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APPLICATION OF ARTIFICIAL INTELLIGENCE TECHNOLOGIES IN VITICULTURE

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Abstract

Currently, artificial intelligence (AI) is widely used in many areas in industry, agriculture, health and even in our everyday life. In agriculture, AI is used for smart farming and is a crucial tool to create sustainable food systems. A particular area of interest in agriculture where AI is being used successfully is viticulture, for example to reduce workload and allow focus on winemaking efficiency, productivity, and vineyard yield. The present review aims to provide an overview on the current uses of precision viticulture techniques and in particular geographic information system (GIS) in viticulture and winemaking, with a detailed focus on the production of high-quality wines.

Key words**:** *artificial intelligence, agriculture, GIS, viticulture, winemaking*

INTRODUCTION

Agriculture is one of the oldest and most important occupations in the world, with a history that began thousands of years ago. It is the science and art of cultivating plants and raising animals.

The different techniques and technologies used in agriculture have improved over time. Modern agronomy technologies, technological developments in plant growth, agrochemicals such as pesticides and fertilisers have increased yields while causing environmental damage. With the increase in global population and the expansion of inhabited areas, the areas used as agricultural land have become smaller. At the same time, the interest shown in agriculture today is much lower than it used to be. With the migration of people from village to city, the interest in agriculture has decreased; people increasingly prefer to buy ready-made products instead of cultivating them in their own garden the way they used to.

Geographical Information System

The Geographic Information System (GIS) proves to be an intuitive and valuable tool for digitally modelling agricultural fields. Through GIS technology, AI contributes to increasing the efficiency of the wine industry by facilitating the production of healthier grapes, pest detection and control, plant disease identifications, the monitoring of plant (vine) growth and soil assessment, the provision of weather forecasts, the characterization of wine quality, and even the manufacture of storage barrels.

The generally accepted definition of GIS is a computer system that analyses and displays geo-referenced information using data attached to a single location.

GIS is a system that creates, manages, analyses, and localises different types of information, connecting them to a map and integrating the location data with all sorts of thematic data. The process establishes a basis for different layers, analysing the content for use in science and other domains, such as telecommunications, health, education, insurance, public safety, sustainability, transportation, government, retail, water, natural resources, real estate, petroleum, public safety, etc.

GIS facilitates better understanding of geographic patterns, relationships, and context. Among the benefits of using GIS are improvements in communication, management, and decision making.

GIS allows its users to visualise many and different types of data on one map, such as streets, buildings, fauna and, in this case, vineyards and crops. With the help of GIS and AI, it is possible to monitor each vineyard in quasi-real time, oversee the behaviour of employees, or identify vegetative problems (leaf diseases, pests), keep track of the vineyard's history regarding pests, diseases, the type, quantity, and location of applied fertiliser, and assess whether some portions of the vineyard need more water than others. AI can even help in forecasting.

Artificial Intelligence

"Artificial life" is the name given to the new discipline that studies "life" by trying to recreate biological phenomena from inside computers or other "artificial" environments [52]. This new discipline combines the analytical approach of traditional biology with a synthetic view that seeks to organise systems that behave similarly to living organisms rather than to study biological phenomena separately to observe their behaviour. The advances in neurology in recent decades have been spectacular, especially those related to the properties of neurons. In the psychology field, new behavioural data have appeared that have revealed many aspects and characteristics of psychological abilities, such as visual perception and memory [6]. Thus, by understanding more about the nature of the brain and the principles that govern its activity, we can also understand different mental functions, such as perception or learning. By understanding the functioning of the human brain and its central nervous system, we can also understand how artificial neural networks (neural networks) appeared and were developed. The idea behind the founding of the artificial intelligence field claims that intelligence can be described and defined so precisely that it can even be simulated by a computer. Most specialty books define artificial intelligence as "the study and design of intelligent agents" (an intelligent agent is defined as a system that perceives the environment and/or acts in such a way as to increase its chances of success) [68]. AI subdomains are based on issues such as reason, knowledge, perception of objects and feelings, learning, communication, etc. In 1955, the most convenient/accepted definition of artificial intelligence was given by John McCarthy [39]: "a machine that behaves in a way that could be considered intelligent, if it were human." One of the main features of artificial intelligence is the ability to constantly improve and learn with or even without help. Alan Turing claimed that artificial intelligence will be achieved when in a conversation we will not be able to tell the difference between a machine/robot and a real person. In 1950, he created the Turing test, which involves two persons and a robot/machine. The first person asks a series of identical questions to both the second person and the robot. Based on the answers, the questioner must figure out who the robot is. If the questioner cannot tell the difference between the person and the robot, then the robot has passed the test and can be said to think.

Edourad Claparede [64] considered intelligence as the ability to adapt quickly to new situations. Being considered intelligent in the living world means one has the ability to communicate with other individuals, to process the information received, to make plans, to establish "smart" relationships and contacts, etc. It is believed that "the essence of life lies in its intelligence," expressed by the ability to discern and process information. Intelligence should not be mistaken for human intellectual capacity, which involves abstract thinking, elaboration of concepts, planning, etc., using verbal symbols. There are

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numerous techniques that are relevant to AI, such as neural networks, genetic algorithms, logic programming, fuzzy logic, qualitative reasoning, expert system, etc.

According to the *Encyclopedia Britannica* (1997) [40] (McGraw Hill, also in 1995 [14]), there are several perspectives on this concept, among which include:

-From the perspective of intelligence—AI is the capacity of computers and/or robots to perform tasks that are usually associated with humans, such as reasoning, discovering, generalising, adapting, and learning from previous experience;

-From the perspective of the philosophy of reason—there have been remarkable advances in the speed of electronic computers; therefore, many philosophers have concluded that a proper program and memory can think intelligently; thus, the term artificial intelligence indicates the area of investigation that seeks to develop computers gifted with such capabilities;

-From the perspective of computer science—robots, whose construction requires the collaboration of specialists in several fields. As many robots are designed to perform functions often performed by humans, many aspects of building robots fall into the realm of artificial intelligence. Example: AI is used to design robot programs that can "react" to unforeseen situations (for example, a robot used on an automatic assembly line must "know" how to pick up incorrectly oriented products or recognise defective ones).

-From the perspective of computer science—expert systems, such as error diagnosis systems [31], meaning all the steps from diagnosing human diseases to diagnosing malfunctions in a space shuttle that are built on the principle of expert systems. The knowledge of human experts is stored and represented as basic knowledge with rules that can be applied to solve possible problems. An interface allows the user to name the symptoms and clarify the problem by answering questions asked by the system. The main goal is for the user to discover the solution to the problem.

Expert systems are the biggest success of artificial intelligence and are expected to increase their area of applicability in the future. There are modernists who are against the use of AI, claiming that it will transcend the limits of progress and transform humanity in such a way that will eventually capture and dominate it, ultimately "swallowing" it completely. One purpose of the artificial neural network (ANN) is to copy the human brain's ability to recognise shapes and patterns. The field of use for ANNs is very wide: identifying fingerprints, faces, and signatures [37], forecasting in medical diagnosis [10] and the economy [46], and predicting human behaviour [36]. An ANN has the ability to learn and to abstract [50], which are very important skills if the abstraction rules of the process of recognition are unknown to the user [56]. ANNs are also used to determine different (wine) aromas. The human brain has the ability to extract information from complex olfactory impressions. Technologies, including robotics, computer vision, and machine learning, have been developed to assess beverages such as beer and sparkling wine [11,60].

Machine Learning

Machine learning is the study of computer algorithms that can improve automatically through experience and the use of data [43, 45]. Research in the fields of artificial intelligence, machine learning, and deep learning is ongoing and progressing rapidly. These are concepts that have been around for decades, but we have only been hearing of them lately because of increasingly powerful computers and the mounting demands that people are making of their accessories and gadgets. Artificial intelligence is the technology for creating computer systems that are considered "smart". Machine learning is a more restrictive discipline that involves creating systems capable of learning from the examples and data they receive. There is common ground between these two concepts; machine learning is the part of AI that refers to the machine's ability to learn on its own. Machine learning-based programs can learn to recognise various trends and make predictions based on stored information [53]. IBM, Microsoft, Amazon, and Google are companies with complex machine learning platforms that operate with mathematical algorithms and are able to manage large amounts of data, learn on their own, and refine their actions. Machine learning differs from AI namely in that AI should act completely independently, whereas machine learning-based systems are under human control and run within well-established parameters. Deep learning was developed as an extension of machine learning and thus artificial intelligence, and it is based on a large amount of data introduced into a computer system through neural networks.

Deep learning can analyse information in greater detail. It also has the ability to remember its past actions and to learn from its own behaviour. Examples of deep learning applications include self-driving car navigation systems, the Google DeepMind system, fraud detection, spam, voice and handwriting recognition, image search, and translation.

Viticulture

Viticulture is the science of vine agrobiological characteristics and their study in which the goal is to continuously develop and improve cultivation technologies to obtain large amounts of high-quality crops. It deals with the cultivation of vines to obtain grapes. Viticulture has spread widely throughout the world, and many countries today are producing wine. The viticulture industry is one of the most important industries in countries that own land designated for wine production, such as Spain, Italy, France, Chile, and Romania, among others.

Economic impact and benefit of the use of GIS technology and AI in viticulture

The intelligence of machines, together with data received from sensors and images, allows winegrowers to improve many aspects involved in vineyard management. For example, AI is used in the vineyards to provide relevant information such as yield and size as quantifiable aspects, as well as in the wineries and distribution.

AI technology, if properly combined with other technologies such as sensing, can bring many economic benefits. It can gather, interpret and learn from the data collected, helping farmers make fact-based and predictive decisions. In wineries, AI collects data from sensors and is used to improve the wine quality and production.

AI can detect plant diseases, pests, insects, and chemical fertilizers, identify plots of land which need to be irrigated, vine voids in plots, and determine the urgency of fertilizer or pesticide treatment [13].

GIS enables the reduction of inputs to the vineyard (pesticides, fertilizers and herbicides) through an optimized spreading of the final products.

New technologies and data sources include satellite and drone remote sensing, field sensors and automated weather stations, which are increasingly deployed and used to improve decision-making due to their enhanced availability, affordability and reliability [44].

The paper aimed to explore various means by which the artificial intelligence (AI) is integrated into viticulture, in particular through the geographic information systems (GIS), as well as to point out the importance of precision viticulture techniques and their practical applications in viticulture and winemaking, having as main objectives the improving of efficiency in grape cultivation and obtaining high quality wines.

MATERIALS AND METHODS

The current review was restricted to articles with English full-text availability. MDPI, Eurostat Regional Yearbook, European Commission, DG Agriculture and Rural Development, Google Scholar, Springer Link, Springer Nature, Elsevier, Encyclopedia Britannica, and Journal of USAMVB (Scientific Papers Series Management) were among the most used information sources. The most common search keywords were used: artificial intelligence technologies in viticulture, GYS, wine, machine learning, winemaking, and detection methods. Additionally, searches were conducted using each term in turn. We also looked for additional references in the bibliographies of the included papers. In our review of the literature, we discovered a sizable number of studies that mostly discussed the GIS technology and AI in viticulture. The results of the thorough search are sorted into categories and listed according to the best techniques discovered. We only included the more than 60 research articles and review papers that were discovered after 1974 because that is when the authors study the growth of the aerial vegetative growth of the vine until 2023 when some concrete examples of the application of AI technology in the wine industry were presented.

RESULTS AND DISCUSSIONS

Brief presentation of viticulture state in the EU and in Romania

According to *Eurostat Regional Yearbook*, 2018 edition, approximately 3.2 million ha of EU land was occupied by vines in the year 2015, both in and not yet in production. The area included 17 EU state members.

This reflects the fact that the northern European expansion of the Roman Empire is linked with the northern limit of the wine plants' presence. More than three-quarters (78.1%) of the area was used to produce quality wines, PDO wines (61.7%) or PGI wines (16.4%) [26].

The evolution of areas under vine in the EU is presented in Figure 1.

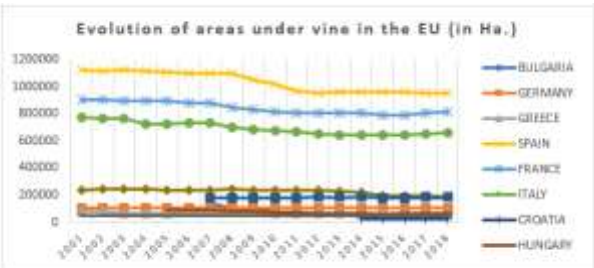

Fig.1. Evolution of areas under vine in the EU (ha). Source: [20].

The evolution of areas under vine in Romania, for example, is presented in Figure 2.

The integration of AI in viticultural agriculture in Romania stands to yield numerous positive impacts. AI technologies can elevate precision farming practices, optimize resource allocation, and enhance overall efficiency in grape cultivation.

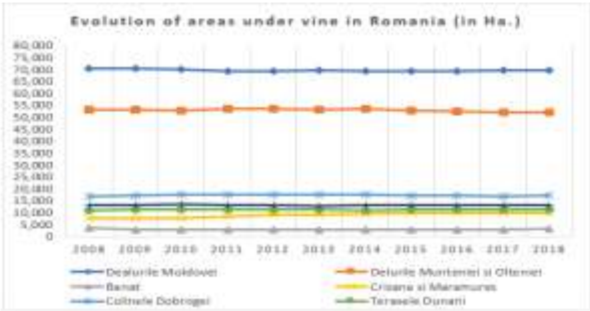

Fig. 2. Evolution of areas under vine in Romania. Source: [21].

By analyzing data from diverse sources, including weather patterns and soil conditions, AI systems can offer valuable insights for informed decision-making. AI-driven applications hold the potential to predict disease outbreaks, optimize irrigation schedules, and streamline vineyard operations, thereby contributing to increased yield, enhanced grape quality, and resource conservation. Furthermore, the incorporation of AI in viticulture can promote sustainability by reducing reliance on pesticides and minimizing environmental impact. Despite these potential benefits, challenges such as initial implementation costs, the need for a skilled workforce, and concerns related to data privacy necessitate careful consideration. The advantages of incorporating artificial intelligence into viticultural cultivation in Romania are diverse, encompassing the potential to significantly reshape grape cultivation by bolstering efficiency, sustainability, and technological advancement. In terms of winemaking, AI algorithms enable the simultaneous analysis of tens of thousands of wines, unveiling correlations between sensory components, classification, and price. Such analyses can also explore the influence of regional soil variations, weather conditions, and other natural factors on wine characteristics. The future trajectory involves integrating sensory reviews from diverse sources with chemical analysis data to unveil connections between different methods of wine evaluation. In Romania, the National Office of Vine and Wine Products (ONVPV) has implemented a control system since 2008, utilizing a

certification mark with a unique alpha-numeric series. This system was subsequently replaced in 2014 by the QR code system, ensuring traceability and certifying the origin and authenticity of the marked wine [13].
Figure 3 [26] presents the vine distribution areas, with distribution heavily distorted in favour of the southern EU regions.

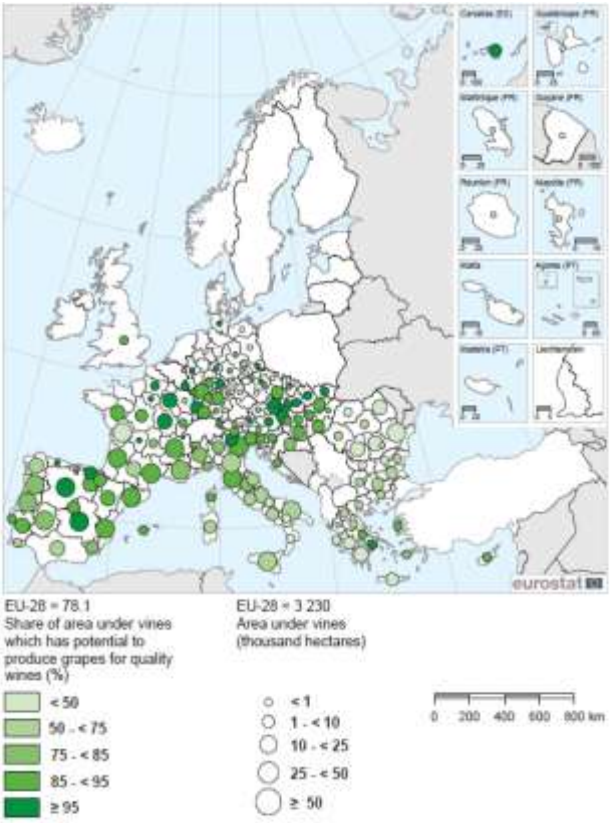

Fig. 3. Vine areas for quality wines, NUTS 2 regions, 2015 (thousand hectares under vines and share of area under vines which is used to produce grapes for quality wine.
Source: [26].

The size of each circle represents the total vine area for each NUTS (Nomenclature of Territorial Units for Statistics) level 2 region. In accordance with the map legend, the colours provide data on the tendency to produce quality wines; darker shades mean a greater share of the total vine area is committed to producing quality wines.
The four regions in the EU that have more than 100,000 ha of vines are Puglia, Castilla-la Mancha, Aquitaine, and Languedoc-Roussillon. According to the 2018 edition of the *Eurostat Regional Yearbook*, there were 18 NUTS level 2 regions in the EU in 2015 where the total area under vines was larger than 50 thousand hectares.
These 18 regions together represented 61% of the total vine area in the EU.

Wine Market Situation and Trade Developments

The transformation of grapes into wine is called vinification. Oenology (also called wine technology) is the science that deals with the study, methods of preparation, conditioning, and storage of wines and products derived from grapes, must, or wine [57]. The generally accepted European definition of wine states that wine is produced exclusively by alcoholic fermentation, in whole or in part, from fresh grapes, crushed or not crushed, or from grape must, with at least 8.5% alcohol by volume. Over the years, wine has undergone different studies aimed at demonstrating its benefits. Producing high-quality wine can be considered an art, and although interest in agriculture has declined, the interest in wine is as intense as ever. Wine is one of the most popular drinks worldwide, and its market is constantly growing. It is believed to be an effective elixir and therefore good for health in moderate quantities. To be considered of quality, a wine must fulfil some requirements that help the buyer to more easily choose, such as a European food/beverage label with guaranteed geographical origin with Recognised know-how (and grapes exclusively from the area in question) [21]:
-An indication of the PDO status, which refers to its connection with an area that is recognised by official rules to produce special foods with special characteristics related to the location [38];
-An indication of PGI status, which is a label for European quality food due to its close relation with a specific region (with at least 85% of the grapes coming from the area in question).
Geographical indication (GI)-recognised products or products that are under consideration can be found on geographical indications registers, which include data regarding the production and geographical specifications for each product. The intellectual properties rights (IPR) for

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products with qualities related to the production area can be established with the help of geographical indications. The geographical indications for food, wine, and spirits include the following aspects [24]:

-Protected designation of origin (PDO) for food and wine;

-Protected geographical indication (PGI) for food and wine;

-Geographical indication (GI) for spirit drinks.

The main differences between PDO and PGI are the ratios of raw materials in the product that should come from a specific area or the proportion of the production process taking place in a specific area. The wine market has become important even in countries without a tradition of consumption [25].

According to fortunebusinessnights.com, the wine market is predicted to grow from USD 340.23 billion in 2021 to USD 456.76 billion between 2021 and 2028, corresponding to a CAGR (compound annual growth rate) of 4.30% [18]. Europe is the biggest wine producer, responsible for more than half of the world's wine output.

In 2019, the EU exported over 7 bn. litres of wine. About 43% of the total wine production, or 3.1 bn. litres, was exported to non-European countries. From this, approximately 0.69 bn. litres were sent to the United Kingdom (around 22% of extra-European wine exports) and 0.65 bn. to the United States (21% of exports). The country that imported the third-largest volume of wine from the EU was Russia, with 0.28 bn. litres (approx. 9% of exports), and the fourth was China, with 0.25 bn. litres of wine (8%). With 1.1 bn. litres or 34% of the EU member states' extra-EU exports of wine, Italy was the number one exporter of wine in 2019. The second place was held by France, with 0.8 bn. Litres or 25%, and the third place belonged to Spain, with 0.7 bn. litres or 22%. Conversely, the top importer was Germany. According to the 2019 import charts, the quantity of wine imported by the EU member states was 4.8 bn. litres, among which only 16% came from non-EU countries such as Chile, with 0.17 bn. litres or 23% of imports and South Africa with 0.16 bn. litres or 21% of total imports. Germany was the largest EU member state wine importer, with 30% of total EU member states' extra-EU imports, amounting to 0.23 bn. litres, and the Netherlands followed in the ranking with 0.11 bn. litres or 15% of imports, Denmark with 0.07 bn. litres or 9% of imports, and Sweden with 0.06 bn. litres or 8% of total imports. Both Belgium and France imported 0.05 bn. litres, which was 7% of total imports. Ireland was ranked sixth place with almost 0.05 bn. litres or 6% of total imports. Figure 4 presents the situation regarding wine trade from 2021 to 2022.

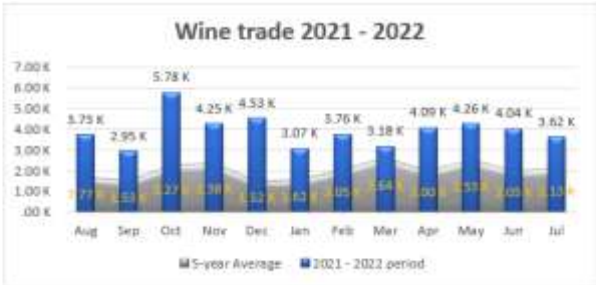

Fig. 4. Wine trade.
Source: [22].

According to the EU Wine Market Observatory, the 2021/2022 wine + must production was 159 million hectolitres (Mio Hl) +7% compared with the forecasted value (148 Mio Hl). The overall production decrease was half of that estimated the previous October (from −13% in October 21 to −7% in March 22), with a decline of −7% compared to the 2020/21 production (170 Mio HL in 2020/21 <-> 159 Mio HL in 2021/22 = −11 Mio Hl = −7%) [16]. The first three wine producers in the EU were Italy, Spain, and France. Italy was the largest EU and world producer, with 50.4 Mio Hl, representing 32% of total production in the Union, followed by Spain (39.4 Mio Hl), which produced 25% of the volume [23]. For the second consecutive year, France took third place (37.2 Mio Hl) with 23% of the produced volume. Two-thirds of produced wines were quality wines (this proportion remained stable: 45% were PDOs and 21% were PGIs) [19]. During the last decade, a slight upward trend in the production of PDO and varietal wines, stability in the level of PGI production, and a downward trend in the production of wines without appellations were observed (Figure 5) [23].

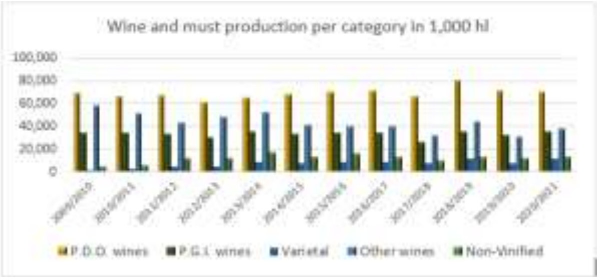

Fig. 5. Evolution of EU-27 wine and must production per category, April 2022 (1,000 hl).
Source: [23].

Figures 6 and 7 present the wine market situation and trade developments in 2022.
According to Kantar, in 2021, household wine consumption decreased by −5.5% in volume vs. −0.8% in volume in 2020 and −6.3% in 2018–2020. The consumption decreased by −1.5% in value compared to 2020.
Unlike other years, consumers tended to buy more expensive wines.

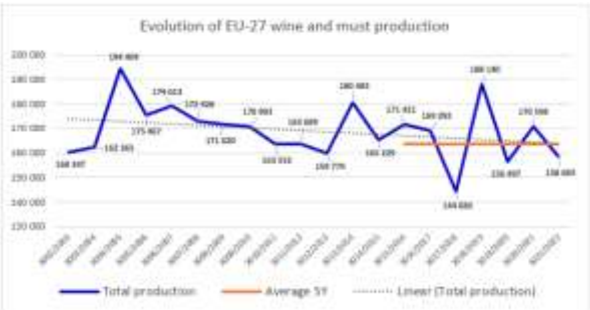

Fig. 6. Evolution of EU-27 wine and must production.
Source: [23].

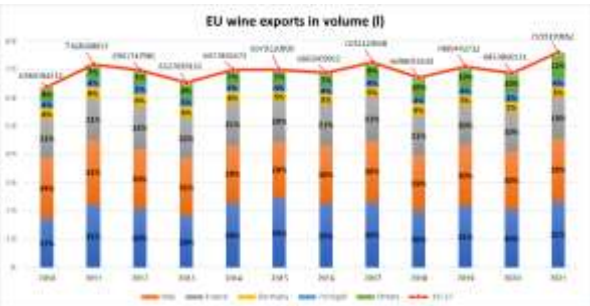

Fig. 7. EU wine exports (2010–2021)
Source: [16, 23].

The average price was EUR 4.91 per litre, up 4.2% from 2020 and +4.9% from 2018–2020, on average. Regarding the colour, only white wine purchases increased in 2021 (+3.2% in volume and +8.5% in value). Sales of still wines decreased by 10% in volume in Q1 2022 compared with Q1 2021 (−10% compared with the 2019/21 average) and 10% in value (−6% compared with the 2018/20 average). In contrast, the price paid was EUR 4.66/l, which remained stable when comparing with 2021 (+4% compared with the 2019/21 average) [17].

AI technologies in viticulture

Among the most relevant uses of AI in viticulture can be mentioned the following: robotics and human assistance technologies with AI capabilities for vineyards with the harvest intended for winemaking; VR (virtual reality) headsets for training; headset with human assistance Augmented Reality (AR), which helps to determine the cut points on a vine trunk so that people can make the cuts correctly; autonomous tractors and combines; robots that dig and plant cuttings; robots that monitor certain factors in the vineyard such as their harvesting yield, vegetative growth, production level and the physicochemical composition of grapes; planting, monitoring, pruning and fertilizing vines, as well as harvesting grapes can be automated; intelligent storage (warehouse automation through robotics and AI); more efficient distribution and marketing with the help of automation; digitalization of certifications (electronic label (e-labelling), electronic certificate (E-Certificate) etc.); automated storage of barrels, wine bottles [13].
The great variety of wines in the world is explained by differences between territories (soil, rainfall, exposition, etc.), grape varieties, winemaking methods, and types of ageing: there are white, red, or rosé wines as well as wines with different residual sugar levels (i.e., dry or sweet wines) or effervescent wines (Figure 8).
Owing to the progression of wine consumption culture assimilation and expansion in the world, the use of digital technologies has affected the domain. As in many other areas, artificial intelligence has been used to reduce workload (humans have been replaced by robots) and allow focusing on crop winemaking efficiency, productivity, and yield, in order to obtain high-quality wines.

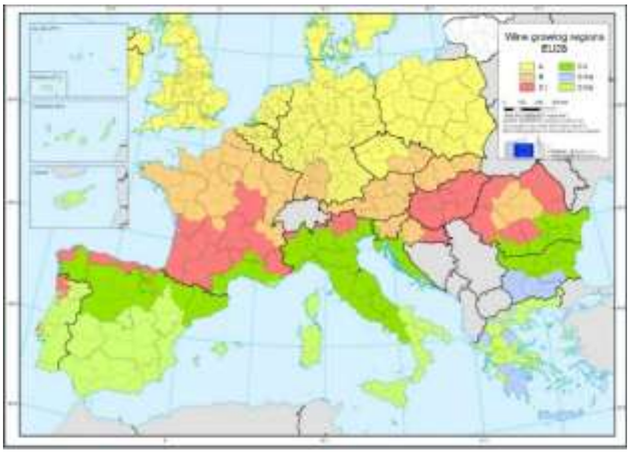

Fig. 8. Wine-growing regions EU28.
Source: [32].

Through GIS, artificial intelligence algorithms contribute to the wine industry efficiency by facilitating production of healthier crops, pest detection and control, plant disease identification, monitoring of soil and plant growth (cultivation, maintenance, and harvesting) and the degree of soil fertility, provision of weather forecasts, wine quality identification, traceability, and even manufacture of storage barrels. Since vineyards are mostly located in dry areas, special hardy varieties and/or a sufficient supply of water at key stages of development in case of severe drought are necessary. Support tools are therefore needed for the optimisation of water use in order to adapt agronomic practices.

Laroche-Pinel E. et al. (2021) presented a solution to this problem in their work, involving large-scale monitoring of the vine water status using Sentinel-2 images [34], which provide spatialised and temporal information. Six plots were observed over three years (2018–2020) of field measurements to determine the water status of vines that were measured from pea size until the ripening stage based on stem water. The images offered by Sentinel-2 were downloaded and analysed in order to extract band reflectance values and compute vegetation indices. Five supervised regression machine learning algorithms were tested in order to determine if there were any relationships between the stem water potential and data provided by Sentinel-2 images (band reflectance values and vegetation indices). In conclusion, promising results for the prediction of stem water potential ($R2 = 0.40$, $RMSE = 0.26$) were obtained through the regression model using Red, Red-Edge, NIR, or SWIR bands.

Bahat I. et al. (2021) [3], in their study of a commercial *Vitis vinifera* 'Cabernet Sauvignon' vineyard in Israel covering 2.5 ha, approached the effect of the terrain as a compound of the micro-terroir factor. In that study, the topographic wetness index (TWI) was used as an integrative, steady-state hydrologic measure to delineate the management zones (MZs) within a vineyard and study the interactions between vine vigour, water status, and the grape and wine quality. The relationships between soil water availability, vine vigour, and water stress are very important, as they can be used to allow appropriate decisions to made involving irrigation.

The decametric resolution satellite and UAV (unmanned aerial vehicle) platforms of low altitude were applied by Khaliq A. et al. (2019) [32] for a comprehensive analysis including a comparison of vineyard multispectral imagery. Spectral indices are considered valuable tools for describing crop spatial and temporal variability. The relationship between the crop vigour and the normalised difference vegetation index (NDVI) was used to evaluate the Sentinel-2 images and high-resolution UAV aerial images. The unbundled spectral contributions of the different elements (i.e., the inter-row terrain, the whole cropland surface, and only the vine canopies) in the vineyard environment were analysed through UAV data processing, which was compared with the satellite imagery by computing three different NDVI indices. The conclusion of the study regarding the maps computed from UAV imagery using only the pixels that represented crop canopies was that these were more reliable than satellite imagery for in-field assessment. Meanwhile, it was concluded that the raw resolution satellite imagery could not reliably describe the vineyard variability because the NDVI computation can be influenced by the inter-row surfaces and their contribution to the sensed dataset, thereby leading to unclear crop descriptors. Cogato A. et al. (2019) [12] assessed the feasibility of using images provided by Sentinel-2 in quantifying the impact that heatwaves have on irrigated vineyards. The study is mostly useful for countries such as Australia, where heatwaves are common in many viticultural areas. During the period of two seasons (2016–2017 and 2017–2018) of the study, the authors investigated the possibility of satellite-based remote sensing to evaluate the effects of high temperatures on grapevines in a South Australian vineyard and investigated the feasibility of assessing the effects of heat stress on grapevines through the utilisation of Sentinel-2 data.

The following steps were undertaken in that study:

- Comparison of the NDVI from medium- and high-resolution satellite images;
- Determination of the correlations between the vegetation indices (VIs) and the environmental conditions [45].
- Identification of the VIs that best indicated heatwave effects.

Although the authors concluded that the results of the study needed confirmation through further investigation, the spectrum regions and the VIs were found to be more suited to heat stress detection based on the analysis of spectral features of vineyards affected by multiple heatwaves. The high correlation of spectral bands and VIs with environmental conditions is an observation that resonates with the results of other studies on water stress using high-resolution imagery.

In the article *Development of Spectral Disease Indices for 'Flavescence Dorée' Grapevine Disease Identification* [1] the authors aimed to develop spectral disease indices (SDIs) for the detection of FD disease in grapevines. The application of SDIs in precision agriculture is demonstrated to improve disease detection, identification, and monitoring. The spectral signatures of the diseased and healthy grapevine leaves were measured using a non-imaging spectroradiometer for two different levels of infection, and the most discriminating wavelengths were selected with the help of a genetic algorithm (GA). Finally, the spatial data enabled the addition of advanced image processing algorithms for more robust FD detection. In order to obtain a certain style of wine of a certain quality, adequate environmental conditions and proper cultural practices are required. The harvest and, by default, the obtained wine can vary from one year to another owing to climate, disease, soil, pests, and other factors. There are vineyards where traditional practices are still used, even though they are more time-consuming and, in the long run, lead to physical and mental stress and fatigue. Over the last decades, new technologies have been implemented to allow machines to take on many tasks and relieve humans of their burden. Examples of such technologies include robotics, wireless sensor network technologies (WSN, useful for real-time monitoring), GPS, and sensors. Examples of robot prototypes and commercial solutions for viticulture [52]: VineRobot [65], VINBOT [49], Wall-Ye [63], VRC Robot [62], Vitirover [62], and Forge Robotic Platform [3]. Precision viticulture is a scientific technique that assists wineries with the management of large areas, maintaining variability, improving their performance, and maximising the grape quality and yield by decreasing risks and environmental impact. This technique depends on new technologies such as Global Navigation Satellite Systems (GNSS), meteorological sensors, and other remote sensing equipment and satellites, as well as GIS for assessing and responding to variability. Through the use of precision viticulture technologies, it becomes easier for vineyard owners and winemakers to control the variability in their vineyards and the factors influencing grapevine performance.

AI technologies in the assessment of technological indicators in grape processing and wine production

Must is unfermented sweet grape juice that is obtained by crushing and pressing grapes. For choosing the moment to start harvesting, the most important parameter is the degree of ripening of the grapes, expressed by the sugar content (in g/l) of the must.

Huglin (1986) [29] considers there to be four fundamental categories among the intrinsic factors of wine quality: sugars, acids, the constituents of the "nose", and phenolic compounds. Thus, quality is a complex concept in which sugar content is only one element [48]. Pierre Huglin developed a bioclimatic heat index for vineyards, called the Huglin heat sum index (thereafter being referred to as the Huglin warmth index or, in short form, the Huglin index). The index works as follows: the temperature sum over the temperature threshold of 10°C is calculated and then summed for all days from the beginning of April until the end of September using the daily average temperatures and the maximum temperatures. The calculated total shows almost no variation according to latitude. For each grape variety, a different amount of heat is needed for successful long-term cultivation in a given area. In general, the obtained heat sums are lower than the actual values in vineyards based on data from different weather stations or climate models. Huglin stated that: "for cool wine-growing possibility, the sugar content is general whenever the grape varieties used are on average at the limit of their growing possibility, the sugar content is the primordial element of quality. In hot regions, on the other hand, the maintenance of sufficient acidity is often the dominating concern" [29].

In his paper, Champagnol (1984) [10] agreed and noted that "in the south of France, with a vintage of a sugar content lower than 10° probable alcohol, *Carignan* or *Grenache* can only give mediocre or passable wine. This wine can become acceptable on average for 11° and often excellent for 12° or 13° with more aromatic varieties, in northern regions, a good wine can be obtained with lower sugar contents. This is however not as good (even after artificial enrichment) as that obtained from a vintage richer in sugar" [48]. One of the main objectives when it comes to the quality of wine in the northern regions is obtaining an optimum (maximum) sugar content. It can be said that quality is a complex concept, the result of the interaction of many components. The sugar content is considered a good indicator of the quality level, as it presents good evidence of the ripening stage together with the parallel evolution of other relevant components. The ripening period plays an important role in the accumulation of sugars [10]. Grape ripening represents the last physiological process in the chain of biochemical transformation. The climate during the ripening period also plays an important role [48]. Ripening of grape is usually considered to have begun when the skin begins to change its colour. This can easily be observed in the case of red grapes, but when it comes to white grapes, there is not only an observable change of colour but also a change in firmness, with grapes becoming softer. The artificial increase in sugar content affects thus only one aspect of quality, being more disturbed by poor grape ripening. The procedure leading to the cartography of sugar content should proceed in stages. First, it must be specified how the grape's sugar content will be determined, followed by translation of the obtained knowledge into area limits of the given sugar content. Both stages have their own characteristics, such as [48]:

-Using the knowledge of the scientific literature;

-Statistically processing relationships between sugar content and explanatory variables;

-Owning a sufficiently dense and representative measurement network of the explanatory variables;

-Comparing different grape varieties regarding a reference value.

There are many causes of the variation in sugar content: climate, yield, nature of the grape varieties, soil, plot topoclimate, and vine-growing methods [48]. In 1979 S. Meriaux, H. Rollin, and P. Rutten studied vineyards in Languedoc [42]. They concluded that drought could have a very different effect depending on the period in which it occurs, being able to reduce the yield and/or sugar content (i.e., without changing the yield) depending on the case [48]. As it can combine experience with progress, AI is, therefore, used in many areas related to agriculture and, implicitly, viticulture and winemaking, in order to combat problems and concerns such as climate change, pests, diseases, insects, vine well-being, and the assessment of wine and must quality (such as through bubble and foam-related parameters). Artificial intelligence techniques can therefore be used as reliable tools by winemakers in formulating their decisions. For example, ANNs are used to determine different (wine) aromas. In the following, some concrete examples of the application of AI in the wine industry are presented. The group data treatment method (GDTM) is suitable for processes that are non-linear, complex, or little known [11, 28]. According to Cleran [11], who compared the GDTM method with neural networks in predicting alcoholic fermentation kinetics, neural networks are provide more accurate predictions than GDTM. On the other hand, GDTM is more robust when applied to atypical fermentation samples. In his paper, Bouyer (1991) [8] evaluated the potential of neural networks for simulating alcoholic fermentations. The experimental values were estimated in laboratory scale fermenters with online monitoring of kinetics [30]. Another experiment was developed with the aim of forecasting the risks at the beginning or in the middle of the fermentation process. This consisted of the combination of statistical and neural networks for predicting the risks of sluggish and stuck fermentations [28, 51]. Moreover, the experiment aimed to compensate for the lack of analytical information with accurate kinetics information (instantaneous CO_2 production rate) and by testing quantities of several types of must. There are networks that can process data regarding fermentation defects [28].

I. Alvarez [2] used the NeuroAgent (IntelliSphère) software, which allows knowledge originating from learning and knowledge extracted from the expert to be visualised in a similar way. Other well-known programs used for neural networks and artificial intelligence are MATLAB and NeuroSolutions.

AI technologies economic impact in viticulture

AI can determine or predict wine quality based on the distribution of its components, track the aging process in barrels, and perform a sensory analysis of the wine. This can directly affect the productivity of the winery, with clear financial advantages and economy of time [13].

Artificial intelligence algorithms allow to analyze and search for interactions in large amounts of data, resulting from many sensors and observing many processes. To maximize the benefits, high-quality data from robust, reliable, low-maintenance, low-cost sensors should be available and collected, and efforts should be made to specify the required data quality [55].

These benefits can generate resource cost savings, improved product quality, faster actions with lower risks, and increased production [47, 59].

According to the research of Burks, Schmouldt and Steiner (2008) [9], the introduction of robotics in agriculture can create more jobs in the general economy than it could initially destroy. It is not realistic to consider just replacing workers with machines because there are many crops for the production of which there is not much skilled labour available, such as pruning in French vineyards.

The requirements for AI advancement in agricultural operations should include a deeper sector-targeted evaluation of the risks, compared to the benefits that AI's restrictive requirements may bring to society [10, 28].

Finally, AI should be considered as a valuable tool for a sustainable viticulture, which is defined as the "global strategy at the scale of grape production and processing systems, incorporating at the same time the economic sustainability of structures and territories, which produce quality products, taking into account the precision requirements in sustainable viticulture, the risks for the environment, product safety and consumer health [41].

Among the most relevant uses of AI and projects implemented in the Romanian viticulture and winemaking the following initiatives can be mentioned: 1) the BIT Software solutions for viticulture, which are specialized and comprehensive applications for wine producers, managing all processes from land and crop management, planning and production of grapes and wine, bottling and labeling to distribution [67]; (2) iOla or the "virtual engineer" is a network of sensors, which collects information, interprets it with the help of AI, and the generated data then helps to make predictions about the environment so that it can be more easily controlled. iOla Agritel is a dedicated solution for agriculture that combines sensors, drone/satellite imagery and data from devices that scan the chemical composition of soil and water for irrigation from groundwater and rivers. All this information is processed by a system based on artificial intelligence that helps the farmer in improving the crops, namely by optimizing irrigation and chemical treatments (for example: NPK, pesticides, etc.), protecting the environment and soil degradation [66]; 3) Jidvei, a renowned Romanian wine producer, in collaboration with Orange and Teraseya, opted for intelligent agriculture through a series of technologies and equipment such as LoRa WAN network, Live Objects solution and different types of sensors of the highest quality. The Teraseya platform designs maps of variable application for areas or parcels with risks of disease or frost, determines the type of soil and the most suitable grape variety for it. It also shows exactly where fertilizers should be used and where irrigation is needed, for a maximum harvest yield [69].

CONCLUSIONS

Most researchers agree that AI is unlikely to develop and display human emotions, such as love or hate and that there is no reason to expect AI to become deliberately benevolent or malicious. AI promotes decentralized information in open-data environments and can help the viticulture and wine production to develop in a more efficient way. Among the fields in the viticulture and wine industry where AI technologies can be successfully applied the following can be mentioned the recognition of different types of wine; the recognition of yeast strain; the recognition of must variety; the forecasting of wine aroma, the prediction of the evolution of the parameters in fermentation processes; the prediction of the acidity content; the wine fermentation control; the wine blending optimisation; the artificial wine taster; the disease detection in different crops; the precision pesticide sprays; the crop yield predictions; the construction of wine barrels; the control of the oxygen transmission rate from within the barrels; the prediction of alcoholic fermentations; the overall mapping (GIS). Finally, integrating data analyses from sensors and other data-retrieving devices, AI machines can supervise the whole wine-making process and recommend measures for improvement that are based on the obtained information.

Although currently in Romania the wine sector is not at a very technologically advanced stage, digitization presents a huge potential, having major benefits for improving productivity, the yield of vineyards, and finally to improve the overall efficiency in the entire wine sector. In addition, AI increases and improves the ability to take decisions and solve problems and can contribute to a healthier diet by minimizing the use of fertilizers and pesticides, as well as to a more sustainable agriculture, for example through the reduction of the impact of the overall activity on the environment.

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