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AGRICULTURAL CHARACTERISTICS AND INNOVATION POTENTIAL IN THE VOJVODINA REGION, SERBIA

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Abstract: Based on a comprehensive literature review, using descriptive and multivariable statistical analysis on primary data, this paper examines agricultural innovation in Vojvodina (Serbia), dominated by small-scale producers using semi-traditional production methods, outdated machinery, gaining experience and developing their skills through practical work rather than formal education. Our research findings reveal while farmers possess strong managerial and production-related skills, there is a significant gap in digital competencies. Structural barriers, including fragmented land holdings, inadequate infrastructure, and limited access to funding, further hinder innovation uptake. One of our key findings is that despite awareness of the importance of innovations, implementation remains limited, highlighting the need to boost skills development, invest in infrastructure, and facilitate collaborative networks.

Key words: agriculture, innovation, Vojvodina region

Abstrakt: Na osnovu sveobuhvatnog pregleda literature, i korišćenjem deskriptivne i multivarijantne statističke analize primarnih podataka, rad istražuje inovacije u poljoprivredi u Vojvodini (Srbija), koju karakteriše mali proizvođača koji koriste polu-tradicionalne metode proizvodnje i zastarelu mehanizaciju. Poljoprivredni proizvođači razvijaju veštine uglavnom kroz praktičan rad, a ne kroz formalno obrazovanje. Rezultati pokazuju da, iako poljoprivrednici poseduju snažne menadžerske i proizvodne veštine, postoji značajan nedostatak digitalnih kompetencija i ograničena primena savremenih tehnologija. Strukturne prepreke, uključujući usitnjena zemljišta, neadekvatna infrastruktura i ograničen pristup finansijama, dodatno otežavaju usvajanje inovacija. Uprkos svesti o značaju inovacija, njihova primena ostaje limitirana.To ukazuje na potrebu za ciljanom podrškom u razvoju veština, ulaganja u infrastrukturu i podsticanje kolaborativnih mreža.

Ključne reči: poljoprivreda, inovacije, region Vojvodine

Absztrakt: Jelen tanulmány, átfogó szakirodalmi áttekintést követően, primer adatokon végzett leíró és többváltozós statisztikai elemzés segítségével, az innovációkat vizsgálja a szerbiai Vajdaság mezőgazdaságában, amelyet a félig hagyományos termelési módszereket és elavult gépeket használó kistermelők jellemeznek, akik inkább gyakorlati munkával, mint formális oktatással szereznek tapasztalatot, fejlesztik készségeiket. A kutatási eredményeink azt mutatják, hogy míg a gazdálkodók erős menedzseri és termeléssel kapcsolatos készségekkel rendelkeznek, a digitális kompetenciák terén jelentős hiányosságokat mutatnak, és a modern technológiákat korlátozottan alkalmazzák. A strukturális akadályok, köztük a széttagolt birtokrendszer, a fejletlen infrastruktúra és a finanszírozáshoz való korlátozott hozzáférés tovább akadályozzák az innovációk bevezetését. Fő megállapításunk, hogy az innováció fontosságának tudatosítása ellenére a gyakorlati alkalmazás alacsony szintű, ami azt jelzi, hogy további célzott támogatásokra van szükség a készségfejlesztés, az infrastrukturális beruházások és az együttműködési hálózatok elősegítése terén.

Kulcsszavak: mezőgazdaság, innováció, Vajdasági régió

Highlights

- Agriculture producers are aware of the importance of innovations in the agriculture sector.
- Agriculture producers have adequate managerial and business skills but limited technological/digital skills to improve production.
- In the Vojvodina region, there are resources driving innovation.

- The Vojvodina region is lacking adequate infrastructural characteristics for agricultural innovations.

1. Introduction

According to the OECD (2015), innovation plays a crucial role in empowering the job market, fostering new businesses, driving economic growth, and enhancing quality of life. Developing countries are placing a strong focus on this topic and are working to establish mutual innovation policies and measures to enhance their innovation capacities and balance their innovation inputs and outputs (see Johnson, Cornell University, INSEAD, WIPO, 2015), as they seek to expand their growth potential. Although the EU (*European Union*) is quite aware of it, knowing how it is diverse. Not every member state has equal innovation capacities and performance levels. More developed regions could adapt to the changes more easily and grow faster by attracting investors and a more skilled labour force, while on the other hand, less developed regions had fewer capacities, and the utilization process is slower (Manfred and Nijkamp, 2013). It can be stated that innovation is a modern tool for economic development, yet the topic is not new. In 1963, OECD (*Organisation for Economic Co-operation and Development*) addressed for the first time the economic importance of innovations, which stepped out of the science and technological framework (see OECD, 1963). It was clearly stated that innovation is not only an R&D (*Research and Development*) activity but also part of an economic dimension. As Schluter (2016) summarized with Research & Innovation Smart Specialized Strategic development plan (RIS3), the opportunity to catch up with the high innovation standards is given even to the developing countries and those which are lagging, the strategic program shall be clear, to identify the innovation niches and their innovation frontier as, besides innovations designs, its commercialization and distribution to the market are highly important.

Since this research focuses on innovation in the agriculture sector and rural areas of Vojvodina (the northern region of Serbia), it is also important to understand why innovation in agriculture matters. Thus, it can encompass new knowledge, technology in agricultural production and processing, as well as solutions for economic and social processes. It can improve rural communities in several ways, such as enabling more efficient production of competitive products, thereby increasing the income of farmers and other rural residents. To some extent, it can create new work positions and reduce the unemployment level, which is one of the significant challenges in rural areas. We agree with Zrobek (2020), who also shares that innovations have a positive impact on bridging the developmental gap in local environments and businesses, meeting people's needs, and increasing the competitive advantage of individual farms. Consequently, innovations are increasingly seen as vital components of the development process and key resources for achieving agricultural objectives. A society characterized by innovation can lead to improved living standards, enhanced national preparedness to tackle global challenges, and increased productivity. It is essential to accurately define and comprehend the concept of innovation, as there are various interpretations within the literature among researchers, policymakers, and different institutions. One of the well-known definitions originates from the renowned economist Schumpeter (2021), who defined innovation as the introduction of new products or services, expansion into new geographical markets, utilization of new raw materials, adoption of novel production methods, and implementation of innovative organizational practices. Livingstone (2000, p. 3) (cited by Hysa and Manski, 2020) characterized innovation as "*the process through which novel concepts are translated into sustainable value-added outcomes via economic activities*". Crumpton (2012) underscores that innovations are directed towards end users, serving to enhance processes, services, ideas, or the cultural environment in which ideas originate. The primary aim of innovations is to bring benefits and meet end users' needs. They are perceived as introducing something novel that exceeds existing models and fulfils market (consumer) demands. OECD (2015) describes the innovation role as vital in tackling urgent social and global challenges, such as aging populations, disease outbreaks, resource shortages, and climate change. Economies that prioritize innovation tend to be more productive, resilient, and adaptable, enabling them to sustain higher living standards.

Fostering innovation is essential for countries striving to achieve greater prosperity and improve the quality of life for their citizens, which has been recognized by the EU. Therefore, the Innovation Union (IU) had launched a set of indicators to measure the innovation performance of 27 EU member states and 4 non-EU countries (Norway, Switzerland, the UK, and Serbia) on the NUTS III level. In the report *"European Innovation Scoreboard"* published by the European Commission (EC, 2021), Serbia is primarily categorized as an "Emerging Innovator," with performance scores ranging between 50% and 70% of the EU average. As shown in Figure 1, the Vojvodina region (RS12) is also marked as an "Emerging Innovator," while only the Belgrade region (the capital, RS11) is designated as a "Moderate Innovator," with scores ranging from 70% to 100% of the EU average.

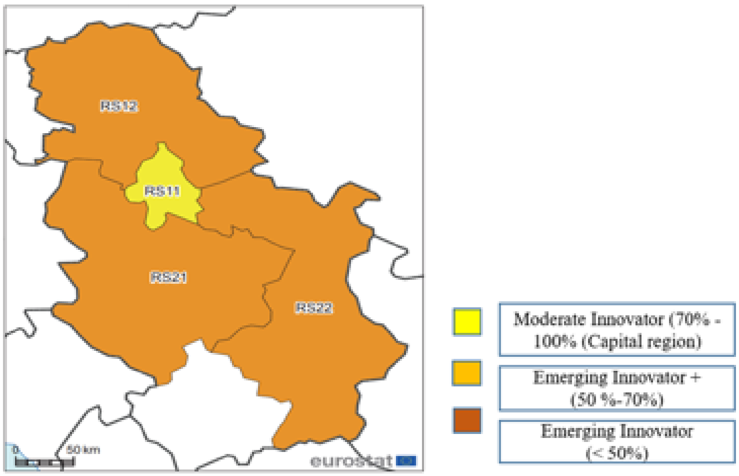

Fig 1. European Innovation Scoreboard map of Serbia. Source: European Commission (2021), references listed under number 71

As per the given report, there are only five top innovators in Europe (Switzerland, Sweden, Finland, Denmark, and Belgium) classified as "*Innovation Leader*", in which performance is above 125% of the average EU level. A country/region whose performance is in the range of 100% and 125%, in total, is a *"Strong Innovator"*. There are nine countries in this group (e.g., the Netherlands, the UK, Germany, and Luxembourg). However, there are significant regional differences in innovation development across Europe. The Global Innovation Index attributes this to the geographical concentration of innovation activities, often grouped in clusters, such as innovation hubs in capital cities or cross-border regional clusters (Berquist et al., 2017). Landabaso (1997) also noted the strong concentration of high-tech advancements in advanced European regions. This clustering aims to create agile centres of excellence for competitive advantage. The authors Landabaso (1997), Bottazzi and Peri (2000) confirmed that Europe's technological gap depends on the access to funding: where developed countries have more effective public financing systems, therefore higher innovation output like Germany or Netherlands while limited funding capacities offer lower innovation output, which can be seen in less developed countries like Greece or Portugal. In addition to regional differences, innovation also varies by sector. Agriculture is also characterised by specific processes (see de Oca Munguia et al., 2021). Therefore, examining the topic of innovation in a predominantly agricultural region of Serbia is a timely and relevant issue.

2. Literature Review

2.1 Forms of Innovations in the agriculture sector worldwide

Over the decades, we have witnessed numerous revolutionary innovation events characterized by computerization, digitization, the Internet of Things (IoT), artificial intelligence (AI) and machine learning (ML) (Table 1).

Tab 1. Industrial and Agricultural revolutions. Source: authors' own interpretation based on Zambon et al. (2019) and Baryshnikova et al. (2022)

Revolution	Industry	Agriculture
1.0	Steam/water machines	Animal power
2.0	Electric power (machines)	Mechanized agriculture
3.0	Programmable logic controller (automation)	GPS, biotechnology, genetic engineering, remote sensing
4.0	Computerization, Intelligent networks	Internet of Things, Cloud
5.0	Digitalization, AI (*Artificial Intelligence*), ML (*Machine Learning*)	

Reflecting on history, we observed that the first industrial revolution commenced with the advent of steam engines. Concurrently, in agriculture, a significant portion of the population, approximately two-thirds, was engaged in the food sector, characterized by labor-intensive practices with minimal mechanization. Animal power played a vital role in cultivation, delineating **Agriculture 1.0.** The era of **Agriculture 2.0** witnessed the introduction of mechanization, alongside the adoption of fertilizers, pesticides, and novel practices aimed at enhancing yield and productivity. While Advancements in **Agriculture 3.0** encompassed the proliferation of biotechnology and genetic engineering, the integration of remote sensing and data analysis techniques, and the implementation of automation technologies to further augment agricultural practices (Baryshnikova et al., 2022). **Agriculture 4.0** is shaped by the Internet of Things (IoT) and Big Data collection. In traditional farming, farmers usually go to the fields and collect data through observation and their experience. Nowadays, this approach is changing as with the help of IoT devices such as sensors, cameras, drones, microphonic recorders, meteorological stations, data about the plants or animals are recorded and transmitted via an internet connection or other communication networks such as Bluetooth, process data and software analysis based on the customized features (Zambon et al., 2019). Algorithms are finally provided as an output result to users in an easily readable, understandable, and moreover accurate format as per Berckmans (2017). IoT finds many different roles in animal husbandry, livestock farming, precision agriculture (Neethirajan et al., 2017; Persaud, 2018), crop management (Trippichio et al., 2018), observation of soil nutrition and water levels (Rossel and Bouma, 2016). Nowadays, the role of technological improvements in the agriculture and food sectors is rapidly increasing due to higher demand for food production and more rigorous quality standards for sustainable development. Various tools can be found in research and practice, such as the use of sensors, cameras, drones, robots, improved machines and production methods in combination with artificial intelligence and machine learning. Technological developments have been reported to yield various positive effects by several researchers, for example, ensuring easier crop planning in hilly areas (Marucci et al., 2017), better site management and supporting agroecology (Bongiovanni and Lowenberg-Deboer, 2004), (Balakrishnan et al., 2017). Tarabella et al. (2000) stated that precision farming is an approach based on digital technologies that enables agricultural producers to enhance productivity, increase profitability, minimize environmental impact, and improve the quality of agricultural products by implementing more precise production processes, models, and tools. Authors Janvry and Sadoulet (2001) confirmed that technological innovations can improve farmer welfare, increase revenues and reduce costs. **Agriculture 5.0** refers to artificial intelligence (AI), machine learning (ML) and robotics. As in the previous era, we faced the development of sensor systems, IoT devices, big data analytics, and other technological advances. Examples of AI/ML applications in agriculture include predicting optimal irrigation timing and quantity, determining the best periods for pesticide or spray application, identifying ideal harvesting times, recommending the use of specific crop protection products, and forecasting weather conditions (Eli-Chukwu, 2019). While the development of robotics arose from the fact that some of the farming operation processes are highly manual, which requires the commitment of the workforce. However, the main goal of robotics in the agricultural sector is to minimize human labor and reduce operating times. Therefore, great importance is currently attached to the robotization of electric mobile agricultural machinery (Serebrenny et al., 2018). While Bechar and Vigneault (2016) argued that processes like harvesting can be performed more quickly and on a larger scale using robots compared to human labor. Nowadays, they can have different functions, apart from harvesting, they can also be used for inventory and weed control (removing or spraying weeds). But on the other hand, such technology is quite expensive and requires significant investments that small producers cannot afford (Kushwaha et al., 2016).

Innovation in agriculture is not limited to advanced digital technologies; it can also encompass a wide range of other transformative changes. Given that agriculture is a homogeneous sector, innovations can take many different forms. These forms may include new and/or improved inputs such as seed varieties, cultivation methods, equipment, and agricultural practices, quality management standards, organizational restructuring, enhanced management practices, expanded sales to new markets, as defined by Pomareda and Hartwich (2006). While Mahroum (2007) finds another form of innovation in the agriculture sector, where new technologies are being applied in traditional rural industries, without having actual technological routes (e.g., agro-tourism, where rural innovation activities are based on urban demand). Authors Abrosimova et al. (2020) conducted a more in-depth analysis and classified agricultural production innovations into four categories: a) selection and genetic (new hybrids, breeds, resistance to diseases and pests etc.); b) technical and technological (refers to the use of new equipment, production that improves nutrients, production energy saving technologies and similarly); c) organizational and managerial (new forms of cooperation, novel forms of innovative developments and others); d) socio-ecological (improving environmental and living conditions in settlements). While Navarro et al. (2018) recognized four main groups of rural innovations: a) economic innovation (creating new methods for products/services pre-existing in specific area, emerging traditional production with new designs or new products and/or services new to the specific area, creation of new economic activities or enterprises associated with innovation); b) territorial innovation (new forms of human, natural, financial potential that can be integrated and utilized better, implementation of solution known elsewhere but new to the specific area); c) human capital innovation (emerging specific knowledge and practices); and d) social innovation (new forms of partnerships, new ways of involving people in decision-making processes, building local networks, collective investments).

As highlighted in reviewed articles, innovation offers numerous benefits to the agricultural sector and rural communities. Several of these benefits, which are also evident in rural regions of Serbia as well as worldwide, include increased income for farmers, more stable economic power, lower food production costs (Willet et al., 2019). Further, Mahroum (2007) argues that fostering innovation in rural areas requires improving local services and quality of life, particularly empowering vulnerable groups, especially women and senior citizens in rural areas, given that many rural residents are self-employed or work in smaller groups where entrepreneurial skills are essential. Innovation contributes to the expansion of knowledge by enhancing educational opportunities and facilitating knowledge exchange, particularly in rural communities. (Esparcia, 2014; Mahroum, 2007). Woodhill (2014) argues that dual exchange of knowledge between academia and industry is essential as it can enhance the overall efficacy and impact of collaborative efforts and networking, and ensure easier implementation of complex and integrated technologies and practices as they require a higher level of skills and knowledge from the farmers (Nelson et al., 2007). The formation of farmers' cooperatives is recognized as a key element for fostering innovation in rural areas (Mahroum, 2007). Furthermore, new forms of stakeholder engagement and networking, such as those facilitated by 'living labs', are essential for building local innovation ecosystems and enhancing rural entrepreneurship (Pastrana-Huguet & Casado-Claro, 2024). Introducing new forms of infrastructure in rural communities, particularly broadband connectivity, plays an important role by enabling the development and dissemination of innovative technologies in such communities (Mahroum, 2007). Van Es and Woodard (2017) highlighted significant advancements in agricultural innovation through the adoption of cross-cutting technologies, including cloud computing, sensors, robotics, digital communication tools, and computational decision-making systems. They also emphasize progress in field technologies such as yield monitoring, GPS (*Global Positioning System*) guidance, precision soil sampling, GIS (*Geographic Information System*), on-board computing systems, and automation technologies in livestock production (e.g., technologies for milking, feeding), which have notably improved productivity and efficiency.

Despite these advancements, the implementation of complex technologies in agricultural production requires careful adaptation and strategic planning, as each farming system has distinct characteristics and needs (Haile et al., 2017). In many cases, the successful integration of new technologies at the farm level demands customized solutions, posing one of the primary challenges to widespread commercialization. Still adoption of innovative solutions by agriculture producers is not an easy process, as several challenges hinder its adoption in rural areas worldwide. These include depopulation (Fanelli, 2021, as cited by Dibbern et al., 2024, p. 6), limited education, small farm sizes, demanding farming activities, perceived barriers (Caffaro and Cavallo, 2019), a conservative mindset, lack of knowledge, insecurity, perceived risks (Gaspar et al., 2021), persistent habits, limited motivation to invest time in enhancing knowledge and skills, reluctance to employ farmers receptive to new technologies, insufficient understanding of how to capitalize on innovations, absence of collaborative investments and partnerships, inadequate awareness of emerging technologies, and the lack of opportunities to trial technologies before their implementation in production (Czibere et al, 2023), lack of funds to acquire new technologies, and poor access to ICT (*Information and Communication Technologies*) infrastructure (Pělucha et al., 2023). Conversely, factors that facilitate adoption among farmers include access to mobile applications and the internet (Michailidis et al., 2011), clear rationale for adoption (Harisudin et al., 2023), age, farm size, technological readiness, work experience, trust, motivation (Schukat and Heis, 2021), and positive experiences, either from peers or the empirical outcomes observed by early adopters (Young, 2009).

2.2 Characteristics of agricultural innovation in Serbia (Vojvodina)

Some of the socio-economic and technological barriers impacting the development and adoption of innovation in the agricultural sector are evident in Serbia too. The most recognized socio-economic challenges include an unfavorable age structure and ongoing depopulation, as emphasized by Bogdanov (2007) and Ristić (2015). Moreover, we share the opinion of Mihailović et al. (2013), who highlighted the weak economic power of small family farm households, which largely rely on non-agricultural income sources such as off-farm employment, pensions, and other financial transfers to maintain economic viability. We agree that this dependency reflects a structural vulnerability within the sector, raising concerns about the sustainability of agricultural innovation in such environments. Tomić and Ševarlić (2010) further pointed out factors contributing to persistently low income levels, notably insufficient capital for investment, restrictive banking policies regarding credit access, and unstable market conditions. We also think these issues suggest systemic financial barriers that impede entrepreneurial activities and modernization efforts among farm households. Additionally, Mihailović et al. (2013) critically identify significant market-related obstacles, including elevated input costs, suppressed output prices, and the limited bargaining power of agricultural producers. Such conditions not only undermine farmers' economic resilience but also question the effectiveness of current market structures and policy interventions intended to support agricultural development. Some of the technological factors that hinder the agriculture sector are, lack of up-to-date knowledge and modern farming practices, confirmed by Mihailović et al. (2013). As it is explained by Bogdanov (2007) and Ristić (2015), agricultural production in Serbia is characterized by extensive production methods and traditional approaches dominate over intensive production methods, heavy land exploitation, the use of outdated machinery, and reliance on heavy industry. Semečenko et al. (2021) highlighted several challenges, including low productivity, insufficient use of modern technologies, and limited food processing activities that could otherwise add value to agricultural products. Further, Semečenko et al. (2021) and Stanojević (2019) appointed weak transfer of new technologies from research to the business and industrial sectors, although poor functioning of agricultural clusters and unions Paraušić and Domazet (2018) and insufficient initiative among farmers and leaders to establish these organizations, as confirmed by Mihailović et al. (2013), which could serve as a place of exchange of good practices and knowledge between agricultural producers. In addition, Semečenko et al. (2021) noteed the problem of an unskilled workforce, while Stanojević (2019) and Nikolić et al. (2015) highlighted inadaptability to the changes or fear of change and conformity, unwillingness to update new knowledge, and low awareness about the importance of innovations shared by Pokrajac (2011) and Mihailović et al. (2013). Moreover, Mihailović et al. (2013) highlighted importance of agriculture infrastructure like warehouses and storage facilities, while Stanojević (2019) and Nikolić et al. (2015) highlighted low technological infrastructure that remains underdeveloped in many parts of Serbia, which we think is similar to Stanojević (2019) – a critical prerequisite for the adoption of IT (*Information Technology*), IoT, and DSS technologies. Paraušić and Domazet (2018) emphasized the importance of innovation infrastructure, e.g., innovation incubators, hubs, technological parks or centers. In Serbia, it is not common, and even if they exist, they are usually concentrated in capitals and bigger cities, so urban areas, founded by donors with a lack of sustainable and long-term strategies. Nikolić et al. (2015) and Pokrajac (2011) found main reasons for low innovative activities among entities whose focus are innovation in the agriculture sector in Serbia: Those are low support from the public sector, lack of IT, lack of source of innovations (R&D, design thinking), weak intellectual property protection system, bureaucratic standards and tax regulations, difficulties in finding partners to cooperate with, market dominated by already stable entrepreneurs, uncertain demand for innovative services/goods, insufficient investments in the innovation, inadequate governmental financial aid/subsidiarity system for SME sector. Paraušić and Domazet (2018) claimed that innovative SMEs do not get adequate support in the form of favorable loans, access to "spin-off programs" or innovative enterprise projects. Although as per the research of Tagarakis et al. (2018), some of the technologies where demand exist in Vojvodina, are robotics and autonomous machines, while some slight interest was expressed for sensing systems and GPS and mapping systems, we highlighted the results of Stanojević (2019) who confirms that the size of a farm household significantly influences the level of adoption of modern technologies like, IT, IoT, and DSS. Smaller farm households tend to have lower levels of adoption. Given that the average farm size in Serbia is approximately 4.4 hectares, households cannot adopt such technologies. Importantly, innovation in agriculture should not be narrowly confined to technological adoption alone; innovations can also encompass market, marketing, and organizational dimensions. For example, certification schemes for traditional, non-GMO products could significantly enhance product visibility and competitiveness or improve the quality standards scheme required for supply chain integration, a gap identified by Mihailović et al. (2013).

2.3 The Impact of Historical Transitions and Socio-Economic Constraints on Agricultural Innovation and Structural Change in Serbia

Long-standing socio-economic factors have significantly constrained the development and innovation capacity of the agricultural sector in Serbia. Understanding their impact requires consideration of key historical events that have shaped rural economies and institutional structures. Over the past 50 years, Serbia's agriculture has faced significant economic and political challenges, particularly during the transition from a socialist to a market-based economy, similar to other Central and Eastern European Countries (CEECs), with lasting negative effects still evident today.The most significant events which marked the agriculture sector are the regime in the 1960s, when the political authorities provided much higher support to the state farms and cooperatives compared to private farming (Bański, 2020; Swain, 2000), which in Serbia was considered as the peasant class constantly being marginalized (Šljukić, 2006). There were some major restrictions in Serbian agriculture, like bans on non-family labor, limited access to modern machinery until 1967, and a mandate sales of produce to state entities under exploitative conditions. Social benefits for peasants, such as health and pension insurance, were introduced much later than for other social groups and remained minimal in value. Even nowadays, this is a significant issue as agricultural producers have a lower standard of living. Finally, in the 1970s, private farmers were able to invest in their farm households by buying new machinery and economic buildings (Šljukić, 2006), but in our research, it is noted that investments in mechanization are a difficulty even nowadays. In the 1980s, approximately 75% of arable land was cultivated by private farmers, who were responsible for around two-thirds of total agricultural production. Despite their dominance in production, private farmers faced structural limitations, including a legal cap of 10 hectares per farm and the widespread fragmentation of land into multiple small plots. In contrast, the socialized sector was characterized by large-scale, vertically and horizontally integrated agricultural enterprises (in Serbia known as "Agrokombinats") (Arcotrass, 2006). Small-scale farm plots are one of the main characteristics of the farm management in Serbia, while the number of cooperatives and their functionality is quite limited. Similar problems were present in other CEECs: private small-scaled farmers with a limited degree of specialization and commercial activities (see e.g., Bański, 2020 or Swain, 2000), while state-owned farms kept a monopoly and had better business relations with the food sector (Swain, 2000). Until the 1990s, Serbia maintained a relatively stable economy and a higher standard of living compared to other countries undergoing economic transition. However, the disintegration of Yugoslavia marked a turning point, leading to a severe economic downturn characterized by hyperinflation. The situation further deteriorated due to escalating political conflicts, culminating in the major crisis of 1998, which inflicted additional damage on the Serbian economy. In response, the Serbian government launched a comprehensive reform program in 2001 aimed at transitioning to a market-based economy, restoring relations with international creditors, and advancing integration into regional, European Union, and global markets. These efforts contributed to macroeconomic stabilization and created a foundation for Serbia's ongoing process of accession to the European Union (Arcotrass, 2006). Jurjević et al. (2022) noted that Serbia, along with other CEEC such as Bulgaria, Romania, Croatia, and other former socialist states, has undergone a significant transition from a centrally planned economic system to a market-oriented economy, also confirmed by (Buckwell, 1997). EU accession enabled the CEECs to benefit from funding programs that facilitated a transition away from industrial-scale agriculture toward more diverse and environmentally sustainable practices. This shift also promoted the development of local food products and traditional production methods, drawing on regional specificities to enhance added value, alongside improvements in land structure (Bański, 2020). The alignment of agricultural production and food processing with the Common Agricultural Policy (CAP) brought about greater specialization, adherence to food quality standards, and improved access to the EU's common agricultural market (Radlińska, 2025). We think the most relevant, CAP funding contributed to enhanced technical efficiency through the adoption of modern technologies and infrastructure, fostered product innovation, supported organizational and structural improvements on farms, and increased farmers' capacity and motivation to invest in advanced machinery and equipment (Détang-Dessendre, 2018). Jurjević et al. (2022) stateed that pre-accession programs like Instrument for Pre-Accession Assistance in Rural Development (IPARD), which is part of the broader Instrument for Pre-Accession Assistance (IPA), are suitable for larger farms, but not for the smaller ones. Still, there is room for further improvements in administrative efficiency, rural infrastructure, environmental measures, farmer education, agriculture modernization to meet the CAP's evolving standards, which we have confirmed in our research.

It is of mutual interest for the EU and Serbia to support the agriculture sector, as even though Serbia holds a small share of the EU-27's agricultural resources, with 3.2 million ha of arable land and 3.5 million ha of utilized agricultural area (UAA), it makes up 44% of Serbia's total land area (of which nearly half is located in Vojvodina, managed by 42% of total farm households) and represents approximately 2% of the UAA across the EU-27. Although agricultural land has some of the strengths compared to the EU, highly fertile soil and favorable agro-ecological conditions (Gabrić-Molnar et al., 2019), labor input remains limited, with Vojvodina contributing less than 20% of Serbia's total annual work units (AWU). The share of agriculture in Serbia's GDP (3.79%) significantly exceeds the EU average (1.3%), reflecting its continued economic importance (FAO, 2014).

3. Data and methodology

The primary objective of this research is to assess the main characteristics of agricultural producers in the Vojvodina region and to identify the key challenges they face, with particular emphasis on factors related to innovation, skills, and infrastructure that hinder progress in the sector. To achieve a comprehensive understanding and draw meaningful conclusions, our study employs a multifaceted approach. This includes a literature review on innovation concepts, understanding its terms and forms, an analysis of secondary data that describes the Vojvodina region and state of the agriculture sector, primary research to understand agriculture producers' view on the importance of innovations, their capacities and needs, and reviewing innovation providers in the Vojvodina region (see Figure 2).

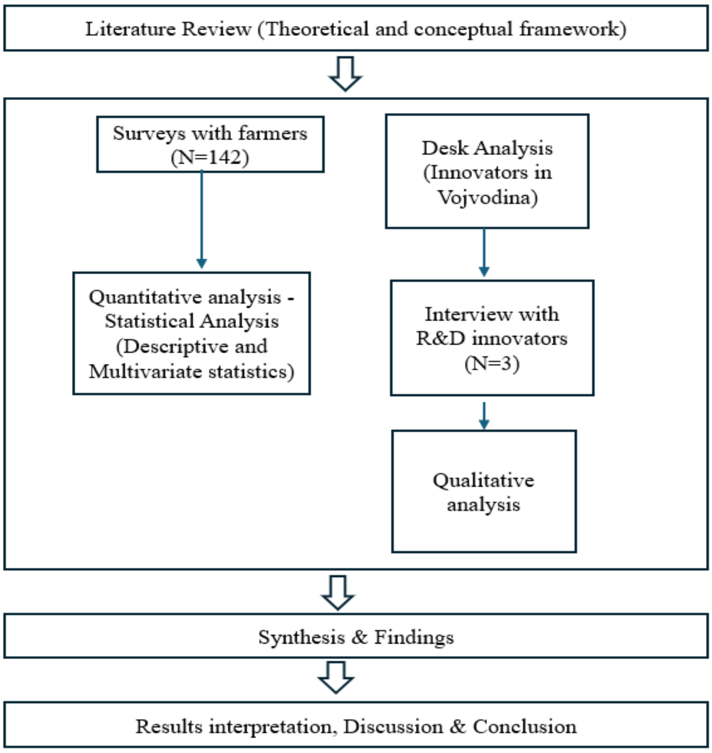

Fig 2. Research design. Source: authors' own elaboration

3.1 Subject of Research

The subject of this research is the Vojvodina region located in Northern Serbia (see Figure 3a), which consists of seven NUTS III regions: North Bačka (Severnobački okrug), West Bačka (Zapadnobački okrug), South Bačka (Južnobački okrug), Srem (Sremski okrug), North Banat (Severnobanatski okrug), Central Banat (Srednjebanatski okrug), and South Banat (Južnobanatski okrug) (Figure 3b).

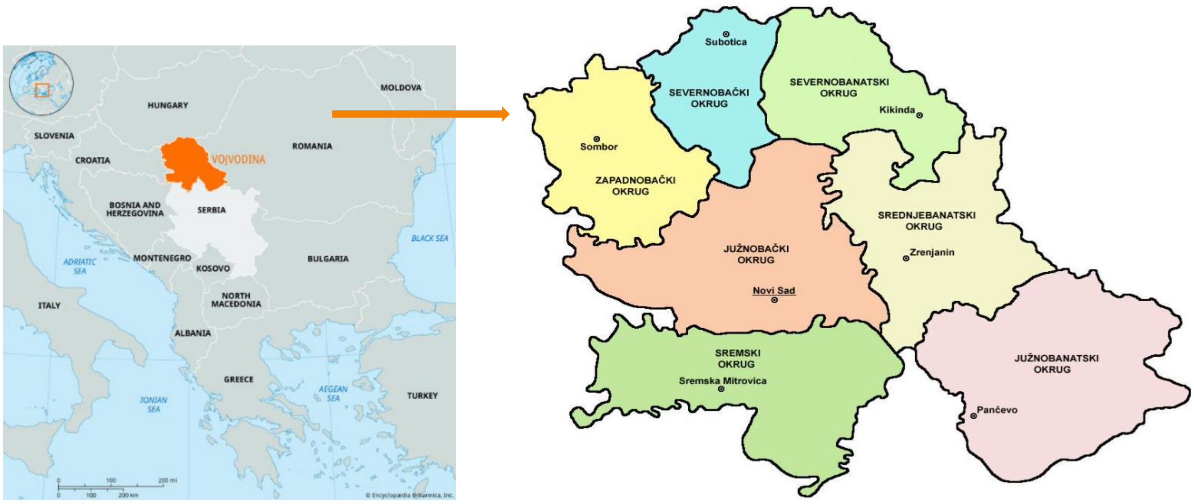

Fig 3a. Location of Vojvodina in Eastern Europe (left) and 3b. Vojvodina NUTS III regions (right)[2].

The main feature of the Vojvodina region is the agriculture's significant role. According to the Strategic plan for rural development (MPŠV, 2009, and Arcotrass, 2006), Vojvodina is described as a region with highly productive agriculture and an integrated economy, characterized by capital-intensive farming supported by favorable natural conditions and a strong economic base, including skilled human resources,

[2] Source: https://www.britannica.com/place/Vojvodina, https://it.m.wikipedia.org/wiki/File:Districts_Vojvodina.jp.

entrepreneurship, industrial diversity, and robust infrastructure. Making it one of the strongest agricultural NUTS II regions in Serbia. This sector is predominantly made up of small-scale producers who typically own farm households of 4.5 ha on average (source: The Republic Statistic Office of Serbia, 2018). In the Vojvodina region, the total agricultural land covers 1,499,521 ha, with predominantly arable land accounting for 1,428,167.72 ha. There are 109,444 registered farm households engaged in agricultural activities (source: *https://popispoljoprivrede.stat.gov.rs/sr-Cyrl/tabele/*), primarily focusing on crop production, including wheat, fodder crops, industrial crops, and the cultivation of vegetables (see Table 2).

Tab 2. Average crop production in Vojvodina's NUTS III regions, 2023 (ha/farm household). Source: authors' own elaboration based on The Republic Statistic Office of Serbia[3]

Region	Wheat	Sugar Beet	Industrial Crop	Fodder Crop	Vegetable
West Bačka	7.91	0.86	4.17	0.32	0.1
South Banat	10.34	0.22	5.14	0.34	0.12
South Bačka	7.5	0.48	4.66	0.22	0.24
North Banat	9.28	0.19	3.69	0.63	0.14
North Bačka	10.74	0.37	3.02	0.49	0.09
Central Banat	12.62	0.27	4.38	0.74	0.12
Srem	7.55	0.3	2.57	0.22	0.11

In addition to crop production, livestock farming also plays an important role, with a primary focus on laying hen production in South Bačka, pig and cattle production in North Bačka and Srem, while sheep and cattle production are significantly less present, and it is mainly known for production of dairy products (see Table 3).

Tab 3. General livestock production in Vojvodina's NUTS III regions, 2023 (stock/farm household). Source: authors' own elaboration based on The Republic Statistic Office of Serbia [4]

Region	Cattle production	Pig production	Sheep production	Laying hen
West Bačka	2.10	9.40	2.84	22.59
South Banat	2.32	3.00	2.77	9.52
South Bačka	0.68	1.80	0.99	55.20
North Banat	5.52	4.07	5.07	3.33
North Bačka	3.44	14.37	7.29	27.76
CentralBanat	2.65	6.12	3.40	10.72
Srem	3.16	14.61	1.52	19.93

3.2 Primary survey data

In 2023, a survey was conducted with 142 agricultural producers from the Vojvodina region between March and November. The survey was initially distributed online via agricultural clusters (email and Google Forms) to 60 producers, only 5 responses were received. Consequently, the majority of the data were collected in person through one-on-one interviews, each lasting 17 to 53 minutes. Only 3 individuals declined to participate during the in-person phase. As a result, the most effective approach proved to be visiting multiple locations or producers directly on-site and survey in person. This brought benefits as

[3] *online data* https://popispoljoprivrede.stat.gov.rs/sr-Cyrl/tabele/
[4] online data https://popispoljoprivrede.stat.gov.rs/sr-Cyrl/tabele/

the longer completion times were often due to respondents taking the opportunity to share additional insights. The survey was administered at various locations, including the Faculty of Agriculture in Novi Sad (targeting students actively involved in the farm households managed by their families), the Agriculture Fair in Novi Sad, wineries in Srem region, distribution center where producers procure supplies, fresh markets in South Bačka, and the Organic Cluster of Vojvodina in Novi Sad (South Bačka).

The survey was structured into several sections: general socio-demographic information, data on the respondents' agricultural households and production activities, satisfaction with municipal infrastructure development, the extent of needed improvements in their production, and their level of business and digital skills. Satisfaction and developmental levels were measured using a 4-point Likert scale, with 1 indicating "non-existence", 2 meaning "not good", 3 meaning "good", and 4 meaning "very good". The number of respondents per region is presented in Table 4. The survey had closed-ended questions. Based on primary data collection, descriptive, multivariate statistics with factor analysis were conducted to conclude.

Tab 4. Surveys' Respondents. Source: authors' own elaboration

Respondent's		**Count – N**	**%**
Total		**142**	**100**
Gender	Male	101	71.1
	Female	41	28.9
Place	North Bačka	11	7.7
	West Bačka	15	10.6
	South Bačka	32	22.5
	Srem	47	33.1
	South Banat	18	12.7
	Middle Banat	8	5.6
	North Banat	11	7.7
Age	18–24	3	2.1
	25–34	21	14.8
	35–44	44	31.0
	45–54	45	31.7
	55–64	27	19.0
	65+	2	1.4

Respondent's	**Count – N**	**%**
Total	**142**	**100**
Education Level		
Primary	7	4.9
Secondary	83	58.5
BSc	41	28.9
MSc	10	7.0
PhD	1	0.7
Type of farm household		
Agriculture household not in the VAT system	55	38.7
Agriculture household in the system of VAT	54	38.0
Private enterprise (SME)	33	23.2

3.3 Desk analysis (Tech providers)

To gain a deeper understanding of the current technological market offer in the examined region, a content desk analysis was conducted by selecting nine entities in total. Three entities were discarded as it was unclear whether they were still actively operating in the domestic market. Organizations were selected through a systematic review of LinkedIn and the R&D call platform – f6s Innovation (https://www.f6s.com/). The primary objective was to identify the specific fields in which technology designers and providers operate and to ascertain the types of novel hardware and/or software solutions they offer. Selected entities were SMEs and R&D institutes operating in the designated region, detailed hereafter:

SMEs:

- ***DunavNet*** (*dunavnet.eu*) (IoT, DSS): DunavNet has a few modules tailored to three groups of agricultural producers: poultry, wine and horticulture. With the use of cameras, meteorological stations, and sensors, data on the production environment is collected in real time. Specific recommendations are provided regarding appropriate measures during critical stages of production.
- ***Agremo*** (*www.agremo.com*) (IoT, DSS): has developed its own Ag-Tool platform for crop and weed management. It helps growers to know in which areas exactly and in what quantity pesticides/herbicides should be applied. It allows growers to optimize production, increase yield, and have an accurate overview of crop development, biomass calculation, crop stress and damage.
- ***Atfield*** (Vojvodina), (*https://atfield.tech/*) (GPS – *Global Positioning system*, ML, DSS): provides software applications that allow wine growers to monitor weather parameters and access the forecast 24/7, allowing them to plan each activity accordingly. They have access to visual data in the form of maps and graphs through the system's notifications.
- ***NSoilab*** (*https://nsoilab.rs/en/home/*) (Biotechnology): biotechnological start-up with the main objective of producing eco-friendly microbiological-based products intended for use in sustainable and organic agriculture, to produce, but also to preserve, high-quality and healthy food and feed soil.
- ***ABS*** (*https://agrobudget.com/en/homepage/*) (AI): The company offers a tool designed to assist both individual farmers and large-scale agricultural producers in establishing their farms, managing operations, and estimating income and costs. It masters an AI-powered spray system that reduces chemical consumption by 70% and applies to any spray machine.
- ***PanonIT*** (*https://www.panonit.com/*) (AI, ML): is a company specialized in software development, AI, ML, embedded systems, and mobile application development, among other areas. One of their products is *CropsIT*, a mobile application designed for growers to monitor specific plant diseases.
- ***IoTartic*** (*https://iotartic.com/*) (IoT, AI/ML): offers arrays of sensor tools to help collect a variety of data related to disease detection, soil and crop management, indoor growing, irrigation management, fertilization, energy and time consumption.

R&D Institutes:

- ***BioSense Institute*** (*https://biosens.rs/en*) (Biotechnology, IoT, AI): located in Novi Sad, Institutes operate in the field of biotechnology and agriculture. They are heavily focused on R&D activities and the generation of IoT devices and smart agri-tech solutions. Its current focus is on creating tools for predicting wheat yield, monitoring physiological traits, detecting pathogens in water, and more.
- ***The Institute for Artificial Intelligence Research and Development of Serbia*** (*https://ivi.ac.rs/en/*) (IoT, AI, ML): promotes industrial development, including the agricultural sector and disseminates AI and ML-based solutions across Serbia and internationally. The Institute is engaged in various national and international R&D projects. The fields they cover are human computer interaction, AI in healthcare and lifesciences, computer vision and remote sensing, Green AI, and smart manufacturing.

3.4 Interviews with selected Tech providers

As part of the primary research, three open interviews were conducted with technology providers and experts from the Vojvodina (South-Bačka) region, each lasting between 15 and 20 minutes. The participating organizations included one private enterprise, DunavNet, and two public institutes, the BioSense Institute and the Institute for Artificial Intelligence Research and Development of Serbia (IAIRDSA). All three selected entities are actively engaged in R&D activities and participate in Horizon

2020, Interreg, and other similar projects. The primary objective of these interviews was to gain insights from both industry and academia, complementing the findings from the conducted desk analysis.

4. Research Results

4.1 Characteristics of the surveyed farm households in the Vojvodina region

In this section, we aim to present findings from our primary survey assessing the main characteristics of the agricultural producers (farm households) in the examined region. The survey reveals agricultural activities varying across regions, reflecting diverse local priorities and conditions, as well as mixed production (combination of different production types, e.g., fodder and/or industrial crops and/or livestock production, and/or food processing, etc.). In Srem, the largest surveyed area with 47 participants, vine production is notably prominent (31.9%), along with a mix of livestock and crop production (19.1%) and food processing (12.8%). South Banat, with 18 participants, has the highest share of beekeeping (22.2%) and livestock production (16.7%), alongside significant involvement in food processing (16.7%) and mixed open-field crop production (11.1%). Central Banat stands out for its emphasis on livestock (25%) and horticulture (25%), while West Bačka focuses on industrial and fodder crops (66.7%) and has notable engagement in horticulture (13.3%) and vegetable production (6.7%). South Bačka, the second-largest group with 32 participants, has a relatively diverse agricultural profile, including horticulture (21.9%), beekeeping (15.6%), and industrial and fodder crops (18.8%). North Banat, though smaller in sample size, is distinguished by a significant proportion engaged in wine and horticulture (36.4%) and beekeeping (18.2%). Lastly, North Bačka, with 11 participants, primarily focuses on industrial and fodder crops (27.3%), along with a mix of crop production and beekeeping (27.3%). Each region demonstrates a unique agricultural landscape, shaped by environmental and economic factors.

The majority of the farmers (37%) operate on smaller plots ranging from 0.1 to 3 ha, indicating a prevalence of small-scale farming. This is followed by 22% of farms within the 5.1 – 10 ha range and 16% in the 10.1 – 20 ha category, showing a gradual decline in representation as farm size increases. A smaller proportion (11%) manage land between 3.1 and 5 ha, while only 8% have holdings between 20.1 and 50 ha. The share further decreases, with just 5% of farms operating on 50.1 – 100 ha, and only 1% managing land larger than 100 ha. Overall, the data highlight that the majority of farms in this sample are small-scale operations, with significantly fewer large-scale agricultural enterprises. Results retrieved from our primary research highlight a predominant reliance on traditional methods or production with varying degrees of modernization. Most of the farmers operate under a "traditional with modern elements" approach, with the highest shares in North Bačka (90.9%), Central Banat (75%), and South Banat (72.2%), indicating gradual technological adoption. Completely traditional farming is most prevalent in South Banat (22.2%) and Srem (19.1%), suggesting a slower transition to modern practices in these areas. In contrast, fully modernized production is most common in West Bačka (33.3%) and North Banat (27.3%), while absent in North Bačka, reflecting regional disparities in agricultural advancement (see Table 5). These trends highlight the ongoing shift toward modernization, though at different paces across regions.

Tab 5. Typology of Agricultural Production in Vojvodina – NUTS III level based on surveyed data (%). Source: authors'own elaboration

Type of production	*North Bačka*	*West Bačka*	*South Bačka*	*Srem*	*South Banat*	*Central Banat*	*North Banat*
*Traditional**	9.10	6.70	18.80	19.10	22.20	12.50	9.10
Traditional with modern elements	90.90	60	53.10	61.70	72.20	75.00	63.60
Modern	-	33.30	28.10	19.10	5.60	12.50	27.30

* Extensive production, without modern technology and mechanization

When it comes to mechanization, it is discovered that agricultural producers mostly use a combination of both old and new machinery, with the highest shares in South Banat (89%) and Central Banat (88%). The use of old machinery (over 15 years) is most common in North Bačka (64%) but is much lower in other regions, especially Central Banat, where none is reported. The adoption of new machinery (under 5 years) is highest in South Bačka (22%) and lowest or non-existent in several areas. Overall, while modernization is occurring, many farms still rely on aging equipment, suggesting room for improvement in farm mechanization (see Table 6).

Tab 6. Age of mechanization at interviewed farm households in Vojvodina – NUTS III level (%). Source: authors' own elaboration

Age of machinery	***North Bačka***	***West Bačka***	***South Bačka***	***Srem***	***South Banat***	***Central Banat***	***North Banat***
Older (>15 years)	64	13	16	21	6	0	9
Mix of old and new	36	87	63	64	89	88	82
Newer (<5 years)	0	0	22	15	6	13	9

We have also observed that non-VAT agricultural households have the highest share of older machinery (33%), while VAT-registered households and SMEs have much less (9% each). Most farms across all groups use a mix of old and new machinery, especially VAT-registered households (85%). New machinery is most common among SMEs (30%), compared to only 6 – 7% in non-VAT agricultural households. This suggests SMEs invest more in modern equipment, while households, particularly non-VAT households, rely on older machinery.

Additionally, there remains potential for reducing on-farm income losses through improvements in financial management and market engagement skills. Among respondents, 16% identified high production costs as a primary contributor to income losses, while 15% cited low sales prices, and 13% pointed to suboptimal production technologies. Notably, 22% reported significant challenges associated with market entry. These problems were especially common among the younger generation with lower education and involved in the farm households in the VAT system, households actively operating in the market. Conversely, relatively few respondents attributed their losses to inadequate machinery (1%), limited knowledge (4%), or shortages in seasonal labour (4%). Moreover, there is a notable degree of independence from other income sources besides agricultural activities. Survey data reveals that 68.3% of respondents do not consider agriculture as their primary income source. Additionally, 42% of respondents express a need for additional financial support, particularly younger and older farmers with lower education levels and those operating as non-VAT farm households.

Further, we wanted to examine if improvements in certain segments of their agriculture production and rural community are desired; thus, we have asked agricultural producers to evaluate some of their production elements (e.g., resources, equipment, etc.), answering positively (yes) or negatively (no) (see Figure 4).

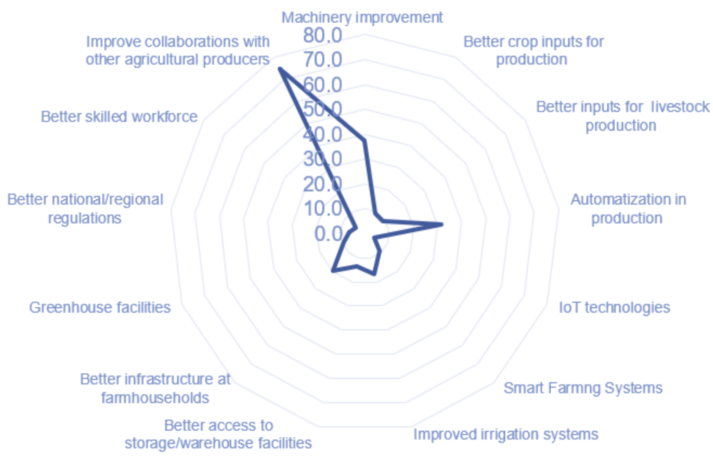

Fig 4. Respondents' perceived needs toward production improvement (%). Source: authors' own elaboration

We had the following answers: there is a need for collaboration and creating new partnerships – 75%, but their level of skills to create new partnerships and collaborative networks is not that high (mean 3). Further, the next necessity is toward automation and better machinery, 32%, while 40% of respondents need better crop inputs. Only 10% of respondents claimed they need to improve infrastructure in their households, and 9% need an improved irrigation system. There is no interest in IoT technologies, and very small toward Smart Farming Systems.

Data in Table 7 indicate that a large majority of respondents recognize the significance of innovation in their activities. Specifically, 58% of respondents consider innovation to be important, and an additional 24% rate it as extremely important. Combined, this means 82% of participants view innovation as a key factor in their operations. In contrast, only 13% perceive innovation as slightly important, and a minimal 6% regard it as unimportant. Despite this broad recognition of innovation's importance, there remains a notable gap in importance and interest regarding specific advanced technologies such as IoT and Smart Farming Systems. This lack of interest is largely attributed to respondents' limited understanding of what these technologies are and how they can be applied in agricultural practice.

Tab 7. Respondents' perception of innovation importance (%). Source: authors' own elaboration

Is innovation important	**%**
Unimportant	6
Slightly important	13
Important	58
Extremely important	24

Supplementary, we aimed to assess the extent to which various factors (infrastructural, operational, business skills, etc.), as perceived by agricultural producers, are important for the further development of their production. Factor analysis was employed utilizing Principal Component Analysis and Varimax rotation with Kaiser Normalization (see Tables 8 and 9). This analysis resulted in the extraction of six factors.

The first factor reflects Decentralized decision-making and local government support. Variables loading highly on this factor include "Decentralized decision making on the municipal level" – 0.786, "Municipality recognition of the agriculture producers' needs" – 0.779 and "Having financial support from the government" – 0.601, which suggests that responsiveness from local government to agricultural demands is an essential component of this factor. Lastly, "Having access to purchase centers" – 0.751 focused on decentralized and supportive infrastructure necessary to enable local agricultural productivity, particularly through flexible governance and resource availability. ***The second factor – Tech and partnership*** improvements emphasizes the importance of building partnerships with domestic and international partners with mechanization and production improvements. This factor is characterized by "Production technological improvement" – 0.830, closely related to "Mechanization improvement needs" – 0.761, suggesting a focus on enhancing productivity and efficiency through mechanical innovations. Further, "Having partners from abroad" – 0.685, "Having partners from Serbia" – 0.504, and "Making adequate new business partnerships" – 0.467 indicate the importance of partnership values and collaboration for the agriculture producers that might be necessary for advancing agricultural practices. ***The third factor – Family support and adoption of modern production techniques*** – reflects a focus on performing more modern, sustainable agriculture. The high loading on "Family support" (0.750) suggests that backing from family plays a vital role in agricultural operations, potentially providing stability and additional resources. "Implementing more modern production concepts and technology" with a loading of 0.747 suggests that both family support and technological adaptation are crucial for agricultural progress, according to respondents' feedback, as they combine traditional stability with modern efficiency, driving the sector toward sustainable practices (0.666). ***The fourth factor – R&D and online financial management*** with loading of "Using R&D services" at 0.982 underscores the significance of research and development in promoting advancements and supporting technological progress. While

“Accessing online tools for finance management” loading at 0.986 indicates the importance of digital financial tools in maintaining efficient and sustainable financial practices. ***The fifth factor – IoT and Digital Partnering***, addresses two factors: “IoT improvement” with loads of 0.816 and “Online platforms for partnering” with loads of 0.769. This factor represents digital and IoT-related improvements. It emphasizes the importance of technology and digital platforms in agriculture, specifically the integration of IoT and online collaboration, which nowadays is essential for modern agriculture. ***The sixth factor – Administrative and access to the agriculture organization,*** with emphasis on sales skills. Sales skills, with a score of 0.651, suggest a strong emphasis on enhancing abilities that directly impact sales effectiveness and market growth. Besides, “Access to the administrative centres” – 0.655 and “Being member of clusters/agriculture unions” – 0.595 emphasize the importance of having stable and accessible access to the main administrative units like banks, insurance companies, posts offices, telecommunication centres adding to it agriculture centres which have important role in providing support to the agricultural producers.

Tab 8. Results of the Factor Analysis – Respondents’ view on different factors impacting their (farm household) development. Source: authors’ own elaboration

Rotated Component Matrix						
	1	**2**	**3**	**4**	**5**	**6**
Decentralized decision-making on the municipal level	**0.786**	0.078	-0.084	-0.019	-0.120	0.296
Municipality recognition of the agriculture producers' needs	**0.779**	-0.056	0.215	-0.025	0.103	0.128
Having access to purchase centers[5]	**0.751**	0.226	0.225	0.115	0.111	0.120
Having financial support from the government	**0.601**	0.021	0.361	-0.103	0.001	-0.329
Production technological improvement	0.022	**0.830**	0.192	0.026	0.127	0.100
Mechanization improvement	-0.179	**0.761**	-0.017	-0.004	-0.010	0.011
Having partners from abroad	0.331	**0.685**	0.110	0.103	0.144	-0.091
Having partners from Serbia	0.355	**0.504**	0.359	-0.071	0.007	0.240
Making adequate new business partnerships	0.215	**0.467**	-0.227	0.159	0.243	0.282
Having family support	0.137	-0.064	**0.750**	-0.007	-0.346	-0.019
Implementing more advanced production concepts/technologies	0.188	0.108	**0.747**	0.122	0.156	0.124
Performing sustainable agriculture	0.129	0.270	**0.666**	-0.070	0.144	0.223
Online tools for finance management	-0.023	0.055	0.029	**0.986**	-0.034	0.007
Using R&D services	0.011	0.049	0.023	**0.982**	-0.075	0.025
IoT improvements	-0.096	0.142	-0.076	-0.022	**0.816**	-0.018
Online platforms for partnering	0.199	0.096	0.139	-0.101	**0.769**	0.017
Access to the administrative centres	0.061	0.177	0.088	0.076	-0.190	**0.655**
Sales skills improvement	0.121	-0.005	0.466	0.098	0.223	**0.651**
Being a member of clusters/agriculture unions	0.406	-0.054	0.073	-0.308	0.169	**0.595**

[5] Supply and distribution centres that facilitate the provision of essential resources to agricultural producers while managing the sale of their products under contractual agreements monitored by the government.

Tab 9. KMO & Bartlett's Test on Respondents Skills. Source: authors' own elaboration

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.677
Bartlett's Test of Sphericity	Approx. Chi-Square	1431.603
	df	171
	Sig.	<0.001

4.2 Agriculture producers' skills and competences

A range of farmers' skills considered essential for the execution and management of agricultural activities at the farm household level were assessed. Results from the primary survey revealed that 65.5% of respondents lack any agricultural educational background, whereas only 34.5% have qualifications in the domain of agriculture. In terms of educational background, the majority of respondents (59%) have completed secondary education, followed by 29% who hold a bachelor's degree. A smaller proportion, 7%, have obtained a master's degree, while 4% have only completed elementary education, and just 1% hold a PhD. When it comes to work experience, 8% of respondents have up to 5 years of agricultural experience, 33% have up to 10 years, and 59% possess more than 10 years of experience. Thus, it can be concluded that the majority of the respondents gain knowledge and expertise through their agricultural activities, mainly as self-learners or, eventually, if they are a second generation of households, usually it is experience passed from one generation to another.

According to data from the Republic Statistical Office of Serbia, based on the Agriculture Census 2023 (Figure 5), two predominant categories emerge regarding the educational background of farm household managers. The majority either lack any formal agricultural education or have acquired their knowledge through practical experience in the field. The proportion of farm household managers with formal agricultural education is less than 10% across all regions. Both the survey data and official statistics from the Republic Statistical Office of Serbia confirm that practical work experience prevails over formal education, even among agricultural producers in higher managerial positions.

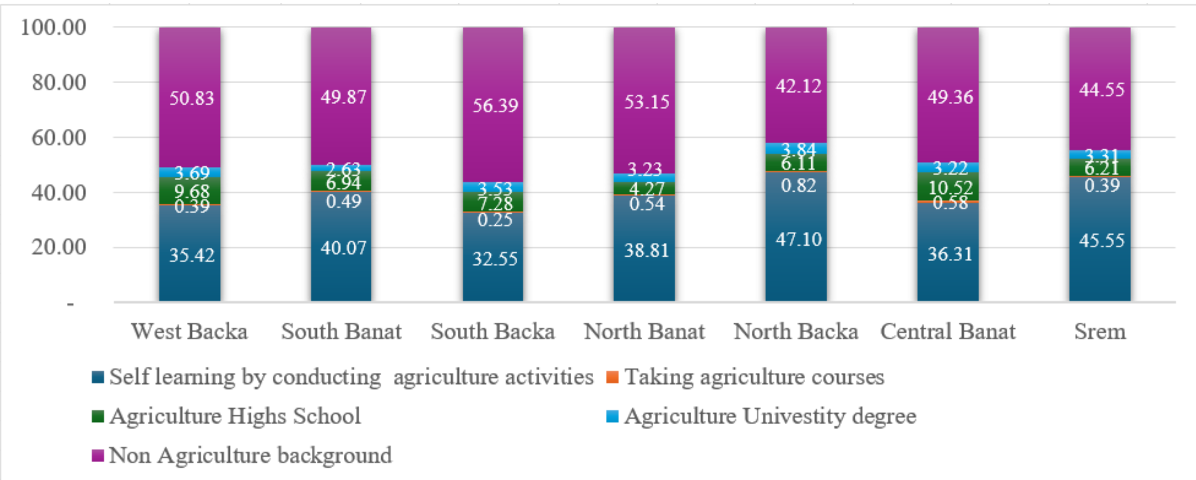

Fig 5. Share of farm household managers per their agricultural education in Vojvodina's NUTS III level regions, 2023 (%). Source: authors' own elaboration based on The Republic Statistic Office of Serbia[6]

The analysis of self-assessed skill levels across age groups reveals consistent trends where mid-career individuals (particularly those aged 35–44 and 45–54) report the highest proficiency across most competencies. These groups demonstrate strong capabilities in management (3.66), financial planning

[6] online data https://popispoljoprivrede.stat.gov.rs/sr-Cyrl/tabele/

(3.48), risk management (3.61), and production cost optimization (3.57), reflecting accumulated professional experience and exposure to complex operational roles. In contrast, the youngest age group (18–24) consistently reports the lowest scores, particularly in strategic and business-oriented skills such as financial planning (2.67), opening SMEs (2.67), investment planning (3.00), collaboration (2.67–3.00), and risk management (2.67). This suggests a pressing need for targeted training programs and mentorship focused on practical, entrepreneurial, and operational competencies for youth entering the workforce. The older age group (65+) also shows significantly lower digital skills (1.00) and limited understanding of SME establishment (2.00) and collaboration with agricultural producers (1.00). These results highlight a strong digital divide and a potential gap in ongoing skill development among seniors, which may limit their participation in digitally driven and collaborative innovation sectors. Interestingly, digital skills peak among the 25–34 age group (3.48), while skills like collaboration with international agricultural producers and production improvement increase in older cohorts, reflecting the role of field experience and accumulated networks in these areas. Overall, the data suggest that while skills grow with age and experience, both younger and senior populations would benefit from structured capacity-building programs, digital upskilling for seniors and entrepreneurial/management training for youth (see Table 10).

Tab 10. Respondents' skills per age and education level (Mean). Source: authors' own elaboration

Skills	Age						Education Level				
	18–24	25–34	35–44	45–54	55–64	65+	Primary	Secondary	BSc	MSc	PhD
Digital	3.33	3.48	3.45	3.27	2.48	1	2.57	2.99	3.54	3.70	3
Management	3	3.62	3.66	3.56	3.42	3	3.71	3.51	3.56	3.80	3
Finance	2.67	3.52	3.48	3.31	3.21	3	3	3.34	3.46	3.40	3
SME establishment	2.67	3.10	3.43	3.27	3.08	2	2.57	3.13	3.41	3.80	3
Seeking & applying expert advice	2.67	3.57	3.27	3.38	3.38	3	3	3.30	3.46	3.60	3
Sales	2.67	3.14	3.30	3.18	3.29	3	2.71	3.09	3.49	3.50	3
Investment planning	3	3.14	3.11	3.27	3.25	2	2.86	3.08	3.32	3.60	3
Production improvement	3	3.21	3.43	3.49	3.46	3	3.14	3.46	3.34	3.50	3
Collaboration with domestic partners	3.00	3.00	3.07	3.11	2.83	1	2	2.91	3.24	3.40	3
Collaboration with international partners	2.67	3.05	2.98	3.02	3.21	3	3.29	2.91	3.10	3.60	3
Production cost optimization	2.67	3.24	3.57	3.49	3.54	3	3.29	3.40	3.56	3.70	3
Risk management	2.67	3.24	3.61	3.40	3.46	3	3.29	3.39	3.46	3.80	3

Farmers registered under the VAT system and SMEs consistently demonstrate higher skill levels across all domains, particularly in digital skills, SME establishment, and production improvement, compared to those outside the VAT system. This suggests that formalization may be linked to greater access to training, advisory services, or more structured business practices. Non-VAT households show especially low levels in digital competencies and collaboration with domestic partners, indicating potential exclusion from modernization and value chain integration initiatives. Targeted interventions may be necessary to enhance their entrepreneurial and technical capacities. Skill levels also vary notably with years of experience in the agricultural sector. Digital skills are highest among those with less than five years of experience and decline steadily with age, reflecting a generational digital divide. In contrast, core business and operational skills, such as management, finance, production optimization, and risk management, peak among farmers with 5 to 20 years of experience, likely due to accumulated knowledge and exposure.

Interestingly, those with over 30 years of experience often score lower across various skills, suggesting a need for lifelong learning opportunities to keep pace with evolving agricultural technologies and business models (see Table 11).

Tab 11. Farmers' skills per farmhousehold legal status and years of working experience (Mean). Source: authors' own elaboration

Skills	***Type of farmhousehold per legal status***			***Working years in the agriculture sector***				
	Not in VAT system	*In VAT system**	*SME*	*0.1–5*	*5.1–10*	*10.1–20*	*20.1–30*	*30+*
Digital	2.71	3.46	3.48	3.58	3.53	3.21	2.86	2.61
Management	3.44	3.65	3.58	3.33	3.72	3.52	3.36	3.56
Finance	3.25	3.44	3.39	3.17	3.45	3.39	3.23	3.36
SME establishment	2.62	3.61	3.58	3.33	3.36	3.45	2.86	2.96
Seeking experts' advice	3.21	3.44	3.42	3.25	3.40	3.33	3.50	3.20
Sales management	3.06	3.33	3.27	2.92	3.28	3.24	3.32	3.12
Investment planning	2.96	3.33	3.24	2.83	3.15	3.27	3.32	3.12
Production improvement	3.14	3.69	3.36	3.42	3.37	3.55	3.50	3.21
Collaboration with domestic partners	2.21	3.52	3.39	3.25	3.28	3.18	2.86	2.24
Collaboration with international partners	3.04	2.87	3.30	2.83	3.09	2.85	3.09	3.24
Optimizing production costs	3.31	3.67	3.36	3.33	3.47	3.55	3.59	3.28
Risk management	3.21	3.67	3.39	3.42	3.47	3.52	3.36	3.32

***** Farmhousehold does not operate as a private entity, it conducts agricultural activity and has a right to sell product through contractual obligations with purchaser/distribution centres managed by the government.

Further, utilizing factor analysis with Principal Component (Varimax rotation and Kaiser Normalization), we wanted to examine whether there is any clustering among presented skills. As a result, factor analysis identified two factors where convergence was achieved after three iterations. The analysis delineated ***Factor 1 – Business and Production Management skills*; and *Factor 2 – Digital Skills*** (see Tables 12 and 13).

Based on our results producers' skills are mainly grouped under Factor 1 loading at 0.998 – skills on how to look for experts' advice, finance, sales and management skills; optimizing production costs, risk management and investment planning skills are loaded at 0.997; collaboration skills on how to open an SME/company is loaded at 0.996, collaborative skills with international agriculture producers scored 0.995 and collaboration skills with domestic agriculture producers is loaded at 0.994. Finally, knowledge of production improvements shows a load of 0.594, with significantly lower scores compared to management, finance and partnership-related skills. This might indicate that knowledge about modern production technologies and methods is lacking. These mainly high values suggest that Factor 1 represents a coherent grouping of skills related to business and management capabilities. Since the loadings are so high and consistently clustered, we could interpret this factor as capturing competencies around strategic planning, financial planning, and collaboration in an agricultural business context. Factor 2, with a load of 0.943, represents digital skills and does not show a high correlation with the set of skills under Factor 1. The reason is that the majority of the respondents have digital skills at a lower level compared to management, business and production-related skills.

Tab 12. Results of the Factor Analysis – Respondents' Skills matrix. Source: authors' own elaboration

Rotated Component Matrix[a]		
	1	2
Business management skills	**0.998**	-0.001
Financial management skills	**0.998**	-0.004
Skill on how to look for experts' advice	**0.998**	-0.009
Sales management skills	**0.998**	0.000
Production costs' optimization skills	**0.997**	-0.006
Risk management skills	**0.997**	-0.005
Investment planning skills	**0.997**	-0.013
Skills in opening SME/company	**0.996**	0.030
Collaborative skills with international agriculture producers	**0.995**	-0.015
Collaborative skills with domestic agriculture producers	**0.994**	0.033
Knowledge about production improvement	**0.594**	-0.428
Digital skills	0.121	**0.943**
Extraction Method: Principal Component Analysis. *Rotation Method: Varimax with Kaiser Normalization.*		
a. Rotation converged in 3 iterations.		

Tab 13. KMO & Bartlett's Test on Respondents' Skills. Source: authors'own elaboration

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.950
Bartlett's Test of Sphericity	Approx. Chi-Square	6611.153
	df	66
	Sig.	< 0.001

4.3 State of Infrastructure in the Vojvodina region as per the agriculture producers' view

Municipal conditions, including the provision of public services and general and agricultural infrastructure, reflect the level of development and rurality. Due to the lack of secondary data on service and infrastructure levels, this aspect was examined through respondents' perspectives. Specifically, we assessed respondents' views from two angles: (i) the extent to which municipalities invest in various aspects of municipal and agricultural infrastructure and (ii) the importance of these elements for agricultural producers who live and operate in the respective municipalities. The surveyed data reveal (Figure 6) that agricultural warehouses, irrigation networks, extension services, and distribution centres are considered the least important from a municipal investment perspective, as per respondents' opinion, with agricultural warehouses and irrigation systems also performing poorly. Medium-level municipal efforts and performance are noted for veterinary services, agricultural cooperatives, collaboration among agricultural producers, healthcare services, and living conditions. The highest developmental progress is observed in the development of road networks, educational facilities, mobile phone and internet networks, and technical services. Overall, while progress is evident in general infrastructure and connectivity, core agricultural support services remain under prioritized in municipal investment strategies, while as per agriculture producers, they deserve high attention.

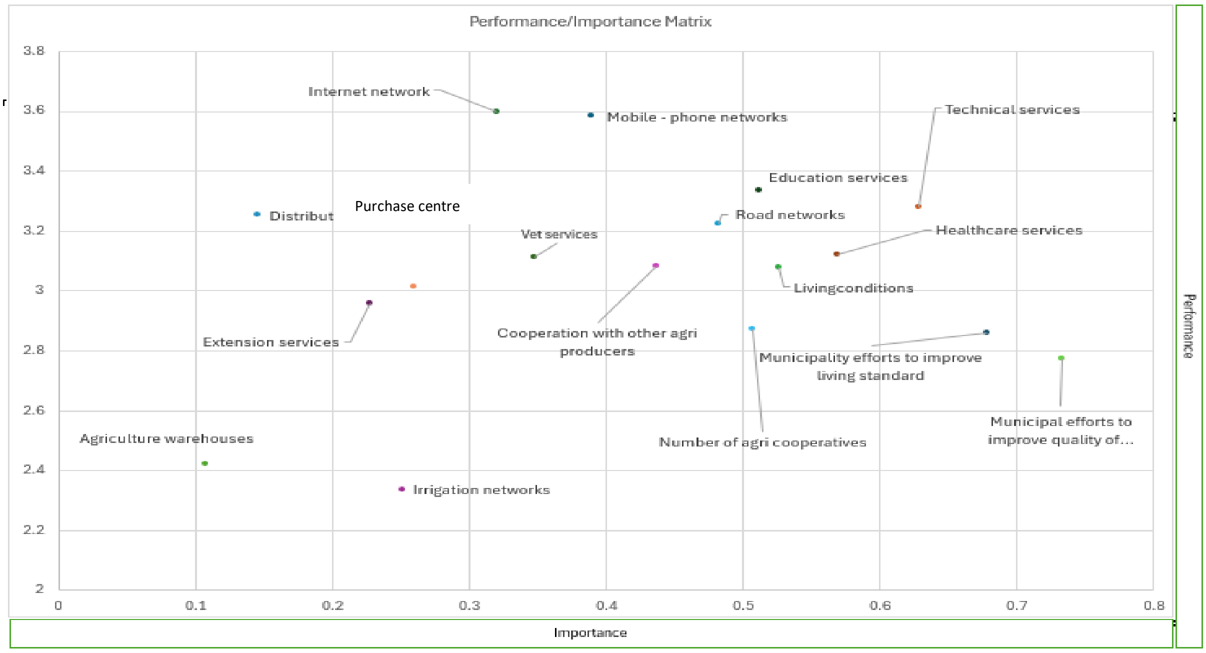

Fig 6. Correlation of the importance and performance of the municipal investments from the respondents' own development perspective. Source: authors' own elaboration

4.4 Tech Providers in Vojvodina region

As per our research it is noted that there is a room for technological improvements and innovations in the agriculture sector in Vojvodina, even though maybe agriculture producers are not fully aware of its role, capacities and how to utilize them. However, there is a small number of innovation generators in Vojvodina, offering different types of technological solutions. There is a small number of companies classified as innovators in Serbia, 11,986 in total, while the share in the food processing sector is 21.6% and in the agriculture sector it is only 1.21% (see Table 14). *(The table below presents the number of innovators on the national level, as regional level data is unavailable.)*

Tab 14. Number of Innovators in Serbia (total), 2021. Source: The Statistic Office of the Republic of Serbia, (online data https://publikacije.stat.gov.rs/G2021/Pdf/G20211334.pdf)

Innovators in total in Serbia	Innovators in the agriculture sector	Innovators in the food processing sector	Unfinished or "in process" innovations
11986	145	2592	2213

In Vojvodina, a few entities (companies and R&D institutes) tailor and offer innovative solutions in the form of products or services for the agriculture sector (see Table 15). Based on the desk analysis conducted via web search on platforms like LinkedIn, the f6s (R&D project platform), and online browsing, seven Small and Medium Enterprises (SMEs) and two R&D Institutes have been identified as innovative agri-tech providers.

Most of these providers offer Software as a Service (SaaS), Internet of Things (IoT) technologies, and decision support systems based on Artificial Intelligence (AI) or Machine Learning (ML). Their target markets include various producers in horticulture, vegetable, and industrial crop production. Notably, only one company, DunavNet, offers IoT technology for livestock production (poultry), while another company, NSoilab, provides eco-friendly microbiological-based products utilizing the latest biotechnology. The listed organizations primarily focus on software design rather than hardware devices, with an emphasis on crop management, crop protection, pest management, weather forecasting, and irrigation management. The primary technological focuses of the selected entities, which have the potential to enhance production optimization, operational efficiency, environmental protection, and decision-making processes for agricultural producers. By leveraging a comprehensive array of up-to-date data on production practices, real-time data, and advanced software design, agricultural producers can obtain valuable insights and recommendations on the optimal actions to take. This approach aims to increase yield and minimize production risks on time. Based on our evaluation, innovators in the domain of automation or robotics in the field of agriculture were not identified in the studied region, most likely due to the narrow market and limited profitability.

Tab 15. Primary technological focuses of the selected entities. Source: authors´ own elaboration

Entity/Type of product/service	Efficient operation	Optimizing Production	Decision Making	R&D
DunavNet	x	x	x	x
Agremo		x	x	
Atfield		x	x	x
NSoilab	x			
ATAR	x		x	
PanonIT			x	x
IoTartic	x		x	
BioSense Institute		x	x	x
IAIRDS	x		x	x

Interviews conducted with the BioSense Institute, the Institute for Artificial Intelligence Research and Development of Serbia (*IAIRDS*), and DunavNet have highlighted several challenges. Agricultural producers show low digital literacy and require continuous support from technology providers, which incurs additional costs for these organizations, and technology transfer is full of challenges. Consequently, these tech providers are increasingly focusing on exporting their solutions to neighbouring or other European countries where agriculture is more advanced. It is also noted that collaboration with larger producers is more feasible, as they are generally aware of the importance of investment and staying aligned with market trends. In contrast, small-scale producers often struggle to understand and adopt new technologies, typically requiring additional assistance from technical support teams, which demands further resources. Moreover, small producers are often not fully engaged in the R&D experimental stages of product development with tech providers primarily due to limited time, motivation, expectations, or knowledge. R&D institutions believe the agricultural sector in Serbia lacks favourable conditions for the development of AI-based tools due to the absence of historical agricultural data, either by agricultural producers or by the Republic Statistic Office of Serbia. The AI Institute asserts that prototype design, testing, and validation in agriculture are complex due to numerous factors that are difficult to oversee. Additionally, a lack of agricultural background can hinder the understanding of problems and the design of effective solutions, which is also caused by having uncertain production plans by the agricultural producers. Therefore, collaboration with small-scale agriculture producers can be challenging and unpredictable.

5. Discussion and conclusion

This study builds upon the conceptual framework outlined in the introduction, where innovation in agriculture was defined as a multidimensional process encompassing technological, managerial, organizational, and socio-economic dimensions (Abrosimova et al., 2020; Navarro et al., 2018). While such innovations, ranging from IoT and AI-based tools to market and value-chain innovations, have been shown to improve agricultural productivity, sustainability, and competitiveness (OECD, 2015; Zrobek, 2020), empirical evidence from the Vojvodina region illustrates a significant disconnect between theoretical innovation frameworks and their practical implementation. The findings of this study confirm that the agricultural sector in the Vojvodina region, while structurally significant within Serbia's economy, continues to face considerable barriers to modernization and innovation adoption. Historically rooted structural limitations, such as small-scale land holdings, fragmented plots, limited financial resources, and a historically under-supported private farming sector, continue to restrict farmers' capacity to invest in modern equipment and technologies (Bański, 2020; Swain, 2000; Šljukić, 2006). The historical legacy of agricultural policy during the socialist period, characterized by preferential support for state farms and restrictive measures against private farmers, still casts a long shadow over the development trajectory of agriculture in Vojvodina. Although market-oriented reforms and Serbia's alignment with EU accession strategies have introduced structural improvements (Arcotrass, 2006; Jurjević et al., 2022), they have not fully compensated for past deficiencies. While CAP alignment and access to pre-accession instruments like IPARD have generated notable progress among larger farms (Détang-Dessendre, 2018; Radlińska, 2025), small-scale producers are yet to fully benefit. This suggests a pressing need to tailor rural development policies more precisely to the structure of the Serbian agricultural sector, with particular attention to the heterogeneous nature of farm sizes and capacities (Jurjević et al., 2022; Bański, 2020).

The theoretical framework highlighted advanced technologies of Agriculture 4.0 and 5.0, such as sensor systems, robotics, and data-driven DSS tools, as central to modern agri-food systems (Zambon et al., 2019; Baryshnikova et al., 2022). These technologies are rarely adopted among Vojvodina producers. Only 32% of respondents reported a need for automation or modern machinery, and interest in smart farming or IoT technologies was negligible, confirming both a lack of awareness and structural inaccessibility due to financial constraints and small farm sizes (~4.4 ha average). These results are aligned with prior studies that point to traditional production methods, outdated machinery, and low levels of mechanization as hallmarks of Serbia's agriculture sector (Mihailović et al., 2013; Semečenko et al., 2021). The analysis also highlights systemic weaknesses in collaborative networks and a fragmented R&D sector insufficiently integrated into the agricultural economy (Paraušić and Domazet, 2018; Mihailović et al., 2013). Although entities offering technological and digital solutions are present (BioSense Institute, DunavNet, Agremo, Atfield, etc.), their outreach is primarily limited to larger or more commercially oriented producers. Anyhow, in the future, localized technology transfer shall be in focus if adequate bridge mechanisms and knowledge intermediaries can be established.

Further, survey results and factor analysis revealed that agricultural producers in Vojvodina exhibit high levels of business and production management skills (Factor 1), including financial management, risk handling, and collaboration with domestic actors. However, their digital skills (Factor 2) remain significantly underdeveloped (loading = 0.943), corroborating the findings of Caffaro and Cavallo (2019) and Stanojević (2019), who noted that digital literacy is a critical barrier to rural innovation adoption. Despite having awareness of the importance of innovation, and 75% of producers recognizing the need for partnerships, their ability to initiate and sustain collaboration remains low (average skill score = 2.90). This reinforces the observation that lack of organizational and social capital, combined with underperforming agricultural unions and clusters, constrains innovation ecosystems in the region (Paraušić & Domazet, 2018). Simultaneously, infrastructural deficits such as poor access to irrigation systems, storage facilities, and extension services limit the effectiveness and attractiveness of innovation investments. Public support measures, especially targeting smaller-scale farmers, remain insufficient, particularly regarding financial incentives, infrastructural upgrades, and tailored education programs (Pokrajac, 2011; Nikolić et al., 2015), which are prerequisites for innovation uptake.

To promote innovation uptake, a multifaceted approach is required. This includes fostering local innovation ecosystems, improving access to infrastructure, strengthening digital skills, and designing inclusive funding schemes adapted to small-scale producers. Government incentives and grant programs should promote value chain integration by supporting small-scale processing for dairy, fruit, and vegetable products. Additionally, certification of traditional and non-GMO products may help improve market access and competitiveness, as noted by Stanojević (2019) and Mihailović et al. (2013).

Boosting agricultural innovation in the Vojvodina region requires a multidimensional approach such as, enhancing access to financial resources and public subsidies for smaller agricultural producers; investing in rural infrastructure, particularly broadband access, agriculture storage facilities and logistics;

strengthening educational and training programs with a strong focus on digital and entrepreneurial skills for farmers; facilitating partnerships between farmers, expanding offers by technology providers and R&D institutions; stimulating the development and functionality of agricultural clusters, cooperatives and living labs; tailoring innovation policies to the specific needs and capacities of different farm sizes and production types. Addressing these constraints will be crucial for Vojvodina's agricultural sector not only to improve competitiveness within the EU market but also to ensure sustainable rural development and resilience against future economic challenges.

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