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Economic feasibility in the development of smart technology in grape and wine production

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Abstract

Background: The use of smart technology in grape and wine production in Serbia in the current economic conditions represents a significant segment of the further development of grape and wine production. The use of smart technology in grape and wine production in Serbia could help and contribute to production in every sense. Unfortunately, the application of new technologies is still limited to individuals.

Purpose: Despite all the unknowns, some farmers are ready to implement this type of production. Therefore, the main goal of this work is to familiarize the interested public with smart technologies in grape and wine production. The authors want to emphasize that this type of production has a future and that it can be developed further.

Study design/methodology/approach: In this paper, the authors used their own research conducted through surveys with winegrowers and winemakers in 2019 and 2023, which relates to the application of smart technologies. In other words, the authors tried to find an answer whether the application of precision technologies has a future.

Findings/conclusions: The application of new technologies in agriculture has great potential that can improve grape and wine production. We believe that Serbian grape and wine producers should be more active and involved in projects that imply the application of new technologies. On the other hand, the state could significantly contribute to facilitating the application of these technologies.

Limitations/future research: A possible limitation for the application of this manuscript, according to the authors, is the lack of information about the benefits and real possibilities of (smart) technologies among grape and wine producers. A major problem in the implementation of this production may be ignorance of its benefits and insufficient state support in providing subsidies.

Keywords

Smart technology, production, economic feasibility, grapes, winemaking, agricultural farms

Introduction

The last decade of the 21st century has seen the development of digital technologies, which have enabled improvements in the way grapes are grown, maintained, and harvested, all with the aim of producing quality wines in a way that is both environmentally and economically sustainable.

This paper discusses various smart farming technologies that can help winegrowers and winemakers in their production. Artificial intelligence is also discussed because it provides grape growers with a tool for transforming data into valuable information to make informed

decisions. Using these technologies, grape and wine growers want to collect and provide data and information to make a more informed decisions regarding land and vine management.

The modernization and progress of viticulture and winemaking depend on the introduction of new technologies. First, it is the way of organizing work with the application of new technologies such as precision agriculture.

As is already known, Serbia has favorable natural conditions for the development of diverse agricultural production. It is in a favorable area of northern latitude characterized by four seasons and four climatic zones. It is precisely these conditions that allow the development of viticulture and winemaking. Climate and soil represent an important natural condition for the development of grape and wine production. In the conditions of climatic, biological, and hydrological changes, soil fertility is subject to changes. These changes are also influenced in many ways by various human activities.

These activities are linked to the development of new technologies that aim to improve production through the application of innovation. This is particularly important for wine production, as growers are facing many challenges, mainly caused by the disruption triggered by climate change and changing weather patterns, compressed seasons, drought, heat, labor shortages, and higher production costs (Fountas et al., 2020). Continuous monitoring of biophysical traits and grapevine performance is increasingly necessary to assess vineyard management.

The application of various types of sensors as an innovation has significantly contributed to changing the way grapes are grown. Sensors allow monitoring of important parameters such as temperature or soil and air humidity (from a distance). Sensors give winegrowers the ability to more precisely control the conditions in which their grapes grow. In practice, this means that they can adjust irrigation and fertilization according to the specific needs of the vine. All this is done to achieve optimal growth and plant health, which should lead to a higher grape yield.

In addition to sensors, drones, and smart irrigation systems, winegrowers can use the internet (Sivchev et al., 2019) and social media to improve their business. The openness and transparency that social media provides can help build a brand and attract new customers. Winegrowers can also use the internet to monitor and analyze weather data, consumer trends, and other relevant information that will enable them to make better business decisions.

We would like to emphasize that the digital transformation of the wine industry extends beyond the vineyard to the winery itself, where technology is used to refine the art of winemaking, but also in innovations in this area aimed at improving quality control, improving efficiency, and exploring new opportunities in wine production.

Grape and wine production still has a modest annual share in the total value of agricultural production of only a few percent (Simonović et al., 2019). We believe that this share can be increased by using new technologies. In the last few years, a deficit in foreign trade has been observed, which is explained by the growing trend of domestic wine consumption. This is a good trend, which can certainly encourage wine producers (Simonović et al., 2021).

Finally, we would like to point out that the use of new technologies can be abused by cyber-attacks or various data frauds due to continuous changes in work patterns, as well as the failure of IT infrastructure and networks, but all this is associated with the risks of doing business in modern conditions (Stojadinović Jovanović et al., 2020).

The structure of the paper is set in terms of its easier understanding. First, we provide a working method based on relevant literature and survey research. Then we gave a brief overview of the beginnings of the application of smart agriculture in the world and in our country. We paid particular attention to the current state of new technologies in viticulture and winemaking, but also to the types of these technologies that are applied in the world and in our country.

1. Methods

The aim of the paper is to analyze the awareness and possibilities of applying smart technologies in grape and wine production in Serbia, and then its cost-effectiveness. To achieve this aim of the paper, the authors studied relevant sources of literature related to this issue. The literature used mainly contained academic articles taken from the Web of Science and SCOPUS databases, but also other professional works that were available on the Internet through the Google Scholar database. The literature review was based on the author's opinion according to the principle of relevance.

In addition to the literature review, the authors also conducted a survey among winegrowers and

winemakers as immediate and direct producers, who can potentially benefit the most from the application of new technologies in their production. The survey organized in this way gave a picture of the current state of this type of agricultural production. A total of 76 producers participated in the survey.

2. Results and Discussion

This chapter focuses on the early days of smart technology adoption and provides an insight into the current state of the application of new technologies. The results of a survey are also included in this chapter.

2.1. The beginnings of smart agriculture implementation

Agriculture in general should be viewed through two segments. The first is that food production depends on agriculture. The second is that agricultural production drives economic development. The question is rightly raised whether agriculture can create conditions that can contribute to more efficient economic development (Simonović et al., 2012).

It is in this direction that the system of development of smart agriculture should be viewed, which includes the application of modern information and communication technologies (ICT) in agricultural production. The application of these new technologies began the so-called third green revolution.

By participating in plant breeding and the genetic revolution, this so-called "third green revolution" affects agricultural production with the application of a wide variety of ICT solutions. These are various precision machines which are connected to the Internet. These include various types of sensors and actuators, geopositioning systems, big data analysis, unmanned aerial vehicles, drones, robots, etc. Additionally, mobile technology in agriculture provides data on weather conditions and soil and plant characteristics and enables wireless communication between different devices or machines (Rađenović et al., 2020).

The use of these technologies should primarily provide farmers with financial benefits on the one hand, and on the other hand, enable the most optimal use of resources. The Smart-AKIS network contains three types of smart agriculture technologies, which are interconnected:

- In the first place is the management of information systems. They collect, process, store and distribute data in the appropriate format so that operations on the estate can be carried out faster and more efficiently.
- This is followed by the management of spatial and temporal variability to improve and create conditions for the return on invested funds. The goal is to reduce input raw materials and reduce environmental pollution.
- Automation in agriculture and the process of applying robotics, through automated control processes and artificial intelligence that can be used in agricultural production.

The use of new smart technologies in agriculture is not new. In fact, the use of these new technologies has its roots in the 1960s. At that time, farmers in some developed countries began to use laser-controlled levelers for precise leveling or irrigation of large agricultural areas.

The concept of precision agriculture, conceived as a way of managing crops in a specific location, emerged in the 1980s. This term was first used in 1990 in Montana (Oliver et al., 2013). In the second half of the 20th century, it was associated with the concept of smart agriculture. The term "smart" comes from the definition of smart communities. These are social units with shared values and ideals that have made conscious efforts to use information technologies to change the organization of life and work in the region in which they are located (Komninos, 2014).

In this sense, "smart technology" in agriculture implies the use of digital and high-tech technology that enables the creation of an interested local community that intends to use it. This type of innovation is conceived as a new idea or method and represents the beginning of smart agriculture (Simonović, 2024).

New forms of innovation should cover all aspects of the agricultural production cycle, throughout the entire value chain system. These types of innovations are focused on crop management, resources, data entry, production organization, marketing, and distribution. New technologies are based on sensors, decision support systems, automation, and robotics (Lombardo et al., 2018). They are available to all interested agricultural producers, with the aim of increasing profits and productivity.

The application of agricultural innovations is not a simple process, as it requires the use of diffusion theory when introducing them. As explained by Rogers, (Rogers et al., 2014). diffusion is the process by which an innovation is

used through various channels among members of the production ecosystem. The process represents a kind of communication for the transfer of new ideas. In this sense, there are four basic elements in the application of diffusion theory. These are: the innovation itself, the communication channel, time and the social system into which the innovation is introduced. Therefore, the effective use of innovations in the production process requires the following:

- understanding changes in action,
- finding the added value of the smart agriculture process,
- checking the reliability of new technologies,
- adjusting production processes (Sarri et al., 2020, p. 7191).

Cloud computing and the Internet of Things (IoT) are two current concepts. Together, they constitute the core of the next-generation information technology industry. Not long after Barack Obama, the President of the United States, proposed the concept of a "smart planet" in 2009, Chinese Premier Wen promoted the development idea of a "Sense of China", which mainly emphasized the need to develop IoT and strategic new industries (Tong Ke, 2013).

The term "Internet of Things" has been used since 1999. On the other hand, the technologies that enable IoT, such as sensor networks, have existed before. They have been in use since the early 1990s. Advances in sensor and cloud technology, as well as data processing and storage capabilities, and the reduction in sensor production costs have led to the growth of sensor applications. Their increase has been recorded especially in the last five years (Perera et al., 2014). By 2020, the European Commission projected that between 50 and 100 billion devices will be connected to the Internet (Sundmaeker et al., 2010, p. 34-36).

The organization of production with these new technologies is tied to a specific location. The starting idea in the organization of production is aimed at doing everything correctly and in the right place at the right time. This concept of organization is as old as agricultural production. In the 20th century, during the process of agricultural mechanization, there was an economic need to cultivate large fields using a single agricultural practice. The application of precision agriculture is also developing in this direction, as it allows for the automation of a specific location, using information technologies, which practically applies location-specific management for commercial production purposes. Smart agriculture encompasses all those agricultural production experiences that use information technology (Simonović et al., 2018).

In the new technology, wireless sensor networks are used to obtain various information. In the first place, these can be plots (vineyards) that are monitored through various integrated miniature sensors. The embedded information system and wireless networks collect information that is then forwarded to the user's terminal. Based on this information, automation and data concentration can lead to the application.

Irrigation system control is unthinkable without the use of a wireless sensor network. Sensor nodes used to collect data from the fields are particularly important for researchers and farmers. In addition, to implement smart irrigation, only data on soil moisture content is obtained from sensor nodes, but not on the amount of water. For the progress and development of this type of technology, a very important segment is the amount of water. Also, at this stage of implementing smart agriculture, it is necessary to try to reduce the costs of wireless sensors, irrigation control devices and hardware and software maintenance (Xiao et al., 2010).

Despite all this, development and application of wireless sensor networks have grown over the past ten years. This has been largely due to the reduction in the prices of sensors and radio transceivers (RTP – radio transceiver) for communication over short distances. This means that today it is possible to create relatively inexpensive devices that are equipped with sensors, a processor, RPP and an independent power supply. By networking such devices, it is possible to create a BSM that can observe a phenomenon from short distances and transmit information to an arbitrary location on the Internet (Zogović et al., 2008).

2.2. Status of smart technology applications in Serbian agriculture

In current documents and strategies of the Government of Serbia, agriculture is an important element of the economic development of Serbia. Agriculture is not only important in economic terms but also has a social and environmental component. So far, Serbian agriculture has achieved the level necessary for food production. However, the agricultural production sector has not yet capitalized fully on the substantial potential created by favorable climatic conditions, natural

soil characteristics, and available water resources (Simonović, 2014, p. 124-132).

Scientific research in Serbian agriculture is carried out by scientific research organizations, or institutes. On the other hand, almost all agricultural faculties have established institutes that deal with scientific work, as part of their departments or sections.

Higher production in agriculture would be further increased by engaging appropriate scientific institutions. These institutions would contribute to the mastery of new technical and technological achievements or would facilitate better use of new procedures in the cultivation of various plant varieties. We believe that in the implementation of smart agriculture, these institutions would become indispensable.

In this regard, the Government of Serbia, in cooperation with the BioSense Institute, opened the Center for Digital Agriculture of Serbia in 2017.

This center is one of the first cooperation between the Government of Serbia and researchers from the BioSense Institute on the implementation of information technologies in agriculture. The center is an example of the practical application of innovative IT solutions and digitalization to increase the efficiency and competitiveness of domestic agriculture.

The BioSense Institute participates in 30 national projects and around 50 international ones, most of which are from the European Union's research and innovation program (Horizon 2020). The most prominent project, ANTARES (H2020), was supported by the European Commission and the Republic of Serbia, which enabled BioSense to become a leading Center of Excellence for Sustainable Agriculture.

The development of sustainable and smart agriculture is also being supported by the start-up companies Cooperation Manager and Terra controlling, which have presented the use of machine learning algorithms in processing large amounts of geospatial data such as satellite images, UAV images, ES probe, GPR, altitudes, etc. to create an optimal surface for causation.

The accelerated development of software solutions, techniques and methods has created the conditions for modern information technologies to find their place in the agricultural sector. The application of these new technologies and information systems in agriculture is the future and creates opportunities for improving agricultural production and the economic operations of agricultural producers.

Introducing our agricultural producers to new technologies would be useful and productive for our agricultural production. Serbian agriculture faces many challenges on its path to the EU. A better organized and reformed agricultural policy, which would rely on the application of technical, technological, and environmental standards in agriculture, is one of the models that would provide a more equal status for our agricultural producers with agricultural entrepreneurs in the European Union.

One of the potential solutions for our agricultural producers could be their joint organization into various associations of agricultural producers or cooperatives, all with the aim of making it easier to obtain the funds necessary for the implementation of smart agriculture. According to the current legislation, cooperatives in Serbia are practical organizations. In the modern world of business, most cooperatives tend to focus on fulfilling their current obligations. This way of thinking can help the cooperative movement to operate in a proper manner (Simonović et al., 2016).

Table 1 Farmers' awareness of the possibility of using smart technology

Year	2019	2023
Aware	4%	9%
Moderate awareness	20%	23%
Low awareness	43%	47%
Unaware	32%	20%

Source: The authors' survey-based calculation

Farmers' awareness of the possibilities of using smart agriculture is very low, as can be seen from (Table 1). Only 4% of farm owners claim to know a lot about the possibilities of applying smart technology in agriculture. Nearly 2/3 of respondents in this survey are not or are partially familiar with smart technology in agriculture. This ratio changes in 2023, where 9% of farm owners claim to know a lot about the possibilities of applying smart agriculture. Compared to 2019, this percentage has almost doubled. Insufficient awareness of agricultural producers and their insufficient willingness to accept the fact that profitable production can be successfully realized by controlling the consumption of external inputs, is a key limiting factor in the wider application of smart technologies. Therefore, it is necessary to raise awareness about the possibilities of saving time, energy, water, and other inputs using new technologies in agriculture.

The introduction of new technologies requires major transformations of the agricultural system, rural economy, natural resource management, and the entire community. This process requires a systematic approach to achieve all potential benefits. The modest use of new technologies in Serbian agriculture is most often explained by economic arguments. Small-scale farms, which are the most numerous, generally do not use new technologies since investments are too high given the size of their plots (Roljević, 2021).

To reduce production costs and increase profits, individual producers with small holdings, but also large farms, prefer to use conventional agricultural methods and apply cheap production equipment rather than introduce new technologies, which they generally consider expensive and unprofitable. In this sense, the association of farms represents a great opportunity for economic strengthening, modernization, and digitalization of production (Paraušić et al., 2018). The formation of cooperatives or associations of farmers is necessary for the consolidation of holdings in Serbia and the survival of small farms, and given that these would be large systems, the use of innovative technologies would no longer be a problem. The lack of partnership between producer associations and educational institutions, along with the generally inefficient transfer of knowledge and innovations to farmers, also limit the dissemination of new knowledge and experiences in the use of new technologies.

We believe that AI offers benefits for agriculture, but there are also numerous challenges in its implementation. One of the biggest challenges is the lack of infrastructure, especially in rural areas. In this whole process, it is necessary to educate farmers so that they can use new technologies in the most efficient way possible. This is supported by the recent digitalization and use of the eAgrar application for monitoring registered agricultural households and e-incentives. In addition, the initial costs of implementing these technologies can be high, which can be an obstacle for smaller farms.

In addition to investing money in the application of new technologies, expertise is also needed. In this regard, the state should promote smart agriculture and train advisors as part of its systemic support. Smart management in agricultural production can be widely applied if the existing subsidy measures are increased to cover a portion of the purchase costs for new technologies.

The future of the application of new technologies is certainly promising. The growing world population is the primary cause of rising food needs. For this reason, the efficiency and sustainability of agriculture are becoming priorities. Innovations in the field of AI and IoT will continue to transform agriculture, making it more productive and sustainable.

Serbia is a country with a rich agricultural heritage with enormous potential and can be well positioned in the field of smart agriculture. To achieve this, investment in infrastructure, research and development, as well as education of farmers is necessary. For AI technologies to be implemented on farms across the country, the state and the private sector should cooperate to provide resources and support. Although technology and agriculture may seem so incompatible, it is precisely this synergy that will ensure the future of quality food and preserve natural resources.

Smart agriculture, as a new technology, undoubtedly brings revolutionary solutions. Investing in technology, education and research ensures a sustainable and prosperous future for all agricultural sectors in Serbia, which often lags, but in many cases manages to keep up with global trends.

2.3. Smart technologies in winemaking

Now that new technologies are available, producers to obtain and use very precise and accurate information about their vineyards. This data gives them a good basis for making appropriate decisions regarding increased productivity, but also environmental and financial sustainability. This toolkit includes remote and proximal sensing technologies, GPS, GIS, geo statistics, AI and DSS. Digital viticulture or precision viticulture are terms commonly used to describe the development and application of smart technologies in viticulture (Ammoniaci et al., 2021, p. 201). Precision viticulture or digital viticulture consists of three steps:

- collecting data from vineyards,
- extracting information from the data obtained, and
- development and implementation of a management plan based on a previously conducted analysis.

Non-invasive sensing technologies such as spectroscopy, MSI, HSI, Chl fluorescence, thermography, ER, LiDAR and CV in wine grape production systems can be used to obtain key

information about the vineyard and its grapevines (Matese et al., 2015a) and (Fountas et al., 2020b). They can be used as portable sensors or can be deployed in ground platforms such as remotely operated vehicles, autonomous robotic systems or airborne platforms such as satellites, small aircraft, and drones (Matese et al., 2015b; Matese et al., 2018). The widespread availability of smartphones and "apps" has changed the way growers can access the information they need and measure the quality of the vines and bunches in the vineyard. Many operations in the vineyard will likely be automated in the future using specially designed robotic devices equipped with non-invasive sensor technologies (Vougioukas, 2019).

The use of digital technologies gives grape growers the ability to map their vineyards with high spatial resolution and great flexibility in the timing of data collection, on grapevine variation and quality such as canopy size (Sanz et al., 2018), water (Gutiérrez et al., 2021), nutrient status (Diago et al., 2016), yield (Aquino et al., 2018), grape composition (Gutiérrez et al., 2019), infections, and diseases (Mahlein et al., 2019). The ability to map the spatial variability of grapevines, soils and topographic features in vineyards also allows grape growers and winemakers to better apply fertilizer use, pest control spraying, and irrigation water (Tardaguila et al., 2021).

AI and other types of precision winemaking in wineries collect data obtained from sensors and use it to improve production (Izquierdo-Bueno et al., 2024). The ability to control the state of wine stocks and barrels in real time allows for optimal production planning based on the analysis performed. The application of these new technologies can help wineries maximize their productivity. Thanks to the information obtained about the conditions in the barrels, AI can determine or predict wine quality based on the distribution of its components, monitor the wine maturation process in the barrels and perform sensory analyses of the fermentation products (acids). In this way, the application of AI directly affects the productivity of the winery by saving time and money.

In the final stage, namely distribution, wine producers use artificial intelligence to reach the end customer, changing the ways consumers buy wine, understanding product preferences and generating end-to-end direct customer channels that will ultimately lead to productivity. One of the interesting uses of the application is in the marketing stage where devices create virtual reality.

Wine tourism can also be promoted through these applications. By wearing virtual reality glasses, consumers can have the impression that they are in an actual vineyard or winery when they are in fact at home tasting different wines. The application of new technologies could create new opportunities for the development of the viticulture and wine sector. This situation could attract investors interested in the development of new technologies, as well as new customers who are open to this type of experience. Another example of a potentially interesting application of AI technologies is a "virtual sommelier" that provides recommendations to an individual consumer.

Viticulture in Serbia in the 21st century is undergoing changes thanks to the advancement of smart technologies. Automation, smart monitoring and digital platforms have become an indispensable part of modern viticulture. It is these innovations that enable precise vineyard management, climate, and soil quality monitoring, and, most importantly, improve the quality of grapes and wine.

The use of smart technologies represents the future, which is gaining strength especially in these conditions when climate change is increasingly present and must be considered more and more. We asked this very question to winegrowers and winemakers: are they ready to use the benefits of smart technologies soon?

Table 2 Are you ready to implement smart technologies in your vineyards?

Year	2019	2023
Yes, I would apply.	44.74%	51.32%
Maybe	30.26%	32.89%
No, I would not apply.	25.00%	15.79%

Source: The authors' survey-based calculation

The data we received from the survey tells us that there is a solid number of winegrowers and winemakers in Serbia who are ready to apply smart technologies in their wine production (Table 2). Survey results indicate a slowly but surely growing trend in interest. It is logical that younger winegrowers and winemakers are more interested in applying smart technologies. They are also more skilled in using smart technologies.

Table 3 What are the biggest limitations in implementing smart technologies in your production?

Year	2019	2023
High price	31.58%	34.21%
Small government subsidies	23.68%	27.63%
Poorly developed internet	44.74%	38.16%

Source: The authors' survey-based calculation

Another problem identified by the survey is related to financing the implementation of new technologies. The high cost, but also insufficient state support, are cited as reasons. However, the biggest problem is the insufficiently developed internet network (Table 3).

2.4. Various smart technologies applied in grape and wine production

The integration of artificial intelligence significantly contributes to the process of grape growing and brings about radical changes through precision agriculture methods, which directly improve crop control and maximize yields. The spectrum of solutions based on artificial intelligence includes various innovations: from algorithms for early disease diagnosis and the use of unmanned aerial vehicles (drones) for pest control, to robotic systems for automated harvesting. Innovative technological progress is accelerating the transition to more economical and environmentally friendly business models in the viticulture sector. The role of these tools will become an indispensable standard for any competitive producer in the future. A more detailed overview of the key technologies follows below.

One of the most important aspects of AI applications in this field are disease identification and prediction models. The functioning of these systems relies on machine learning and the analysis of previous experiences, climatic parameters and environmental conditions to assess the risk of infections. Given that pathogen control is of particular importance for preserving the vitality of vineyards, artificial intelligence offers sophisticated mechanisms to make the process significantly more efficient.

The foundation of a successful technological model is the systematic collection of data to facilitate disease prevention. Information is drawn from a variety of channels, including automated weather stations, ground-based sensors, and satellite detection. These sources generate valuable data on the conditions that determine the health status of the vine. For example, a sensor network deployed within the plots continuously measures parameters such as soil and leaf moisture, as well as air temperature. It is these indicators that play a crucial role in the emergence and spread of critical diseases, such as downy mildew and powdery mildew (Marcu et al., 2022).

An innovative breakthrough is predictive modeling, which relies on the formation of algorithms that can predict the appearance of pathogens in real time by processing data. For example, by analyzing current climatic conditions and humidity levels, the system can assess the risk of powdery mildew with high precision. This predictive ability allows vineyard management to focus on preventive and localized measures before the epidemic affects the entire plantation (Maddalena et al., 2023).

The effectiveness of these models relies on their connection to decision support systems, which provide producers with concrete and practical guidance. For example, the application can generate alerts when environmental factors become favorable for diseases, suggesting changes in irrigation cycles or adequate application of protective agents and nutrients. This proactive management model reduces the traditional reliance on spraying calendars typical of conventional agronomy, thus affirming more environmentally sustainable approaches (Rossi et al., 2010). The continuous implementation of IoT (Internet of Things) technologies and advanced machine learning further optimizes these platforms, enabling superior monitoring and immediate response in the field (Jovanovska et al., 2022).

A significant transformation in the pest control segment is brought about using drones (UAVs) that integrate artificial intelligence-based imaging systems. These drones capture high-resolution images, which are then subjected to detailed algorithmic analysis to locate the initial hotspots of insect infestations. Sophisticated AI software recognizes specific visual anomalies on the foliage that signal the presence of destructive species, such as phylloxera or grapevine moth (Jain et al., 2023).

The use of drones offers numerous benefits compared to conventional pest monitoring methods. These systems allow for efficient scanning of large areas under vineyards, achieving a complete insight into the condition of the plantations in an incomparably shorter time than is the case with a physical field visit. The speed with which data is collected from the air is crucial for early diagnosis of problems, thus ensuring continuous and accurate monitoring (Dubuis et al., 2022). Unlike modern solutions, manual inspections require considerable effort and time,

and are often subject to subjective oversights, especially in difficult-to-reach plots.

A revolutionary shift in the domain of primary production is brought about by the introduction of automated harvesting guided by artificial intelligence. This complex concept combines several advanced branches of technology:

- robotics, which is used for grape harvesting,
- computer evaluation of grape bunches, and
- machine learning designed to interpret visual inputs and make decisions in a split second.

The application of all these combinations allows the selection of grapes at their optimal maturity (Chen et al., 2023).

Like drones, robotic pickers are equipped with a network of optical sensors to create detailed images of the harvested fruit. AI algorithms analyze high-resolution images in real time, determining quality through analysis of color, size, geometry, and skin morphology, thus clearly separating optimally ripe from unripe fruits. This precise selection directly improves the quality of the final product and minimizes losses caused by poor-quality raw materials (Xu et al., 2023). Modern artificial intelligence models are undergoing constant evolution, demonstrating extraordinary reliability in recognizing quality fruits even in environments with variable lighting or in dense foliage (Slimani et al., 2023).

Water resource control is a fundamental element in viticulture, as it directly determines yield and fruit characteristics. The application of AI solutions enables high precision in irrigation by processing input from soil moisture sensors, forecasting meteorological conditions, and monitoring indicators of the physiological stress of the vine (Lowe et al., 2022).

In addition to the operational efficiency brought about by innovation, managing potential risks and improving production phases are the backbone of modern oenology. This branch is exposed to numerous challenges, primarily unpredictable biological factors and diseases, which can degrade the value of the final product. Adequate risk management is crucial to neutralizing these dangers and achieving lasting stability in the winery's business. With the help of artificial intelligence, producers can anticipate and prevent threats using predictive models, real-time monitoring and strict regulation of environmental factors. For example, AI systems can identify the presence of mycotoxins and other harmful substances, thus guaranteeing that the wine meets the highest sanitary and safety criteria (Qian et al., 2023).

Additionally, AI-based platforms can aggregate information from across the entire supply chain. This enables complete transparency of the production path – from the field to the end customer – which is key to building consumer loyalty and complying with legal regulations (Liu et al., 2023, p. 1242).

From all the above, we can see that new technologies have become a key factor in grape growing in the 21st century (Rivera Chavez et al., 2025). Winegrowers who utilize these tools to optimize their business will have an edge over their competitors. In a rapidly changing world, winegrowers need to remain open to innovations and use them properly to achieve success in their production.

Finally, we would like to emphasize that uncertainty about environmental protection is a key issue in agricultural production in general, given that this sector is completely dependent on natural resources and climatic factors. Climate change affects all countries in the world, limits the availability of natural resources, slows down national economies and affects people's lives (Kasimati et al., 2024). The increase in temperature and changes in the precipitation regime due to climate change are likely to have serious implications for the availability of natural resources and thus for agriculture (Kopsacheilis et al., 2024). In this sense, the changes that await us in the future in the production of grapes and wine in certain areas intended for this, represent the safest method of production, which ensures precise climate control, high yields and availability of products in the usual part of the year, high energy efficiency, as well as a relatively high financial result. We propose to increase research that primarily relates to the safety, environmental and economic aspects of the wine industry. Such research is still lacking (Adamashvili et al., 2024). has been a lot of progress in applying new technologies in developed countries, especially in the West. The percentage of agricultural producers who use new technologies ranges from 15% to 75%. A very modest range from non-application to

Conclusion

The application of new technologies in agricultural production, i.e. viticulture and winemaking, has great potential that can improve production. There

25% is observed in Europe. The Republic of Serbia also falls into this European average. Other countries in the world, such as China and India, are increasingly investing in and developing this method of agricultural production. We can see from all the above that smart agriculture represents the future.

Climate change, which is increasingly present, may affect the current way of producing food, and therefore the production of grapes and wine. Furthermore, climate change is an additional motive that contributes to the development, and then the application of new technologies. All this may also affect the change in the current attitude in agricultural production in Serbia. The goal of developing new technologies in agriculture should be to support global food security and reduce poverty and hunger.

We believe that new technologies should not be limited to large and developed agricultural holdings. They should contribute to the development of other forms of agricultural activity, such as viticulture and winemaking. When implementing new technologies, attention should first and foremost be directed to small family farms.

It is precisely the application of new technologies that can improve the prestige of Serbian winegrowers and winemakers among European consumers. By reducing water usage or optimizing pesticide use, new technologies can contribute to environmental protection.

Finally, we would like to emphasize that agricultural producers in Serbia should be more active and more involved in projects that promote the use of new technologies. The Ministry of Agriculture could help in the application of new technologies, facilitate preparations for a future that, as it seems, will increasingly depend on climate change The Ministry of Agriculture has a role to play in applying new technologies and preparing for future that depends increasingly on climate change. We believe that this could be done through subsidizing this type of production, but also by using systems that are present and are already being applied in smart agriculture.

Declarations

Availability of data and materials

The datasets used and analyzed during the current study is available from the corresponding author on reasonable request.

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