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INNOVATIVENESS OF THE AGRI-FOOD SECTOR AS A FUNCTION OF SUSTAINABLE DEVELOPMENT

Inovativnost poljoprivredno-prehrambenog sektora u funkciji održivog razvoja

Abstract

Innovation is very important for sustainable development of countries. In agriculture, innovations shift the focus from mere productivity-based technology to the economic, ecological and social aspects of sustainable development. Given that there is no unique framework for measuring innovation in the agri-food sector, and no single conclusion can be drawn as to which country is the most innovative in agriculture, the subject of the paper is the measurement of innovation in the agri-food sector of the most innovative countries and the Republic of Serbia. The aim of the paper is to prove the necessity of introducing innovations in the agricultural sector of the Republic of Serbia, in accordance with the innovations introduced by more agriculturally innovative countries. Innovative approaches such as precision agriculture and others, which are in line with sustainable development, play an increasingly important role in agriculture. The OLS panel regression on the example of innovative countries and the Republic of Serbia proved that the introduction of innovation in agriculture has a positive impact on sustainable development. Only in the case of inputs used in agriculture, this impact was negative, which is why it is important to introduce modern technologies and innovative approaches in order to increase their productivity, optimization and less use. The Kruskall-Wallis test proved that the Republic of Serbia lags behind agriculturally innovative countries, which is why it is important to follow the example of innovative countries in terms of introducing innovative approaches in agriculture and increasing input productivity.

Keywords: *agri-food sector, innovations, conceptual framework, Republic of Serbia vs. innovative countries, precision agriculture, sustainable development*

Sažetak

Inovacije su veoma važne za održivi razvoj zemalja. Inovacije u poljoprivredi pomeraju akcenat sa tehnologije, koja se odnosi na produktivnost, na ekonomske, ekološke i socijalne aspekte održivog razvoja. S obzirom na to da ne postoji jedinstven okvir za merenje inovativnosti u poljoprivredno-prehrambenom sektoru i ne može se izvesti jedinstven zaključak koja je zemlja najinovativnija u poljoprivredi, predmet rada je merenje inovativnosti u poljoprivredno-prehrambenom sektoru najinovativnijih zemalja i Republike Srbije. Cilj rada je da dokaže neophodnost uvođenja inovacija u poljoprivredni sektor Republike Srbije, u skladu sa inovacijama koje uvode poljoprivredno inovativnije zemlje. Inovativni pristupi kao što su precizna poljoprivreda i drugi, koji su u skladu sa održivim razvojem, igraju sve značajniju ulogu u poljoprivredi. OLS panel regresija na primeru inovativnih zemalja i Republike Srbije dokazala je da uvođenje inovacija u poljoprivredu pozitivno utiče na održivi razvoj. Samo kod inputa koji se koriste u poljoprivredi ovaj uticaj je bio negativan, zbog čega je važno uvesti savremene tehnologije i inovativne pristupe u cilju povećanja njihove produktivnosti, optimizacije i manje upotrebe. Kruskall-Wallis test je pokazao da Republika Srbija zaostaje za poljoprivredno inovativnim zemljama, zbog čega je važno slediti primer inovativnih zemalja u pogledu uvođenja inovativnih pristupa u poljoprivredi i povećanja produktivnosti inputa.

Ključne reči: *poljoprivredno-prehrambeni sektor, inovacije, konceptualni okvir, Republika Srbija naspram inovativnih zemalja, precizna poljoprivreda, održivi razvoj*

Introduction

The agri-food sector is very important in countries, contributing to GDP and national welfare. Constant supply of food results in enormous environmental costs. Improving the system of food production is key to sustainable development. That is why innovations that lead to the sustainable development of the agri-food sector are important [22]. Innovation leads to increased competitiveness of the agri-food sector and overall economic development [13]. Improving the competitiveness of the economy is achieved through the development of innovations and innovative activities [29].

Innovations in agriculture have mostly been related to technology, with the aim of achieving economic goals and increasing productivity. Innovations in agriculture shift the emphasis from technology and productivity to balance in nature and between economic, ecological and social goals of sustainable development [1].

There is a growing interest for these sustainable development goals in the agri-food supply chain. Also, there is an increasing use of new technologies within agriculture 4.0, which significantly affect the sustainability of supply chains [28]. Innovations in the agrarian value chain include agricultural producers, suppliers of agricultural inputs, as well as processors and distributors of finished products [32].

Traditionally, the agri-food sector has a low level of connectivity and application of innovations in business. On the other hand, agriculture is one of the biggest polluters, which is why the application of innovations, in order to reduce soil degradation, water pollution and biodiversity, is very important to achieve the mentioned goals of sustainable development and reduction of climate change. That is why economic and environmental goals, such as profitability and environmental protection, should be linked [23].

The 21st century is characterized by intensive agricultural production that leads to major environmental problems. Such agricultural systems with excessive use of pesticides and fertilizers have negative consequences for biodiversity. This requires a radical transformation of agriculture in order to reduce synthetic inputs [39].

Organic agriculture can be of great importance in overcoming these challenges. A low level of chemical inputs minimizes environmental pollution. That is why "Organic 3.0" is said to be an innovation [26]. The transition from a linear to a circular economy in agriculture can significantly affect the reduction of environmental pollution, while innovations play a significant role in that transition. The application of the circular economy in agriculture means as little as possible external inputs in the production [19]. But these approaches generally do not achieve satisfactory economic results. In contrast to them, precision agriculture, with help of variable application of inputs, achieves both economic and ecological goals [33] and is in line with sustainable development. Automated and autonomous agricultural equipment has the potential to ensure food safety for consumers, reduce environmental pollution and increase labor productivity [15], as well as reduce production costs and maximize profits [16]. In that sense, for the purpose of mapping and monitoring of different crop yields, remote sensing [20] which use the satellite remote sensing [6], as well as geographic information system (GIS) technology [12], unmanned aerial vehicle (UAV), artificial intelligence (AI) [4], [46] etc., are used.

Bearing in mind that the agri-food sector mainly consists of small and medium sized enterprises, greater connection and cooperation between them can lead to the development of technological and eco-innovations, which will further increase their competitive advantage and enable them to use limited resources efficiently [24]. The non-competitiveness of small agricultural households requires solutions such as the development of a Food Hub, digital store, the association of all participants in agribusiness, maintain the connection between the producers and the consumers etc. [30].

The agri-food sector is currently in the era of the development of "Agriculture 4.0", which implies efficient use of resources, automation and digitalization. This implies the use of modern machines, ICT technologies, Internet of Things (IoT), etc. [17]. Innovations driven by digital transformation in agri-food supply chains are the main objective of "Agri-Food 4.0". Cyber-physical systems are the main strengths in applications in precision agriculture, such as robots, drones, sensors, etc. [7].

The fourth agricultural revolution brought technological innovations, such as the IoT, Cloud Computing, artificial intelligence (AI) and etc., which have the potential to improve agriculture. Smart agriculture can provide huge benefits for sustainable agriculture development, in line with increasing productivity and environmental protection [27]. The agri-food sector has a responsible function to provide quality and safe food for the growing population. However, various constraints such as the global pandemic and climate change highlight the importance of innovation in order to overcome them and build an efficient supply chain. That is why it is crucial that manufacturers adopt new technologies and follow the innovative potential of Industry 4.0 technologies in the agri-food sector [21]. Opportunities should be sought in a potential such as better access to new technologies, as well as development of strategic relationships within food supply chain, creating value added products [25]. Further development of information technologies is expected, especially in sectors that modestly used the support of information technologies in their activities, such as agriculture [45].

The subject of the paper, which is based on the author's PhD thesis, is the review and measurement of innovativeness in the agri-food sector of the most innovative countries and the Republic of Serbia (RS), while the goal of the paper is to prove the necessity of introducing innovations into the agricultural sector of RS, in line with the innovations introduced by more agriculturally innovative countries.

According to the defined subject and research goal, the following hypotheses were defined:

H1: The introduction of innovations in the agri-food sector has a positive impact on the economic and sustainable development of countries.

H2: RS lags significantly behind more agriculturally innovative countries.

Material and methods

Innovation in agriculture is challenging for several reasons. First of all, it is important to point out that agri-food systems include many different sub-sectors. Innovations occur along the entire value chain. Therefore, a model

Table 1: Definition of used variables

Label	Definition	Source
	Dependent variables	
HDI	Human Development Index	[36]
GDP_pc	Gross domestic product per capita (GDP per capita)	[43]
	Agricultural independent variables	
Ag_gradu	Share of graduated students in the fields of agriculture, forestry, fisheries and veterinary, in the total number of graduated students of higher education (%)	[37]
Ag_cred	Loans to agriculture, mil. US $	[11]
Ag_fert	The use of mineral fertilizers - t	[38]
Ag_mac	Use of agricultural machinery	[38]
Ag_reg_pla	Registered plant varieties	[41]
Ag_gva/pw	Gross value added per worker in agriculture (productivity)	[43]
Agf_exp	Export of agri-food products (HS classification)	[35]
Ag_In_des	Agri-food industrial design (Locarno classification)	[41]
Ag_tradem	Agri-food trademarks (Nice classification)	[41]
	Control variables	
Ino	Innovation countries vs. Republic of Serbia – Dummy variable	Author's research.
GERD	Expenditure on research and development (% of GDP)	[43]
Ter_enr	Enrollment of students in higher education institutions	[43]
Cred	Domestic loans to the private sector (% of GDP)	[43].
ICT_imp	Import of high technology	[43].
GDP_pc_gr	GDP growth per capita	[43]
Patent	Patents by origin	[41]
Hi_tec_ex	Export of high technology products	[43]
Ind_des	Industrial design	[41]
Tradem	Product trademarks	[41]

Source: Author's research

based on the GII (Global Innovation Index) framework is proposed for measuring innovations in the agri-food sector [8, p. 74]. Based on the GII framework adapted to agri-food sector (Appendix 1), agricultural variables, as well as their associated control variables from GII framework, were used (Table 1).

The research refers to the introduction of innovation in the agri-food sector of RS and ten the most innovative countries [42]: Switzerland, Sweden, USA, UK, Netherlands, Denmark, Finland, Singapore, Germany and Republic of Korea, and its impact on sustainable development. The research was conducted with the OLS panel regression, for the time period 1999-2019. Due to the Hausman test, a random effect was used. The multicollinearity of the variables (Appendix 2) determined research models. This research was conducted with econometric software EViews.

In the second part of the research, the agriculture of RS was compared with the most innovative countries in the field of agriculture. For the comparison of agricultural indicators, for the period 1999-2019, the non-parametric Kruskall-Wallis test was used. This research was conducted with SPSS.

Results and discussions

The general public sees innovation as a key driver of sustainability [31]. In both developed and developing countries it has an important role in achieving sustainable development. Agricultural innovation brings new products and processes to socio-economic use [18].

The impact of innovation on the economic and sustainable development of innovative countries and RS was examined using the following regression equations:

$$GDP\_pc_{i,t} = \alpha + \beta_1 AGRICULTURE_{i,t} + \beta_2 Ino_{i,t} + \beta_{3GERDi,t} + \beta_{4ter\_enri,t} + \beta_{5credi,t} + \beta_{6ICT\_impi,t} + \beta_{7GDP\_pc\_gri,t} + \beta_{8patenti,t} + \beta_{9hi\_tec\_exi,t} + \beta_{10ind\_desi,t} + \beta_{11trdemi,t} + \varepsilon_{i,t} \quad (1)$$

$$HDI_{i,t} = \alpha + \beta_1 AGRICULTURE_{i,t} + \beta_2 Ino_{i,t} + \beta_{3GERDi,t} + \beta_{4ter\_enri,t} + \beta_{5credi,t} + \beta_{6ICT\_impi,t} + \beta_{7GDP\_pc\_gri,t} + \beta_{8patenti,t} + \beta_{9hi\_tec\_exi,t} + \beta_{10ind\_desi,t} + \beta_{11trdemi,t} + \varepsilon_{i,t} \quad (2)$$

where agriculture refers to Ag_gradu, Ag_cred, Ag_fert, Ag_mac, Ag_reg_pla, Ag_gva/pw, Agf_exp, Ag_In_des, Ag_tradem country i in the year t.

As for the introduction of innovations in the agricultural sector and its impact on economic development (Table 2 and Table 3), all agricultural indicators are statistically significant as well as the research models. The share of agricultural, forestry, fishery and veterinary graduates in the total number of higher education graduates (%), the number of agricultural machines, as well as the amount of fertilizer used in agriculture showed a statistically negative impact on economic development, while agricultural loans, registered plant varieties, GVA per to the worker in agriculture

Table 2: Significance of agricultural innovation for economic development of RS and innovative countries - models 1-4

Label	Dependent variable GDP_pc			
	Model 1	Model 2	Model 3	Model 4
Intercept	**-39733.38 (-2.25)	-8034.81 (-0.63)	-462.51 (-0.05)	1215.22 (0.13)
Ag_gradu	***-6057.67 (-3.36)			
Ag_cred		***0.47 (6.65)		
Ag_fert			*-0.01 (-1.66)	
Ag_mac				***-0.01 (-2.62)
Ter_enr	***51156.00 (4.48)			
GERD	-510.41 (-0.27)	***8824.86 (3.82)	387.39 (0.22)	486.05 (0.27)
Cred		***209.24 (5.12)	***211.28 (6.11)	***220.50 (6.37)
ICT_imp		***-661.12 (-4.78)	***-731.37 (-5.01)	***-729.31 (-5.04)
GDP_pc_gr	-333.00 (-1.22)	*458.11 (1.89)	*297.17 (1.35)	*299.79 (1.38)
Ind_des	***0.15 (4.01)		***0.17 (5.72)	***0.16 (5.52)
Ino	***32804.31 (3.23)	-2404.47 (-0.16)	**21345.76 (1.95)	**20608.08 (1.91)
Adjusted R^2	0.49	0.52	0.53	0.54
F-statistic	***21.16	***22.26	***26.37	***27.55

Source: Author's research
Note: beta coefficients in front of parentheses, t-values in parentheses; *, **, *** indicate statistical significance at the 10%, 5%, and 1% level, respectively.

(productivity), export of agri-food products, agricultural trademarks and industrial design in agriculture showed a statistically positive impact on economic development. In contrast to highly automated production processes, agriculture, despite the automation increase, is still a labor-intensive activity. Raising the level of competitiveness of Serbian agriculture implies increasing the productivity and cost-effectiveness of processes, with the achievement of the lowest possible unit price of production [2]. In order to increase productivity, it is necessary to increase the financing of innovation [40].

Considering that only agriculture inputs had a negative impact on economic development, increasing their productivity by introducing new technologies and efficient use must be imperative. Given that the world's population is expected to grow and there are significant climate changes, the digitization of agriculture can help to overcome these challenges. Digital tools will enable

Table 3: Significance of agricultural innovation for economic development of RS and innovative countries - models 5-9

Label	Dependent variable GDP_pc				
	Model 5	Model 6	Model 7	Model 8	Model 9
Intercept	-839.33 (-0.06)	-1516.15 (-0.17)	529.68 (0.04)	-4693.19 (-0.55)	-6172.91 (-0.58)
Ag_reg_pla	*3.92 (1.70)				
Ag_gva/pw		**0.12 (2.25)			
Agf_exp			***0.01 (4.11)		
Ag_In_des				***1.33 (5.57)	
Ag_tradem					***0.08 (4.86)
GERD	*3598.11 (1.80)	1499.01 (1.01)	1522.36 (1.09)	**3039.50 (2.08)	***3445.92 (2.38)
Cred	*79.80 (1.66)	***189.43 (5.92)	***106.76 (3.51)	***257.97 (7.74)	***221.56 (6.35)
ICT_imp	224.50 (0.73)	***-680.45 (-4.86)		***-791.28 (-5.58)	-10.75 (-0.07)
GDP_pc_gr		*313.06 (1.51)		**436.88 (2.02)	192.35 (1.02)
Hi_tec_ex			0.01 (0.65)		
Ind_des		***0.15 (5.20)			
Ino	*27173.93 (1.79)	*15177.26 (1.53)	*21685.06 (1.65)	*16194.09 (1.66)	12314.48 (1.04)
Adjusted R^2	0.17	0.54	0.23	0.52	0.34
F-statistic	***4.38	***30.81	***8.26	***32.71	***13.95

Source: Author's research
Note: beta coefficients in front of parentheses, t-values in parentheses; *, **, *** indicate statistical significance at the 10%, 5%, and 1% level, respectively.

Table 4: Significance of agricultural innovation for sustainable development of RS and innovative countries – models 1 - 4

Label	Dependent variable HDI			
	Model 1	Model 2	Model 3	Model 4
Intercept	***0.73 (21.14)	***0.78 (67.07)	***0.77 (73.67)	***0.77 (75.65)
Ag_gradu	***-0.02 (-4.73)			
Ag_cred		***0.01 (3.63)		
Ag_fert			**-0.01 (-2.34)	
Ag_mac				***-0.01 (-3.12)
Ter_enr	***0.07 (3.12)			
GERD	***0.01 (3.05)	*0.01 (1.43)	***0.01 (3.27)	***0.01 (3.30)
Cred		0.01 (0.19)	***0.01 (3.76)	***0.01 (3.99)
ICT_imp		***-0.01 (-7.69)	***-0.01 (-8.69)	***-0.01 (-8.69)
GDP_pc_gr	0.00 (-0.77)	0.01 (0.78)	0.01 (1.25)	0.01 (1.23)
Ind_des	***0.01 (3.95)		***0.01 (5.51)	***0.01 (5.61)
Ino	***0.08 (4.36)	***0.13 (8.11)	***0.10 (7.89)	***0.10 (7.86)
Adjusted R^2	0.63	0.61	0.68	0.68
F-statistic	***37.23	***31.49	***48.71	***50.33

Source: Author's research
Note: beta coefficients in front of parentheses, t-values in parentheses; *, **, *** indicate statistical significance at the 10%, 5%, and 1% level, respectively.

production to grow in a way that reduces the stress on ecosystems [14], in line with sustainable development.

Regarding the impact of innovation in agriculture on sustainable development of the RS and innovative countries (Table 4 and Table 5), in relation to economic development, there are no significant differences. All observed models, as well as agricultural indicators, except registered plant varieties, are statistically significant. Agriculture inputs (agricultural students, number of agricultural machines, amount of fertilizer used in agriculture) have a statistical negative impact on sustainable development, while agricultural loans, registered plant varieties, GVA per worker in agriculture (productivity), export of agri-food products, agricultural trademarks and industrial design in agriculture, have a statistically positive impact on sustainable development. In that sense, innovative approaches must be introduced in agriculture in order to reduce and efficiently use inputs, which will also increase the productivity of agriculture (GVA per worker), as well as registered plant varieties, agricultural trademarks and design etc.

The agri-food sector requires a good technological, social, economic and ecological connection [10]. Sustainable agriculture is based on quality, environmentally friendly and more socially responsible system. Therefore, there are more and more initiatives in agri-food sector towards sustainable development [5].

All agricultural indicators used to analyze the introduction of innovation in the agricultural sector had a statistically positive impact both on economic and sustainable development, except the inputs. In the continuation of the research, the agriculture of RS was compared with the most innovative countries in the field of agriculture.

The agriculture of RS lags behind the agriculturally innovative countries according to all observed indicators, observed in relation to each agriculturally innovative country separately (Table 6), as well as in relation to agriculturally innovative countries in total (Appendix 3). The agri-food sector is very complex and constantly changing. Today, robotics, biotechnological and digital technologies are applied in all areas, including agri-food production, especially in developed countries [8]. Although agriculture has experienced significant changes, it is still going through the age of innovation, digital development and environmental protection. The development of this sector moves from economic to sustainable development [3]. Smart agriculture enables such goals and implies the modernization and use of 4.0 technologies, which include IoT, big data, digitization, which further facilitates the use of data and leads to new innovations [21]. The Republic of Serbia should follow the development of the fourth industrial revolution and apply important technologies

Table 5: Significance of agricultural innovation for sustainable development of RS and innovative countries - models 5 - 9

Label	Dependent variable HDI				
	Model 5	Model 6	Model 7	Model 8	Model 9
Intercept	***0.79 (59.93)	***0.77 (75.33)	***0.78 (82.37)	***0.77 (87.44)	***0.76 (69.35)
Ag_reg_pla	0.01 (0.87)				
Ag_gva/pw		***0.01 (4.50)			
Agf_exp			**0.01 (1.97)		
Ag_In_des				***0.01 (5.90)	
Ag_tradem					***0.01 (6.58)
GERD	0.01 (1.20)	***0.01 (4.45)	**0.01 (1.90)	***0.01 (4.57)	***0.01 (4.06)
Cred	-0.01 (-1.55)	***0.01 (2.86)	0.00 (-0.27)	***0.01 (4.41)	***0.01 (3.68)
ICT_imp	0.01 (1.40)	***-0.01 (-8.51)		***-0.01 (-9.59)	***-0.01 (-2.42)
GDP_pc_gr		*0.01 (1.89)		*0.01 (1.54)	*0.01 (1.44)
Hi_tec_ex			0.00 (-1.04)		
Ind_des		***0.01 (4.63)			
Ino	***0.14 (7.98)	***0.09 (6.71)	***0.13 (9.97)	***0.10 (9.14)	***0.09 (6.33)
Adjusted R^2	0.57	0.68	0.63	0.67	0.59
F-statistic	***22.57	***54.20	***42.46	***61.37	***35.91

Source: Author's research

Note: beta coefficients in front of parentheses, t-values in parentheses; *, **, *** indicate statistical significance at the 10%, 5%, and 1% level, respectively.

in its business, such as artificial intelligence, blockchain, robotics, cloud computing, etc. [34]. Innovation data sources focus mainly on the industrial production and services sector, often excluding primary agriculture. However, innovations are also introduced at the farm level, not only in agricultural enterprises, which makes it difficult to collect data on it. From a statistical point of view, the recording of activities on farms has its own specificities in relation to legal entities. As a result, the perception of innovation in the agri-food system is difficult [8]. Precisely because of this, the unavailability of certain data is a limitation of this paper, especially

Table 6: The difference in terms of agricultural innovation in RS and countries that are innovative in the field of agriculture

Name	Country	Mean Rank
ODA education in agriculture	Afghanistan	75.35
	Ethiopia	66.44
	China	55.08
	Indonesia	31.95
	Uganda	72.33
	Serbia	22.72
Chi-Square		***43.179
Expenditure on research and development in agriculture (in US$ 000)	India	44.00
	Korea	31.79
	China	19.20
	Netherlands	33.71
	Australia	20.33
	Serbia	7.71
Chi-Square		***34.418
ODA research and development in agriculture	Nigeria	45.24
	Argentina	21.05
	India	83.95
	Uganda	66.37
	Ethiopia	71.48
	Serbia	14.22
Chi-Square		***66.858
Percentage of graduated students in agricultural sciences (calculation based on the share of graduated students in the field of agriculture, forestry, fisheries and veterinary science in the total number of graduated students of higher education, in %)	Ethiopia	40.14
	Uzbekistan	42.75
	Cambodia	16.00
	Vietnam	35.13
	Albania	19.92
	Serbia	12.82
Chi-Square		***30.346
Loans to agriculture (calculation based on loans to agriculture in million US $)	USA	80.57
	Germany	61.14
	Australia	51.38
	France	81.88
	New Zealand	32.00
	Serbia	6.50
Chi-Square		***65.125
Loans to agriculture (calculation based on participation in total US$ loans, in %)	New Zealand	70.29
	Uruguay	60.52
	Kyrgyzstan	55.52
	Tajikistan	75.25
	Bolivia	41.33
	Serbia	16.83
Chi-Square		***32.467

Name	Country	Mean Rank
Fertilizer application -t	China	99.50
	India	75.44
	USA	69.56
	Brazil	45.33
	Indonesia	27.67
	Serbia	9.50
Chi-Square		***101.273
Use of machines	China	89.67
	India	70.39
	USA	66.06
	Japan	38.61
	Poland	22.78
	Serbia	6.50
Chi-Square		***89.773
Productivity in agriculture - GVA per worker	Slovenia	39.71
	Bahrain	38.07
	Luxembourg	74.81
	Belgium	80.10
	Serbia	11.00
Chi-Square		***84.201
Export of agri-food products - mil. US $	USA	55.50
	Netherlands	44.20
	Germany	36.40
	Brazil	18.85
	China	16.55
	Serbia	11.50
Chi-Square		***50.502
Registered plant varieties - overall application	Netherlands	46.83
	China	40.17
	USA	36.00
	France	19.94
	Germany	17.06
	Serbia	5.00
Chi-Square		***46.509
Trademark - application in the agri-food sector (Nice classification)	China	86.13
	Korea	45.38
	Turkey	42.38
	Italy	63.88
	Russia	44.63
	Serbia	8.63
Chi-Square		***68.131

Source: Author's research, based on [11], [37], [38], [41], [43], [44]
Note: *, **, *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

for precision agriculture, such as number of drones, multipurpose machines etc.

Conclusions

When researching innovation in agriculture, one of the main limitations is that there is no unique framework, nor a precise measure of innovation. In the GII framework, adapted to the agri-food sector, indicators are used do not reflect innovation in the best way, and even can show a negative impact on sustainable development, such as the use of inadequate mechanization, given that this indicator covers the use of all machines in agriculture, such as tractors, attachment machines, etc., which from the aspect of innovation should be replaced by new ones, for example, multipurpose machines with automatic guidance, drones, machines that use renewable energy sources and thus do not pollute the environment. Also, experts who are able to use these technologies and who can create them should be educated. The use of chemical fertilizers should be reduced and replaced with organic fertilizers, in line with sustainable development. This is the only way to change the currently used inputs in agriculture and to increase their productivity, in line with sustainable development. Also, only education in this direction can create experts capable of such technologies. On the other hand, many developed countries record a decrease in the use of agricultural machinery and fertilizers, which are replaced by modern technologies. Today, robotics, biotechnological and digital technologies are applied in the agri-food sector, especially in developed countries, and indicators of their application, which can be used to quantify these changes, are not entirely available.

Furthermore, not every GII indicator has the same indicator adapted for the agri-food sector, which is why the GII framework for the agri-food sector is incomplete, but there is no better generally accepted framework. On the other hand, in this research, it was not possible to point out to the agriculturally innovative countries within one sample, like innovative countries, because, depending on the observation indicators, these are different countries. In contrast to the innovative countries of the world that can be more simply ranked, this cannot be also refers to agriculturally innovative countries, so it was therefore not possible to draw a single conclusion as to which country is the most innovative in agriculture.

The special contribution of this paper, which is based on the author's PhD thesis, is that the innovativeness of the agri-food sector of RS was investigated in a new way and compared with other innovative countries in this sector, which gave clear recommendations for the creators of the agrarian policy of RS and other countries. Also, for the first time, with this framework, the impact and importance of innovation in agri-food sector on the sustainable development of countries was examined. The introduction of new and sustainable approaches in agricultural development is a topic that has not been sufficiently researched, especially empirically. At the same time, measuring agricultural innovation represents an important challenge, because a unique system for measuring innovation in the agri-food sector has not yet been developed. It is a topic that, as it is estimated, will be increasingly relevant in the future, and accordingly, it will require new approaches and knowledge, applicable in practice. The measurement of innovation, both in the primary and in other economic sectors, is a recommendation for future research, given the unexplored nature of this topic and its great importance.

Measuring innovation in agriculture is a challenge, and the GII framework adapted to the agri-food sector was used to prove hypotheses and measure innovation. Regarding the first hypothesis, the research indicated that the agricultural indicators used to show the introduction of innovation in agriculture have a positive impact, both on economic and sustainable development, except the agriculture inputs. That is why it is important to innovate inputs, in order to increase their productivity, and not only increase their number, which can often create additional costs and have a negative impact on productivity, as well as on economic and sustainable development. Also, it is important to introduce innovative approaches in agricultural production, such as precision agriculture, considering the positive impact on sustainable development, as well as increasing the productivity of inputs, considering that the productivity of agriculture inputs also has a positive impact on both the economic and sustainable development of the observed countries. All of this is especially important to apply and introduce more intensively in RS, considering that it lags significantly behind more agriculturally innovative countries, which also proves the second hypothesis.

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Appendix 1

Adaptation of the GII framework for the agri-food sector

GII pillars	GII indicator	Are indicators available for the agri-food sector?	Appropriate indicator in the agri-food sector	Additional indicators
Human capital and research	Expenditure on education	For just a few economies	/	/
	Tertiary enrollment	Yes	Tertiary education students on agricultural programs	/
	Graduate students	Yes	ODA for agricultural education / training	/
	Researchers	Yes	Agricultural researchers	/
	Gross expenditure on R&D	Yes	Expenditure on R&D in agriculture	ODA for agricultural research
	Global spending by companies on R&D, average spending	Not	/	/
	QS (Quacquarelli Symonds) university rankings	Not	/	/
Market sophistication	Ease of getting a loan	For just a few economies	/	/
	Domestic loans to the private sector	Yes	Loans to agriculture	/
	Gross microfinance loans	For just a few economies	/	/
	Venture Capital Offers	Not	/	/
	Customs duty rate applied	Yes	Applied customs rate for agricultural and food products	/
	Intensity of local competition	Not	/	/
Business sophistication	Knowledge - intensive employment	/	/	/
	Firms that offer formal training	Yes	Firms that offer formal training in food processing	/
	GERD (Gross expenditure on research and development) business derived	For just a few economies	/	/
	GERD funded from operations	Not	/	/
	Employed women with / diplomas of higher education	Not	/	/
	University / industrial cooperation in research	Not	/	/
	State of cluster development	Not	/	/
	Foreign funded GERD	Not	/	/
	JV (Joint Ventures) – joint investments	Not	/	/
	Patents	Yes	Agricultural and food patents	/
	International payments	Not	/	/
	Import of high technology	Yes	Import of high technology for the agricultural and food sector	Fertilizer use, machinery in use
	Net inflow of FDI	Yes	Inflows of foreign investments in the agricultural and food sector	/
Results of knowledge and technology	Patents by origin	Yes	Agricultural and food patents according to origin	Registered plant varieties
	PCT (Patent Cooperation Treaty) patent applications	Yes	Agri-food PCT patent applications	/
	Useful models by origin	Yes	Agricultural and food utility models according to origin	/
	Scientific and technical works	Yes	Scientific and technical works in agriculture	/
	Available documents by H index	Yes	Available documents in the agricultural and food sector	/
	Growth rate of GDP per worker, PPP (purchasing power parity) $	Yes	Growth of labor productivity in agriculture	/
	New businesses	Not	/	/
	ISO 9001 quality certificates	Not	/	/
	IP receipts	Not	/	/
	Export of high technology	Yes	Export of agricultural and food products	/
	Net FDI outflows	Yes	FDI outflows from agriculture	/
Creative output	Trademarks	Yes	Agricultural and food protective trademarks	It does not register geographical indications
	Industrial design	Yes	Agricultural and food industrial design	/
	ICT and business model creation	Not	/	/
	ICT and the creation of an organizational model	Not	/	/

Source: [8, p. 74]

Appendix 2

Multicollinearity of variables

Label	GDP_pc	HDI	Ag_gradu	Ag_cred	Ag_fert	Ag_mac	Ag_reg_pla	Ag_gva/pw	Agf_exp	Ag_In_des	Ag_tradem	GERD	Ter_enr	Cred	ICT_imp	GDP_pc_gr	Patent	Hi_tec_ex	Ind_des	Tradem	Ino
GDP_ Pc	1.00																				
HDI	*** 0.87	1.00																			
Ag_gradu	*** -0.54	*** -0.56	1.00																		
Ag_cred	* 0.36	** 0.36	*** -0.55	1.00																	
Ag_fert	** 0.38	0.20	** -0.42	*** 0.85	1.00																
Ag_mac	* 0.32	0.16	** -0.39	*** 0.86	*** 0.99	1.00															
Ag_reg_pla	* 0.36	* 0.27	*** -0.48	*** 0.95	*** 0.94	*** 0.95	1.00														
Ag_gva/pw	*** 0.65	*** 0.62	* -0.26	*** 0.58	*** 0.67	*** 0.64	*** 0.59	1.00													
Agf_exp	** 0.37	** 0.37	*** -0.44	*** 0.96	*** 0.82	*** 0.83	*** 0.91	*** 0.59	1.00												
Ag_In_des	* 0.30	* 0.36	* -0.26	*** 0.74	*** 0.48	*** 0.48	*** 0.61	** 0.41	*** 0.80	1.00											
Ag_tradem	* 0.34	*** 0.45	*** -0.43	*** 0.78	*** 0.45	*** 0.45	*** 0.60	*** 0.46	*** 0.83	*** 0.86	1.00										
GERD	*** 0.49	*** 0.65	-0.23	* 0.25	0.11	0.11	* 0.27	* 0.32	0.20	0.10	0.05	1.00									
Ter_enr	0.11	-0.18	0.07	0.02	** 0.38	* 0.34	0.10	** 0.40	0.09	0.02	0.04	*** -0.65	1.00								
Cred	*** 0.69	*** 0.60	*** -0.85	*** 0.67	*** 0.66	*** 0.63	*** 0.67	*** 0.57	*** 0.57	* 0.30	*** 0.44	* 0.32	0.09	1.00							
ICT_ imp	* 0.35	** 0.41	*** -0.75	** 0.44	** 0.39	** 0.38	** 0.45	0.11	** 0.39	0.18	0.18	* 0.33	-0.20	*** 0.50	1.00						
GDP_pc_gr	** -0.40	* -0.32	-0.09	0.14	0.04	0.07	0.11	* -0.33	0.05	0.04	0.01	-0.20	-0.18	-0.05	0.20	1.00					
Patent	* 0.34	* 0.27	*** -0.50	*** 0.94	*** 0.94	*** 0.95	*** 0.99	*** 0.58	*** 0.87	*** 0.55	*** 0.53	* 0.32	0.05	*** 0.68	*** 0.49	0.13	1.00				
Hi_tec_ex	** 0.35	*** 0.44	*** -0.67	*** 0.91	*** 0.64	*** 0.65	*** 0.82	* 0.33	*** 0.89	*** 0.71	*** 0.77	* 0.34	-0.24	*** 0.61	*** 0.65	0.19	*** 0.80	1.00			
Ind_des	* 0.32	** 0.44	*** -0.57	*** 0.93	*** 0.63	*** 0.65	*** 0.83	** 0.44	*** 0.88	*** 0.75	*** 0.83	** 0.39	* -0.25	*** 0.62	** 0.42	0.15	*** 0.82	*** 0.93	1.00		
Tradem	*** 0.43	** 0.40	*** -0.54	*** 0.97	*** 0.85	*** 0.85	*** 0.91	*** 0.66	*** 0.96	*** 0.78	*** 0.84	0.12	0.21	*** 0.68	** 0.36	0.05	*** 0.88	*** 0.84	*** 0.88	1.00	
Ino	*** 0.81	*** 0.97	*** -0.64	** 0.40	0.23	0.19	* 0.30	*** 0.62	** 0.38	* 0.30	*** 0.44	*** 0.68	-0.22	*** 0.68	*** 0.45	* -0.29	* 0.32	*** 0.48	*** 0.48	** 0.41	1.00

Source: Author's research

Note: *, **, *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Appendix 3

The difference in the agricultural innovation of RS and agriculturally innovative countries

Label	Country	Mean Rank
ODA education in agriculture	Agriculturally innovative	58.97
	Serbia	22.72
	Chi-Square	***18.894
Expenditure on research and development in agriculture (in US$ 000)	Agriculturally innovative	29.40
	Serbia	7.71
	Chi-Square	***27.206
ODA research and development in agriculture	Agriculturally innovative	57.65
	Serbia	14.22
	Chi-Square	***16.150
Percentage of graduated students in agricultural sciences (calculation based on the share of graduated students in the field of agriculture, forestry, fisheries and veterinary science in the total number of graduated students of higher education, in %)	Agriculturally innovative	28.53
	Serbia	12.82
	Chi-Square	***10.311
Loans to agriculture (calculation based on loans to agriculture in million US $)	Agriculturally innovative	58.50
	Serbia	6.50
	Chi-Square	***31.543
Loans to agriculture (calculation based on participation in total US$ loans, in %)	Agriculturally innovative	59.21
	Serbia	16.83
	Chi-Square	***19.524
Fertilizer application -t	Agriculturally innovative	63.50
	Serbia	9.50
	Chi-Square	***44.587
Use of machines	Agriculturally innovative	57.50
	Serbia	6.50
	Chi-Square	***31.456
Productivity in agriculture - GVA per worker	Agriculturally innovative	60.00
	Serbia	11.00
	Chi-Square	***49.00
Export of agri-food products - mil. US $	Agriculturally innovative	34.30
	Serbia	11.50
	Chi-Square	***14.217
Registered plant varieties - overall application	Agriculturally innovative	32.00
	Serbia	5.00
	Chi-Square	***22.093
Trademark - application in the agri-food sector (Nice classification)	Agriculturally innovative	56.48
	Serbia	8.63
	Chi-Square	***39.341

Source: Author's research, based on [11], [37], [38], [41], [43], [44]
Note: *, **, *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

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