less developed countries are extremely important. Louppis and Kontominas (2024), propose that promoting the adoption of emerging technologies like block chain would be advantageous for establishing traceability systems that are both secure and transparent. In addition to that, Machine learning (ML), deep learning (DL), remote sensing, and unmanned aerial vehicles (UAVs) are expected to decrease the time needed for data collection in large-scale orchards, be non-intrusive, and enhance the precision of yield estimation (He et al., 2022).

Stricter standards for determining olive oil authenticity should be implemented in order to protect consumers and actual manufacturers. The implementation of modern analytical procedures and standards must be supported by government policies. (Louppis and Kontominas, 2024). Similarly, stricter laws for olive oil authentication need to be implemented and supervised for the purpose of protect customers and real producers. Government policies to the implementation of advanced analytical techniques and standards can be supported. (He et al., 2022). Louppis and Kontominas (2024) highlighted the importance of integrating advanced technology and promoting collaboration among many stakeholders to enhance the quality, truthfulness, and sustainability of olive oil production and distribution.

Research undertaken for a number of specialized aims has led to the conclusion as the implementation of image-based applications, chemical content quality, and disease detection are all very detailed. For the purposes of this analysis, it is possible to consider the fact that olive oil and other crops necessitate a substantial amount of research which was conducted using the term olive farming. The use of machine learning and deep learning technology in olive cultivation has resulted in substantial transformations across social, sectoral, and governmental dimensions. Social findings indicate that the shift from manual labour to automated systems in yield prediction has improved accuracy and efficiency but also highlights challenges in data processing and analysis from multiple sensors. This transition has resulted in a decrease in labour expenses and has helped to resolve labour scarcity issues. It can be argued that small-scale farmers have limited access to new technology, and this can be attributed to the high costs associated with equipment and maintenance, leading to a digital divide. Considering the obstacles in the integration of smart agricultural technologies, there are concerns about the lack of advanced technical systems and data protection in rural areas. As a result, the necessity of education and training initiatives is emphasized for farmers to adapt to adopt and use these new technologies. From a sectoral findings perspective, the focus is on integrating advanced technologies such as remote sensing, UAVs, and machine vision systems for large-scale orchards, which increase yield estimation accuracy and economic viability. However, for larger areas as well as smaller orchards, it is crucial to strike a balance between technical progress and cost-efficient alternatives. The government findings highlight the role of government initiatives in advancing agricultural technologies, highlighting the importance of funding and support from national and provincial science foundations. As a way of government incentives, it is to improve smart agricultural management by directing cooperation between engineers and gardeners to work together across legislation and disciplines.

Conclusion

There are now 285 items that have been officially recognized and registered with the status of Protected Geographical Indication (PGI) and Protected Designation of Origin (PDO) stated by Louppis and Kontominas (2024). Out of these, there are 147 items classified as wines, 50 items classified as fruits, vegetables, and cereals, 33 items classified as olive oils and olives, 25 items classified as cheeses, 11 items classified as spirits, 4 items classified as meats, and 3 items classified as honeys. Despite the fact that olives and olive oil are considered to be a tradition that dates back to ancient times, this demonstrates that their significance is still present in contemporary society. In comparison to a wide variety of processed and unprocessed fruit and vegetable products, it contains more than twenty percent of the protected area. On the other hand, agricultural regions are receiving increased attention as a result of climate change and food shortages.

It is possible to draw conclusions from the literature regarding the significance of olive cultivation and olive output when these two scenarios are taken into consideration. Furthermore, the consequences of emerging technology in the field of agriculture should not be neglected nor should they be disregarded. On the other hand, taking into account the viewpoint of those who are employed in the agricultural sector, it is possible that a number of applications could be necessary, or that certain applications will be launched on a governmental basis with the objective is to build effective communication and collaboration with individuals in the agriculture sector and individuals from diverse backgrounds, while staying up-to-date with technology advancements and ensuring clear understanding among all parties involved. Mainly due to the fact that it is evident that technology advancements would make it possible to boost productivity in the field of agriculture not only through the employment of updated vehicles but also through the utilization of a variety of approaches.

According to the findings of this study, which is centred on olive cultivation and machine learning, it is possible to assert that the body of literature in this area is undergoing a trend of development. There has been a general trend toward an increase in the volume of scientific research conducted in this field from 2018 to the present day, more particularly between 2018 and 2024. As far as the locations where the research is carried out in the literature, it is clear that these studies are also focused in areas where there is a great quantity of olive production. This is a pattern that can be observed. Spain has the highest rate, which stands at 15%. Italy is next with a percentage of 11%, followed by Greece with 8%. Furthermore, research conducted in the Mediterranean region accounted for 2% of the total area, in addition to the three countries mentioned before which collectively represent 34% of the area. Turkey, Iran, Morocco, Australia, Algeria, Jordan, Tunisia, and Saudi Arabia all have a 2% share. Four percent of the studies show that research has been conducted in many regions.

In the future, any dimensions can be added to methodology in terms of broader view as machine learning. Although there is extensive research being carried out in areas that continue to advantage from the favourable conditions for olive farming. However, it is also reasonable to expect that other regions will also develop research on olive cultivation due to climate change.

Acknowledgements

This study was supported by Scientific and Technological Research Council of Türkiye (TUBITAK) under Grant Number 123N549. The authors thank TUBITAK for their support. The article has been prepared in accordance with research and publication ethics.

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