Title: Attitudes and Perceptions of Winegrowers about Nanotech Solution for Plant Protection from Fungal Diseases in The Republic of Moldova

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ABSTRACT
This research explores winegrowers' attitudes towards nanotech plant protection for managing ESCA, a fungal disease in vineyards. The wineries of the Republic of Moldova were chosen as a sample for this investigation. Via semi-structured interviews conducted with Moldavian winegrowers, the extent of openness to innovative approaches and the potential advantages of nanotech treatments was highlighted, such as fungal disease control and increased sustainability. Due to the novelty of the proposed treatment method, the interviewees shared their first impressions and sincere feelings about the suggestion. Overall, shared attitudes about nanotech plant protection have a positive tendency toward further implementation in the case of climate change progression. However, technology adoption is strongly related to innovation, individual and company characteristics, as well as social context and economic factors in which the company operates.

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INTRODUCTION

Climate change is an essential factor that influences the agricultural sector. The rising temperatures associated with global warming may cause crop decline and accelerated development of the plant's edible parts. Additionally, even though the impact of precipitation on yields is steadier, excessive or insufficient watering may be crucial for gaining rich crops (Sutton, 2013). Furthermore, these future climatic conditions will be more favorable for the development and spread of most fungi (Rienth, 2021).

One such fungal disease that has long plagued the viticulture industry is ESCA. This disease manifests as discoloration and stains on leaves, trunks, and clusters, spreading throughout the entire plant. The current ESCA control methods primarily focus on prevention or slowing the disease's progression but fail to provide a solution for its elimination (Ouadi, 2019). Given the projected trend of temperature rise by 2050, according to Sutton (2013), these challenges are likely to worsen over time. That means a change in approaches, actions, and beliefs, in general, is needed for successfully managing emerging troubles (Mayers, 2014).

Nowadays, the ESCA problem can be solved by implementing nanotech innovation, which involves using nano fungicides in a sustainable bio-polymer capsule. This innovation tends to reduce the harm of fungicides on human health and the environment and rationalize resources' use (Machado et al., 2022). However, despite all the benefits, the technology acceptance by winegrowers is not known in advance and has become a field for research.

The goal of this study is to analyze winegrowers' attitudes toward the implementation of nanotech plant protection from ESCA. By exploring winegrowers' perceptions, the research aims to gain insights into their acceptance and potential barriers to adopting this innovative approach. Specifically, it seeks to answer the question of winegrowers' perceptions regarding introducing nanotech plant protection from ESCA. This research question focuses on understanding the attitudes of winegrowers towards the use of nanotech plant protection, encompassing the type of approach (nanotech), the type of organization (winegrowers), and the type of issue (ESCA). Due to the country's agricultural activity specification and fame in the wine industry, Moldavian wineries are taken as a research sample to explore the topic.

This study supports technological adoption, sustainable farming practices, and agricultural innovation. Examining winegrowers' opinions on nanotech plant protection can help the research enhance knowledge and comprehension in these academic domains. The results of this study are also practically applicable to the agriculture and wine industries. Understanding how winegrowers feel about and accept nanotech plant protection may be extremely helpful in creating and putting into practice sustainable fungal disease prevention measures. It can help business stakeholders and winegrowers make educated decisions about implementing innovative treatments for fungal diseases and reducing their adverse effects on vineyards and wine production.

The paper is organized as follows: Chapter 1 will introduce the research issue and describe the study's setting, challenges, and objectives. The theoretical framework for the research will be established in Chapter 2 through a review of the pertinent literature on the adoption of innovations, technological acceptability, and agricultural practices. The research methodology will be described in detail in Chapter 3, along with the research design, sample selection and its description, measurement, data collection process, and analysis methods. The research results are discussed in Chapter 4, along with the winegrowers' attitudes and impressions of nanotech plant protection. The key findings and limitations will be discussed in Chapter 5, which will also examine the research's academic and practical relevance and address suggestions for further study.

THEORETICAL FRAMEWORK

The theoretical framework of this research is based on an understanding of technology adoption in the agricultural sector, emphasizing the attitudes of Moldavian winegrowers toward the use of nanotech solutions for fungal disease control. The process of adopting new technology in agriculture is complex and is affected by several variables. Learning the factors influencing people's attitudes is crucial to better understand the case. First of all, technology adoption is the progression through a series of stages by which an individual or other decision-making units moves from *initial knowledge* of an innovation through the *formation of an attitude* toward it to a *decision* to adopt or reject, and finally through the *implementation* and use of the new idea and *confirmation* of this decision. Factors that contribute to whether or not people adopt new technologies are a *relative advantage* - the degree to which a new idea is seen as better than the one it replaces; *compatibility* - how well an innovation fits with the established beliefs and past experiences; *complexity* - how difficult an invention is to understand and apply; *trialability* - the extent to which an innovative concept may be tested, and *observability* - how clearly others can see the outcome of the innovation (Rogers, 2003). Moreover, adopting new technologies in agriculture is affected by *innovation*, *individual* and *company characteristics,* and *social context* (Kutter et al., 2011).

Innovation

The problems in Moldavian winegrowing are caused by grapevine wood fungal diseases such as grapevine apoplexy (ESCA) and others (excoriosis and eutyposis), which development is strongly related to the weather, i.e., climate change (Shmatkovskaya, 2016). ESCA is a severe disease of grapevine trunks that can lead to vine death. It affects the physiological function of grapevine trunks and potentially leads to plant death. Esca is now managed by pruning practices, fungicide sprays, and protective coatings on pruning wounds; nonetheless, these practices only prevent or slow the spread of the disease but do not eliminate the problem (Ouadi L et al., 2019). Fungicides are also often used to fight fungal diseases. Their use, however, has been linked to soil and food contamination and other environmental hazards. The nanotechnological biopolymer-based shell is an ecologically beneficial alternative to conventional petrol-based capsules for fungicides. These biopolymers, which include cellulose and lignin, are biodegradable, renewable, and low in toxicity, and they integrate well into biogeochemical cycles (Machado et al., 2022). The benefits of using the nanotech solution are more freedom in administration, better crop foliage, and fewer fungicides needed. However, they cause changes in phytophysiology produced by nanoparticles and, consequently, the need for more study into their environmental and food safety consequences. Despite these obstacles, biopolymers have

considerable promise for soil ecology and human health since they reduce farmers' work and the number of active compounds put into the soil, leading to more efficient use of available resources (Machado et al., 2022).

Individual

Davis's (1989) Technology Acceptance Model (TAM) is another framework for anticipating and explaining how users will respond to novel types of technology. TAM claims that the two most essential elements in determining whether or not a person would adopt new technology are the technology's *perceived usefulness* and its *ease of use* (Figure 1). The adopters' perception of a system's *usefulness* is measured by how much they feel it will help them do their job more efficiently, while their perception of the system's *ease of use* is measured by how little they believe they will have to change their current workflow to take advantage of it. TAM may be used to investigate the variables that influence winemakers in Moldova to use nanotech solutions for ESCA management. Nanotech solutions may be more widely accepted if their potential advantages are widely known and appreciated. These advantages involve lowering negative environmental and human health impacts and using available resources more efficiently. The winegrowers' familiarity with comparable technologies and the availability of information and support services might affect the nanotech solutions' perceived ease of use. The winegrowers' impressions of the effectiveness and simplicity of the nanotechnology solutions may play a role in decision-making.

In addition, the adoption of nanotechnology solutions for ESCA control may also be influenced by the views and opinions of winegrowers. According to Ajzen's (1991) Theory of Planned Behavior (TPB), an individual's actions are determined by his or her intention to perform the behavior, which is affected by the individual's attitude toward the behavior, the subjective norms surrounding the behavior, and the individual's perceived behavioral control (Figure 2). Therefore, winegrowers' intentions to use nanotech solutions for ESCA control may be influenced by their attitudes about the technology, the social norms around using such solutions, and their perceived abilities to apply such solutions.

Company

Economic considerations may also influence technology adoption. According to Feder et al. (1985), the adoption of new technologies in agriculture is often impacted by the predicted profitability of the technology, the availability of finance, and the amount of risk associated with the technology. Moldovan winegrowers may use nanotechnology technologies for ESCA control depending on their estimations of the potential profit and dangers of doing so. For instance, they could be more open to adopting nanotech solutions if they see them as economically viable and beneficial. However, if nanotechnology solutions are considered hazardous and unpredictable, they may be less likely to be adopted.

Moreover, according to Schilling, 2020, mature firms are more able to obtain financing for innovations. However, they have more bureaucratic inertia and strategic commitments, which can slow down or hinder the process. Small companies, on the other hand, are usually more flexible, entrepreneurial, and open to modern technologies. However, they are less capable of investing in innovation and managing performance.

Social context

The social and cultural environment in which the winemakers operate impacts their likelihood of adopting nanotech solutions for ESCA control. Pannell et al. (2006) argue that social and cultural contexts, including social norms, cultural values, and social networks, might affect the acceptance of new technology in agriculture. Nanotechnology solutions may be less likely to be adopted by the wine industry if they are seen as at odds with the norms and customs.

METHODOLOGY

The qualitative research approach was chosen to answer the research question and explore the fungal disease problem extent among local winegrowers. That was implemented through five semi-interviews conducted during May-June 2023 with local winemakers. Qualitative research is the most suitable approach because it aims to discover and comprehend the significance people attribute to social phenomena by analyzing non-numerical data. It entails gathering information through observations, interviews, or other techniques, then analyzing it to find correlations and trends.

Selection and Sample

First of all, the Republic of Moldova has been chosen as a place for the research conduction. The Republic of Moldova is a small country (area: 33.800 sq km; population: 2.6 million) located in Eastern Europe between Romania and Ukraine. Its climate can be determined as temperate continental (Biroul National de Statistica al Republicii Moldova, 2022), and about 75% of the nation's entire land area is occupied by Chernozem – the most fertile and diverse soil cover. These factors favor agriculture, making the country mostly oriented to this activity type. Moldova is worldly known for its wines. According to Table 1, 14.272 hectares of agricultural area are specialized for vineyards, and 77% are specialized for winemaking (Agricultură, 2023). In 32 international competitions in 2020, Moldovan wines received 956 medals. The medals won in international competitions uphold the history of honoring the worth of qualitative wines produced in the Republic of Moldova and place the nation among other wine producers worldwide (Wine of Moldova, 2023). According to the 2030 Wine of Moldova Strategy (2017), Moldavian winegrowers will not stop there and will introduce innovative technologies and methods to keep up with the times and correspond to international standards. Therefore, the quality of grapes and the great harvest are key factors in implementing the goals. All these characteristics exhibit the appropriateness of the country's choice.

Companies were carefully selected to reflect the target audience, which was made up mostly of local winemakers with direct knowledge of the ESCA issue. Moreover, two large-, one medium-, and two small-sized companies were interviewed to explore the size relation to the attitudes about nanotech adoption. Experts in agriculture from Purcari, Et Cetera, MIGDAL-P, DAC, and Cricova wineries contributed to the sample, broadening the scope of discussion. The gathered data varies because of their perspectives, life experiences, and firms' size and strategy.

Interview Protocol

The interviews allow the direct gaining of the actual information about the extent of the ESCA problem in the country, the winemaker's experience with it, techniques they are using to get rid of the disease, awareness of innovative solutions, attitudes towards nano fungicides, and willingness for the implementation. The semi-structured interview approach was chosen because it integrates the adaptability of an unstructured interview with the organization of a structured interview. It involves developing a framework for the debate while allowing participants to express their opinions through open-ended questions. Studying the entrepreneurial identities of winegrowers might benefit from using semi-structured interviews since they are an effective tool for examining nuanced and subjective perceptions and viewpoints.

The interview protocol was centered around understanding the extent of the ESCA problem, the winemakers' experiences with the disease, current prevention methods, awareness of nanotech treatment, attitudes towards the solution, and willingness to implement it.

Data Collection

Data was collected through face-to-face interviews conducted in Russian or Romanian languages, depending on the participant's preference. The interviews were guided by the Interview Guide (Appendix 1), which ensured consistency across all interviews while allowing for individual experiences to be fully expressed. The conversations were recorded with the participant's permission and then documented and organized for further analysis.

Data Analysis

The data collected from the interviews were processed and summarized in sections about each interviewed company. The cross-case analysis was also done to clarify the similarities and differences between wineries and understand the current situation and future possibilities for ESCA eradication in Moldova. The results were processed manually due to the small sample size.

RESULTS

During the research, representatives of Moldavian wine-making companies were visited and interviewed in order to explore relation and implementation of Sustainable Development Goals (SDGs), fungal diseases commitment and current management approaches, awareness about the nanotech treatment of fungal plant diseases, and winegrowers' attitudes and perceptions about this innovative solution. This chapter represents summaries of gained information from each company in separate sections following the same structure.

Purcari

The worldly known winery Purcari has a rich history firmly anchored in Moldova's winemaking tradition. Purcari has continuously strived for perfection in producing remarkable wines since it was founded in 1827. Purcari has been established as a recognizable figure in the winemaking landscape of Moldova due to his stunning vines and commitment to preserving traditions. The firm's history is based on a diverse array of domestic and foreign grape varietals (*The History of the Purcari Winery*, n.d.). The company owns over 2,000 hectares of vineyards in Moldova, occupying almost the entire area of Ștefan Vodă and expanding its holdings to neighboring countries - Romania and Bulgaria. The interview was held with the agronomist of the company Purcari who manages 130 hectares in the Novoanensky district.

Purcari places a substantial emphasis on crop sustainability and aligns its practices with the United Nations' Sustainable Development Goals (SDGs). The company has been instituting numerous practices to improve sustainability, including reducing harmful chemicals and mitigating environmental impacts. They are aware that their company is exposed to risks due to climate change, most notably in the form of an increase in plant diseases. They are eager to explore innovative solutions, such as nanotechnology-based remedies, to mitigate these risks.

The ESCA disease is a cause for worry for Purcari since it presents several difficulties relating to vineyard illnesses. Due to ESCA, their inventory has failed, resulting in financial losses. However, it was estimated that the average loss of a failed plant, including replacement and the time required to produce a comparable quality yield, was insignificant. Utilizing pesticides and eradicating infected bushes constitute their current methods of risk management.

Regarding nanotechnology treatments for the management of fungal diseases, Purcari is ambiguous. On the one hand, they recognize the potential of nanotechnology to provide targeted and effective disease control, reduce environmental damage, and boost vineyard yield. The company thinks incorporating nanotechnology may positively influence customer perception of their wines. However, they appreciate preserving traditional winemaking methods that are still working. They find it challenging to introduce new ones.

Purcari emphasizes the significance of information and evidence regarding the efficacy and safety of nanotechnology-based therapies concerning decision-making. They highlighted the practical aspect - the opportunity to try the product by themselves- essential in deciding on the purchase. They favor products from primary research conducted by universities or other institutions. They believe that the minimum efficacy rate should be around 95% to consider and support the product acquisition.

Overall, Purcari recognizes the long-term benefits of nanotech treatments, which include increased disease management, decreased dependency on conventional pesticides, and greater vineyard sustainability. Compared to traditional methods, they do not show high expectations for the efficacy of nanotechnology solutions in controlling ESCA due to the lack of knowledge in this field. However, they believe that by implementing nanotechnology solutions, the wine industry can improve its sustainability by promoting ecological balance and decreasing environmental impacts. Purcari shows conservatism and is wary of nanotechnology solutions in fungal disease management for themselves. But they expressed that these kinds of solutions might be successful in the wine industry in the long run.

Cricova

Cricova, an internationally recognized winery located in Moldova's center, was founded in 1952 and has since become a synonym for quality in Moldovan wine. Cricova is home to an outstanding wine collection, including rare vintages and sparkling varietals, stored in a vast subterranean basement system stretching over 120 kilometers. Cricova's superb wines come from carefully picked local and foreign grape types, and they are

known for their rigorous attention to detail and devotion to workmanship. The unique terroir and centuries-old winemaking traditions of Moldova are reflected in each bottle's high quality (*Cricova*, n.d.). To better understand Cricova's perspective on nanotech solutions for vineyard protection against fungal diseases, especially ESCA, this section summarizes the answers supplied by a winegrower from Cricova.

The representative works in the company for almost 12 years, taking the position of agricultural specialist on the land of 70 hectares in the Codru region. He clarified the history of his educational background at the Agricultural University in Chisinau and highlighted his ties to the viticulturist community.

The respondent highlighted the significance of responsible behaviors while talking about crop sustainability. Their attempts to tackle social, economic, and environmental problems, and although they didn't disclose many specifics about their Sustainable Development Plan, they were committed to achieving the SDGs.

The reply acknowledged that the effect of climate change on the development of plant diseases might be potentially harmful to the company.

The difficulties in dealing with plant diseases were underlined, and the interviewee's experience with fungal diseases was highlighted in particular. The present method of risk management was discussed, and issues like ESCA and plant diseases were explicitly mentioned. In discussing the preventative measures taken, the responder mentioned the application of pesticides, but the most common way of dealing with the problem turned out the uprooting. The winegrower rated the existing methods as valid for the time being but was open to discussing new possibilities for plant protection if the global warming situation worsens over time.

The representative did not hear about nanotech treatment before and listened carefully to the explanation. After the explanation and the he defended the economic feasibility of nanotech solution purchase and emphasized issues of safety. The maintenance of traditional viticulture methods in place is crucial for the company. Therefore, if they considered the transition to new ways of eliminating the disease associated with fungal diseases in the vineyards, then only partially as an experiment (at least for today). Cricova has called for trustworthy data and evidence of the other wineries' experience with nanotech solutions to support the claims that the way of treatment is effective, sustainable, and safe, with a minimum efficacy rate of around 90-95%.

Results from the interview with Cricova show that they are aware of the problems presented by plant diseases like ESCA and are not entirely ready to think about novel approaches to these problems, such as nanotech remedies. Preserving the traditions of Moldovan winemaking is an important part of the company's policy, so new approaches are hard to accept. However, the company does not deny the possible transition to nanotechnological solutions in fungal disease management, if the problem develops, and will keep this method in mind for the future.

MIGDAL-P

MIGDAL-P is a winery in the Moldovan area of Codru that has a long history of growing grapes and making wine. The business was established in 1995, and the first production lines were installed in December 1999 (CasaMare, n.d.). MIGDAL-P has been around for decades, making it a significant participant in the wine market. The corporation presently possesses approximately 400 hectares on which it cultivates a diversity of grape varieties. The section presents the findings of an interview conducted with an agronomist from MIGDAL-P to examine the attitudes and perceptions regarding nanotechnology-based solutions for vineyard protection from fungal diseases.

The representative of the company has been engaged in the MIGDAL-P activities for an extended time since 2005, carrying a wealth of wine-growing expertise with them. His educational heritage, which includes high agricultural education, demonstrates an awareness of the industry and its dynamic development.

The interviewee highlighted the significance of agricultural sustainability and acknowledged the importance of the Sustainable Development Goals (SDGs) in influencing their approach. MIGDAL-P implements practices that align with SDGs, such as responsible consumption, production, and climate action. Nanotech solutions provide a possible path for more effective disease management while lowering environmental impact, and they are aware of the need to prevent and control plant diseases like ESCA.

Climate change became a significant concern, posing potential risks to their livelihood. The winegrower said they were aware of the need to take preventative measures against the development of plant diseases due to climate change. Regarding ESCA disease, the interviewee emphasized their difficulties with the safety of remedies used to combat it. Fungal diseases were perceived as a threat to the company's future development, with variable levels of impact reported annually. The financial repercussions and the probable expense of replacing unhealthy plants were also highlighted as the economic effects of ESCA-related stock failure.

The existing techniques of ESCA prevention were evaluated as partially efficient, and the representative voiced interest in looking into potential replacements. Although familiar with current choices like pesticides and constant fungal treatment, they were willing to consider new methods. The presenter was optimistic about the potential of nanotech solutions for ESCA management and acknowledged the limited success of existing preventative techniques. Initially, the representative demonstrated unfamiliarity with nanotechnology but, after the explanation, viewed it as a potentially effective solution. Key issues influencing their choice to embrace nanotech treatments were sustainability and safety. However, employees' training and the maintenance of traditional winemaking methods have emerged as obstacle factors.

Nanotechnology-based medicines were thought to need credible data showing their efficacy and safety before they could be widely used. Primary research was viewed as especially valuable for establishing credibility. Clearly, the representative was interested in the advantages of nanotech treatments.

Regarding long-term benefits, the interviewee emphasized the potential for healthier vines, enhanced grape quality, and increased productivity due to nanotechnology solutions. The success of nanotech solutions in regulating ESCA is expected to be high; however, it was mentioned that the financial aspect will also play a significant role in purchase decision-making.

The representative recognized the positive impact of nanotech treatments on the general sustainability of the wine industry. By reducing reliance on traditional pesticides and adopting a more targeted and eco-friendly approach, nanotech treatments contribute to a more sustainable vineyard management strategy. He advised other winegrowers interested in nanotechnology plant

protection to conduct extensive research and pay special attention to the practical aspect.

In conclusion, the results of the interview with MIGDAL-P show that they are supportive of innovation, but only with a high level of efficiency and relevance of the product, as well as a clear strategic plan for implementation, which, for example, will include training to improve the skills of employees in this area. The representative's comments all illuminate their dedication to sustainability, knowledge of the dangers of climate change, and understanding of the financial effects of plant diseases. Overall, implementing nanotech solutions has the potential for revolutionary vineyard protection and disease management advancements, thereby contributing to the wine industry's long-term viability and prosperity.

Et Cetera

Et Cetera Winery, founded in 2003 by the Luchianov Family, has an impassioned and daring history. Alexandru Luchianov decided to settle down and pursue a career in grape farming and winemaking despite having a degree in mathematics and prior experiences as a scuba diver and skydiver. In 2009, along with his brother Igor, he invested in a winery to further develop the Et Cetera Estate, which he and his brother Igor began developing in 2006. Within its small area of 24 hectares, the winery employs both innovative and traditional winemaking practices, which, when combined, provide unique flavors. Et Cetera produces exceptional wines that capture the essence of Moldavian soil by cultivating relationships with the land and the people. With an annual production of 150 tons of grapes and a wide variety of grape varieties, they maintain a responsible approach to grape harvesting, ensuring that only the finest fruits are used to produce premium wines through meticulous selection and manual collection (*About – Et Cetera*, n.d.). The interview was conducted with one of the company's founders – Igor Luchianov, to determine their attitude toward nanotechnology implementation in fungal disease control.

The company's founder imparted extensive knowledge of viticulture and emphasized the significance of sustainable practices. They committed to implementing the Sustainable Development Goals (SDGs) and stressed the importance of SDG 3 (Good Health and Well-Being) in preventing and controlling plant diseases such as ESCA. The winemaker also recognized the effects of climate change on their industry and the need to deal with these dangers.

The interview disclosed that the company confronts numerous obstacles in its vineyards, with ESCA disease being one of the concerns. The winegrower stated that fungal diseases threaten their business and that they have observed stock failures due to the disease. Overall, they rate the danger of the problem as 7 out of 10 on the scale.

The winemaker described their current approach to risk management and disease prevention, including the use of pesticides. However, they expressed a desire to reduce the use of pesticides and investigate alternative methods. Current preventative strategies, such as pesticides, were assessed as mostly efficient but dangerous for health, revealing the dire need for more efficient solutions.

Igor was unfamiliar with the nanotechnology-based ESCA management strategy but showed great interest in that topic. He saw the promise in nanotechnology's capacity to help control the disease and was curious about the technology's long-term viability. However, potential obstacles were identified as safety issues, customer image, and the transition from traditional winemaking methods and organic farming practices.

When asked what data or evidence is necessary to guarantee the safety and efficacy of nanotech medicines, the company stressed the significance of scientific data and practical application. However, they also tend to rely on private companies' offers to provide the necessary evidence of the product's effectiveness.

The founder had high hopes for nanotechnology solutions and anticipated a substantial decrease in ESCA incidence and an improvement in vineyard health. He believes implementing nanotechnology treatments could improve the wine industry's long-term viability. Other winegrowers who are interested in nanotechnology plant protection were advised to conduct extensive research, initiate experimental projects, collaborate with research institutions, and utilize knowledge-sharing platforms.

In conclusion, the interview yielded helpful information on the winegrower's perspective on Et Cetera's nanotech solutions for vineyard security. The company showed sincere openness and enthusiasm in exploring and trying the nanotech solution for fungi control in their vineyards.

DAC

DAC is a young wine company founded in 2013 and located in the Codru region of the Republic of Moldova. The family business produces high-quality exclusive European standard wines in small quantities, mostly for export to Romania, the Netherlands, Poland, and the Czech Republic (Dac winery, n.d.). The interview was conducted with the founder and director of the winery - Constantin Furculete, who shared his attitudes about the nanotech treatment of his vineyards.

The company's attention to sustainable crop production and the Sustainable Development Goals (SDGs) is indicative of its concern for ethical manufacturing and ecological preservation. The effects of climate change on their industry are being closely monitored, and they are taking measures to combat the difficulties posed by plant diseases like ESCA, which may have serious consequences for vineyard output.

Despite the small number of vineyards, the firm places a premium on sustainable crop production and has adopted SDGs as part of its strategy for ethically sourcing and processing goods. They are aware that climate change poses a risk to their company, and those suitable disease management methods are essential to ensuring the company's continued success.

Concerning ESCA illness, DAC has encountered several obstacles. Constant care and preventative actions are required since certain grape types within their vineyards are vulnerable to this fungal disease. However, ESCA does not threaten DAC's continued existence by causing stock failure and economic losses. Due to the size of the company, the economic impact of fungal diseases does not seem so critical.

Preventative methods, such as the usage of pesticides, are an integral part of DAC's present strategy for controlling plant diseases. However, they want to use fewer pesticides and investigate other options. DAC acknowledges that present preventative strategies are helpful, but they are also interested in learning more about new options for ESCA management due to their orientation to the European market with high quality and ecological standards.

DAC is unaware of the technique for regulating ESCA with nanotechnology, but they showed openness to learning about it. Although they just heard about nanotech methods for ESCA

control, they are optimistic about its potential. Sustainable plant preservation is important to DAC, and the company understands the connection between customer loyalty to its wines and the spread of sustainable innovations in wine growing. Being a small young company, they don't hold much to traditional winemaking and organic farming approaches.

DAC stresses the need for thorough scientific data and practical proof from credible institutes to assure the efficacy and safety of nanotech medicines. They are ready to spend money on nanotech therapies with a high success rate, ideally above 90%. However, the price of the treatment has to balance out with the savings and advantages of less time spent on illness care and higher quality yields.

The use of nanotechnology in vineyards has several long-term benefits, including better disease control, higher quality yields, and less environmental effect, all of which have been acknowledged by DAC. Nanotech solutions to ESCA control are expected by the company to be more effective than previous techniques. DAC thinks that the wine sector as a whole may benefit from the use of nanotech therapies.

With its positive outlook on ESCA's nanotech approaches to vineyard protection, DAC demonstrates its dedication to environmental responsibility, technological advancement, and the enhancement of its winemaking techniques. Overall, DAC's perspective on nanotech solutions for vineyard protection from ESCA underscores the company's commitment to sustainability, innovation, and the continuous improvement of its wine production practices.

Cross-case analysis

Interviews with winegrowers from the Purcari, Et Cetera, MIGDAL-P, DAC, and Cricova wineries gained insight into nanotech-based solutions. Table 2 summarizes the main points found during the conversations with the representatives of these companies. It shows that winemakers were well aware of the dangers posed by climate change and its possible effect on their vines and recognized the need for novel solutions to meet the issues presented by fungal diseases in the context of the aggravation of the situation. This acknowledgment shows their openness to trying novel methods like nanotech-based treatments.

Representatives have seen the promise in nanotechnology-based methods of preventing ESCA. Targeted and efficient disease management, less environmental harm, more vineyard sustainability, and higher grape quality and yield are just some of the advantages. Some winegrowers were skeptical about nanotech solutions because of their lack of expertise in the field, while others were more optimistic.

They have stressed the value of knowing that nanotech treatments are safe and effective, with a high efficacy rate of more than 90%. They also emphasized the importance of actually using the product and chose those backed by original research from universities or other organizations. It was determined that credible nanotechnology therapies required both scientific evidence and actual use in the real world.

Several issues and problems must be addressed before nanotech solutions for ESCA control can be widely used. These included safety concerns, the preservation of traditional winemaking techniques, customer perception, financial considerations, and the training of employees. Winegrowers were wary of new technology due to a lack of knowledge and stressed the need for a plan of action.

They also have shown their dedication to the environment by acknowledging nanotech solutions' potential to improve the wine industry's long-term viability. Nanotech treatments were thought to be a solution to enhance ecological balance and reduce environmental consequences by lowering dependence on traditional pesticides apply and adopting a more focused and eco-friendly approach.

	Purcari	Cricova	MIGDAL-P	Et Cetera	DAC
Founding year	1827	1952	1995	2003	2013
Region (Figure 3)	Ștefan Vodă	Codru	Codru	Ștefan Vodă	Codru
Number of hectares	>2000 (Moldova)	>600	400	24	10
SDG implementation	Yes (Reducing harmful chemicals and mitigating environmental impacts)	Yes	Yes (Responsible consumption & production, climate action)	Yes (Good Health and Well-Being)	Yes (Ethical manufacturing and ecological preservation)
Climate change impact	Yes	Yes	Yes	Yes	Yes
ESCA threat to the business	Low	Low	Medium	High	Low
Current ESCA prevention methods	Pesticides, uprooting	Uprooting, pesticides	Pesticides, fungal treatment	Pesticides	Pesticides
Need for alternative methods	Low	Low (now)	Medium	High	Low
Awareness of nanotech solution (before interview)	No	No	No	No	No
Estimated efficacy rate	95%	90-95%	95%	>85%	>90%
Expected customer perspective	Positive	Neutral	Positive	Positive	Positive
Expected impact on general sustainability of wine industry	High	High	High	High	High
Significance of maintenance of traditional methods	High	High	Medium	Low	Low
Importance of employees' education and training	Yes	Yes	Yes	Yes	Yes
Importance of scientific evidence	Yes (+ practical application)	Yes (+ other wineries experience)	Yes (Private offers as well)	Yes (Private offers as well + practical application)	Yes (+ practical proof)
Expected long-term benefits	Improved sustainability, decreased environmental impacts	Higher efficiency in fungal disease management and sustainability	Potential for healthier vines, enhanced grape quality, and increased productivity	Higher efficiency regarding current methods, sustainability, vineyard health	Better disease control, higher quality yields, and less environmental effect
Main challenges for adoption	Lack of information and practical proof, maintenance of traditional methods	Need for education and training, preservation of traditional practices	The financial aspect, strategic plan for the implementation, trainings	Safety issues, customer image, and costs	The financial aspect, lack of knowledge
Attitudes towards nanotech solution	Ambiguous	Skeptical	Sees as a potential solution	Openness and enthusiasm	Openness to learning

Table 2. Summary of the main points gained during the interviews with Moldavian winegrowers.

DISCUSSION & CONCLUSION

The theoretical framework of this study was based on several theories, including Rogers' (2003) Diffusion of Innovations theory, Davis's (1989) Technology Acceptance Model (TAM), and Ajzen's (1991) Theory of Planned Behavior (TPB). This section makes an overview of those theories' usefulness, relevance, and applicability in terms of the research.

All winegrowers recognized the potential benefits of nanotech solutions, such as reducing harmful effects on the environment and human health and rational use of resources, which can be seen as the relative advantage of the technology from the Diffusion of Innovations theory. However, they also expressed concerns about the complexity of the technology and the lack of information and support services, which can affect the trialability and observability of the technology (Rogers, 2003).

The research showed that technology acceptance and openness to innovation depend on the company's size and maturity, which supports Schilling's (2020) theory. Larger wineries Purcari and Cricova expressed their concern and unwillingness at the moment to introduce nanotechnological treatment of fungal diseases, referring to their policy of maintaining traditional wine-growing methods. Young companies DAC and Et Cetera, in turn, were enthusiastic about the proposal and were open to trying it in practice, but they also wondered more about the financial component of this innovation than the representation es of large companies. The medium-sized company MIGDAL-P from the sample taken, showed a mixed attitude towards the proposed nanotechnology solution. Although the firm is open to exploring novel ESCA prevention and control approaches, it is not yet prepared to entirely forsake its established practices.

The factors of TAM (Davis, 1989) were also evident in the attitudes and perceptions of the winegrowers. The winegrowers perceived nanotech solutions as useful for managing ESCA and improving vineyard health (perceived usefulness). However, they also expressed concerns about the technology's ease of use, particularly regarding the availability of information and the need for employee training.

TPB (Ajzen, 1991) explains why winegrowers are hindered in nanotech implementation. Even though customers will implement the attitudes toward the behavior in the views of all companies, the subjective norms as maintenance of traditional methods in mature companies and lack of knowledge and practical proof – perceived behavior control, are not fully followed up. So, the interview results directly align with the theory – the more points fulfilled, the more positive attitude and openness to nanotech treatment was observed.

The study also considered the influence of economic factors (Feder et al., 1985) and the social and cultural context (Pannell et al., 2006). The winegrowers from MIGDAL-P and DAC acknowledged the potential economic benefits of nanotech solutions, such as increased vineyard yield and reduced use of fungicides. However, they also expressed concerns about the economic risks associated with the technology, such as the high cost of implementation and the uncertainty of the return on investment. Similarly, the winegrowers from Cricova, Purcari, and MIGDAL-P mentioned the influence of social and cultural norms on their decision to adopt nanotech solutions, particularly regarding the compatibility of the technology with traditional winemaking practices.

The findings of this study suggest that the adoption of nanotech solutions by Moldavian winegrowers is influenced by a complex interplay of factors, including the perceived benefits and risks of the technology, the availability of information, the compatibility of the technology with existing practices, and the social and cultural norms surrounding the use of the technology. Overall, the study's findings showed that the questioned winegrowers had a favorable impression of nanotech solutions for ESCA management. Despite differences in knowledge and anticipation, vintners generally saw nanotech treatments positively impacting vineyard sustainability. However, there are obstacles to the widespread use of nanotech solutions, such as the need for additional proof and the maintenance of traditional winemaking practices. The results of this research may be used to improve the wine industry's decision-making processes and foster the development of long-term strategies for preventing ESCA.

Limitations

In order to provide a complete picture of the research, the limitations should be taken it account. Future research may expand on this study and add to a more comprehensive knowledge of the issue by identifying the possible restrictions and concerns.

First, the sample size was small since interviews were only performed with certain winegrowers from a few Moldovan wineries. The results may not indicate the opinions and perspectives of all winegrowers in that country.

Second, the interviews were limited to the wineries in Moldova only. This might make it difficult to extrapolate the results to other locations or countries with similar agricultural methods and wine business features.

Third, the interviewed winegrowers need to gain prior knowledge regarding nanotech solutions, which raises the possibility of bias in the results from a brief review of the subject. Because only first impressions were shared, the results might be inaccurate. Winegrowers should study the long-term effects and impacts of nanotech solutions in vineyards in the future to establish their viability and effectiveness.

Fourth, there was insufficient comparative analysis since the interviews concentrated on winemakers' impressions of nanotech methods for ESCA management. However, the results did not include a comparison of different approaches or tools for handling ESCA. Conducting a more thorough evaluation considering various techniques is essential to fully appreciate nanotech solutions' possible advantages and downsides.

Fifth, the interviews did not go further into the financial barriers winemakers may encounter when using nanotech solutions. Operational, educational, transportation, and product expenses may be needed to implement for the winegrower's better understanding. It may also be difficult for wineries to efficiently embrace and apply nanotech solutions if they lack the necessary technical resources or specialist knowledge.

Sixth, the interviews didn't take into account human factors such as personal feelings about the nanotechnologies of the representative. The opinion of the winemakers about the nanotechnology solution was influenced by their own views and concerns about the proposed method, as well as their personal desire to preserve traditional winemaking methods.

Practical implications

This section highlights some of the most actionable information gained from the interviews with winegrowers about their attitudes toward Esca's nanotech management. These practical implications provide insight into the acceptability and challenges of using nanotechnologies for plant protection in the wine industry.

The findings from the interviews show how important it is to provide winemakers with trustworthy data on the effectiveness and safety of nanotechnology for ESCA control. Moreover, winegrowers were interested in collaborating with research organizations and universities. In order to get credible data and proof of the efficacy of nanotech therapies, educational institutions, and wineries can collaborate on research and develop venues for exchanging information. Building trust between these two communities and encouraging them to work together may lead to more accurate scientific data being collected and used.

The respondents also stressed the need for training and educating winegrowers on the application of nanotechnology in fungal disease management. It indicates that training and education programs should be created to help them learn more about this innovative solution and its applications in the wine-growing process.

The interview data shows that the cost of implementing nanotech treatments is a major factor in the decision-making process for winegrowers. The long-term economic advantages of these solutions, such as higher grape production, better quality, and decreased dependence on pesticides, need to be addressed and shown. Wineries may evaluate the viability of using nanotech solutions by discussing the economic benefits and possible return on investment.

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APPENDIXES

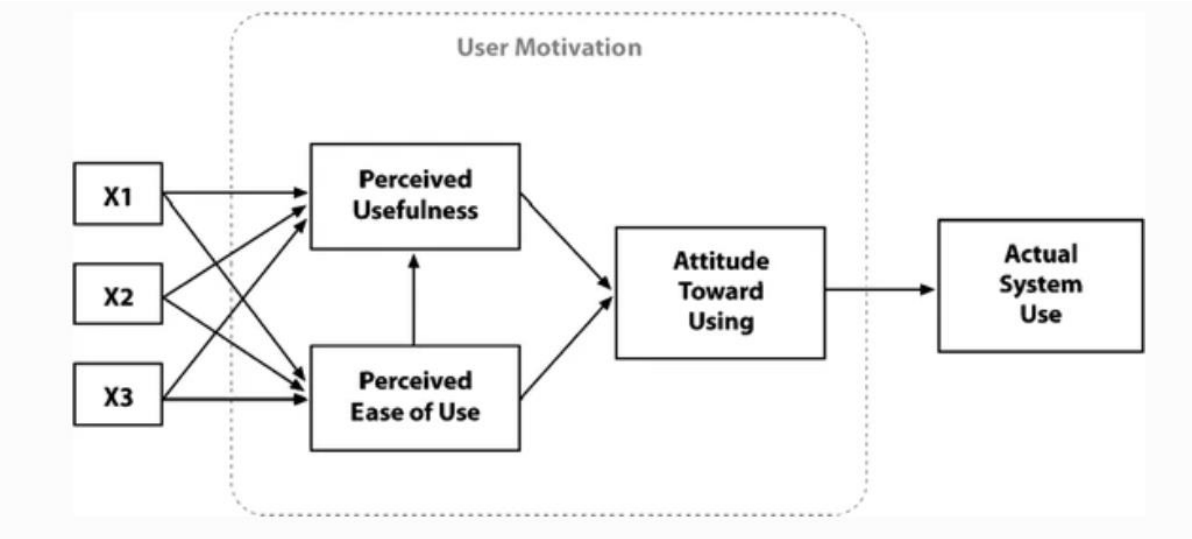

Figure 1. Technology Acceptance Model.
Retrieved from: Marangunić, N., & Granić, A. (2014). Technology acceptance model: a literature review from 1986 to 2013. Universal Access in the Information Society, 14(1), 81–95. https://doi.org/10.1007/s10209-014-0348-1

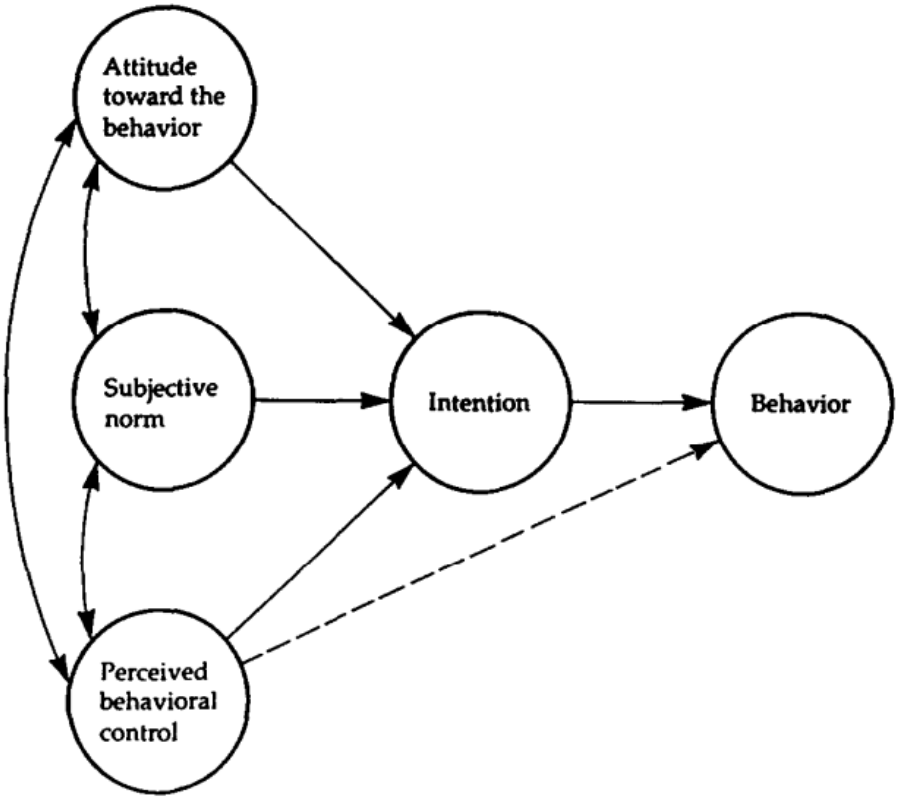

Figure 2. Theory of Planned Behavior.
Retrieved from: Ajzen, I. (1991). The theory of planned behavior. Organizational Behavior and Human Decision Processes, 50(2), 179-211. https://doi.org/10.1016/0749-5978(91)90020-T

Type of agricultural activity	*TOTAL agricultural holdings (number)*	*Economic size of agricultural holdings (thou. Euros)*	*Utilised agricultural area (hectares)*
SPECIALIZED FOR PERMANENT CROPS (Total)	1268	56910,01	54233,01
Specialized for vineyards	**274**	**13418,72**	**14272,00**
Specialized for quality wine	145	9749,90	11078,00
Specialized for table grapes	98	2473,69	1962,00
Other vineyards	31	1195,13	1232,00

Table 1. The agricultural area used for growing vineyards, the number of holdings, and their economic size.
Retrieved from: https://statistica.gov.md/ro/statistic_indicator_details/15

Appendix 1. Interview Guide

Clarification: the spoken content will be recorded with the participant's permission to transcribe the interview afterward. Some content may be published anonymously. This is a semi-structured interview including open questions. Participation in the interview is voluntary and takes place offline. By participating in this interview, you agree with these terms.

Intro – Topic overview

The research is aimed to explore the attitudes and perceptions of nanotech solutions for vineyards' protection from fungal diseases (specifically from ESCA).

Section 0. General questions

1. Tell me, please, about your company and its history.
   1.1. What grape varieties do you grow?
2. What role do you play in the company, and for how long?
3. Could you please, take me through your wine-growing experience?
   3.1. What is your educational history? What did you study and where? (to discover whether they have been entrepreneurially educated)
   3.2. What is your relationship to the viticulturist community?
   3.3. Are you part of a winemakers union?
4. How many hectares of vineyard belong to your winery?
5. To what extent does crop sustainability play a role for you?
   5.1. Does your company implement SDGs? How?

*Sustainable Development Goals (SDGs)- 17 international purposes created by the UN to solve social, economic, and environmental problems that the world is facing now till 2030.

   5.2. Do you have a Sustainable Development Plan? What kind of practices does it include?
6. Climate change could affect the spread of plant diseases, do you think climate change poses threats to your business in this form? How big is this threat? Do you think climate change is a threat at all?

Section 1. Plant diseases and their control

7. What kind of challenges do you face with your vineyards?
8. Describe, please, your experience with ESCA disease.
   8.1. Which grape varieties are more susceptible to fungal disease in your vineyard?
9. Do you think the ESCA disease poses a risk to the existence of your business? If yes, how and to what extent? (May ask to scale the threat from 0 to 10, where 0 – the problem doesn't exist, and 10 – has the crucial effect)

10. How much ESCA-related stock failure do you have on average per year (in plants), and how has the failure developed over the last 10 years?
11. How much (in euros) do you estimate the average loss of a plant that has failed due to ESCA (replacing the plant, including the time until it again produces a comparable quality of yield)? -> In case of an inappropriate answer:
    11.1. What is the approximate price of a new grapevine?
    11.2. Based on your experience, how often do you have to replace diseased plants with new ones?
    11.3. How much time is needed for a new plant to produce a comparable quality of yield?
    11.4. According to the previous years, what is the probability that the new plant will not survive in the old vineyard? (e.g., 2 out of 10/ 20% of plants will not take root)
12. What is your current way of dealing with risks such as plant diseases?
    12.1 What are you currently doing to prevent plant diseases like ESCA?
    12.2 Do you use pesticides? How do you administrate them?
    12.3 Do you plan to reduce the use of pesticides? When and how (what are other alternatives?)
13. What is your opinion about the current methods of prevention? Are they effective (scale from 0 to 10)?
14. Do you know about other existing solutions? If yes, do you plan to apply them? -> How OR Why not?

* **Current solutions**: Ignoring the problem, Burning infected plants, Spraying pesticides, applying contestant fungus

15. What characteristics does a crop protection product against ESCA need to have for you to make a purchase decision? What is the most important characteristic crop protection needs to offer you?

Section 2. Attitudes toward nanotech treatment

16. Are you familiar with the strategy for controlling ESCA using nanotechnology? If yes, how knowledgeable about this remedy are you?

***Brief explanation**: the nanotechnology consists in planting fungicides in a biopolymer capsule on a diseased plant, which is stable and safe (reduces environmental problems, the number of fungicides required for treatment, and the number of active substances introduced in the soil). After use, the plant will be fully cured and protected for approximately 5 years, increasing the yield, and reducing the effort and cost of preventing methods or planting new vineyards.

17. What is your impression of using nanotechnology in plant protection? Do you think that the treatment will be efficient in ESCA management? Why?
18. What aspects would you consider crucial when deciding whether to use nanotechnology in wine growing?
    18.1. Would you attach importance to sustainability in plant protection through nanotechnology?
    18.2. Do you have any concerns about the safety and health of humans that are connected to nanotechnology treatments?
    18.3. Do you believe that consumers' perceptions and acceptance of your wines might be impacted by the adoption of nanotech therapies for ESCA control?
    18.4. How significant do you find the maintenance of conventional winemaking techniques and organic agricultural practices to be?
    18.5. How important are employees' education and training (e.g., learning to use innovative technologies in practice) to your capacity to incorporate and make use of new technologies in your vineyards?
19. What kind of information or proof would you need to be confident of the effectiveness and security of nanotech therapies for the management of ESCA?
    19.1. Would you feel greater trust in products derived from primary research (university or other public/third-party institution) or private companies?
20. What should the minimum efficacy rate be (%)?
21. How much would you be willing to pay for one dose applied for one vine plant if the vaccine protects the plant for multiple years?

Section 3. Final Conclusions

22. What are your thoughts on the long-term advantages and disadvantages of using nanotech treatments in vineyards?
23. What are your expectations for nanotech solution success in controlling ESCA compared to conventional methods?
24. How do you believe the use of nanotech treatments for ESCA management may affect the general sustainability of the wine industry?
25. What suggestions would you offer to other winegrowers which are exploring nanotechnology plant protection?

Section 4. Demographic questions

26. May I ask your age? Age:
27. Gender:
28. Nationality:
29. Wine-growing region:

Figure 3. Map of Moldavian Wine Regions
Retrieved from: https://www.exoticwinetravel.com/moldovan-wine-introduction/#Moldova_Born_to_Wine