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Uptake of decision support system for mycotoxin management in wheat by Serbian and EU farmers

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Abstract

A decision support system (DSS) is a computer-based information system that aims to support decision makers to make rational choices by analysing uncertain conditions and risks. A DSS can support farmers in choosing the best mycotoxin management measures to prevent and control mycotoxin contamination in wheat, specifically for their farm situation. However, the current acceptance of such systems among farmers is low, the uptake of a DSS is not common practice yet and is expected to change in the future.

The aim of the study was to investigate the relationship between farm(er) characteristics and the uptake of DSS by wheat farmers for mycotoxin management in wheat. Online questionnaires were sent to wheat farmers from Serbia and four EU countries. In total 292 questionnaires were collected, 87 from Serbia, 120 from the Netherlands, 9 from Austria, 47 from Italy and 29 from the UK.

Over half of the respondents use a DSS in Austria, Italy and the UK, while only 11.5% and 16.7% of respondents were DSS users in Serbia and the Netherlands. The results of binary logistic regression analysis show that farmers in higher ages, make decision by themselves ($P \leq 0.05$), higher knowledge level of mycotoxin contamination in wheat, and use non-grains as rotation crop ($P \leq 0.001$) have positive influence on the uptake of DSS by wheat farmers. The empirical results have managerial implications for crop industries, consulting, government agencies and farmers. By changing the potential relationship based on the result of research may help improve the acceptance and uptake of DSS by wheat farmers.

Keywords: Decision support system; Wheat farmers; Mycotoxin contamination; European countries; Farm characteristics; Farmer characteristics; Binary logistic regression model

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1 Introduction

1.1 Mycotoxin management in wheat

Wheat is one of the most dominant staple foods of the European population. FAO estimated that from 2014 to 2016, the average wheat production quantity is approximately 250 million tons in the whole of Europe and 150 million tons in the European Union per year, which account for about 34% and 21% of the total wheat production in the world respectively (FAO, 2018). Serbia and four EU countries: the Netherlands, Austria, Italy and the United Kingdom (UK) can represent the European situation to some extent.

Table 1.1 summaries the average production quantity of these five countries per year from 2014 to 2016 and the export rate of wheat and wheat related products in 2013 (FAO, 2018). Thus, they are major grain exporting countries and many humans and animals consume food products derived from wheat produced in these countries.

Table 1.1 The average production quantity and export rate of wheat in five countries

Country	Average production quantity/million tons (2014-2016)	Export rate (2013)
The Netherlands	1.21	99.7%
Austria	1.83	60.2%
Serbia	2.57	50.7%
Italy	7.52	49.8%
UK	15.81	11.0%

Mycotoxins are toxic secondary metabolites produced by certain filamentous fungi, which may lead to adverse health effects (chronic or acute illnesses of human and animals) and result in large economic losses (Zain, 2011; Kumar et al., 2008). They can contaminate agricultural products before harvest or during transportation or storage (Suttajit, 1989) and transfer throughout the supply chain and end up in final products, such as animal feed and food products (Hussein & Brasel, 2001).

The presence of mycotoxins in grains varies among different cereal species. Amongst other crops, wheat can adapt and grow more easily in different climate regions and can be exposed to toxigenic fungi more frequently (Mankeviciene et al., 2007). The most well-known mycotoxins in wheat are fumonisins, zearalenone (ZEA) and deoxynivalenol (DON) produced by *Fusarium* spp. (Kumar et al., 2008), which have been identified to have carcinogenic risks by IARC (1993). Therefore, studying mycotoxins in wheat is meaningful to improve food safety and food security.

Since mycotoxin contamination is unavoidable and naturally occurring in grains (Murphy et al., 2006), prevention of mycotoxin contamination in grains is an important task in food safety management. Janssen et al. (2019) found that nowadays six measures against *Fusarium* spp. in wheat are commonly applied by Dutch farmers. The combination of pre-harvest measures such as fungicide use, selection of a *Fusarium* resistant wheat variety, ploughing after grain harvest and crop rotation (no grains as pre-crop) is a common management strategy. More importantly, researches showed that repeated cultivation of the same crop and using grains (e.g., wheat, barley, or maize) as previous crop can increase DON content in wheat. Whether a previous crop was susceptible to the fungus and the frequency of the crop involved in the rotation plan are important factors. (Pirgozliev et al., 2003; Landschoot et al., 2011; Shah et al., 2018; Worldatlas, 2017).

1.2 Decision support system

A decision support system (DSS) is a computer-based information system that aims to support decision makers to make rational choices by analysing uncertain conditions and risks. Hundreds of DSSs have been developed over the years and some decision support platforms have been created.

For example, Agricultural decision support system (AgriDSS) of Smart Fertilizer Management Software was designed in 2014 and put farmers in the driver's seat of their farms. By these platforms, farmers have easier access for using a DSS (Smart Fertilizer Management, 2018). Furthermore, DSSs are readily available in many domains and expected to be adopted by farmers widely. For instance, farm managers use DSSs for integrated pest management of plant diseases (Shtienberg, 2013); an epidemiological information management system (EpiMAN) has been developed for animal disease emergency (Sanson, 1993); scientists use DSSs for prediction of the microbial spoilage in foods (Zwietering et al., 1992). DSSs help users predict risks, decrease losses, reduce costs and get higher benefits.

For mycotoxin management in wheat, a DSS can handle various inputs including economic resources, agronomic factors and their effectivity, and other factors, and then ideally provides an analysis of how these factors work together in mycotoxin management.

As the world population grows and the availability of arable land diminishes, there is an increasing need to make smart use of each piece of land in order to produce more and safer wheat. Especially in recent years, climate change in EU has been expected to increase difficulty to mycotoxin management in grains so that the crop managers face increasing complexity and risks (Van der Fels-Klerx et al., 2016).

To prevent mycotoxin contamination in wheat, farmers are the major actor and they can implement various intervention measures to reduce the contamination of wheat. A DSS can support farmers in choosing the best mycotoxin management measures to prevent and control mycotoxin contamination in wheat, specifically for their farm situation.

However, the current acceptance of such systems among farmers is low due to many barriers (Parker, 2004; Parker, 2005; Short et al., 2004). The uptake of DSS is not common practice yet and it is expected to change in the future (Smart Fertilizer Management, 2018).

1.3 Farm and farmer characteristic influence uptake

Many studies showed that farmer's behaviour was influenced by farm characteristics and farmer characteristics (socio-demographics). Based on these backgrounds, many studies investigated how predictive factors influenced the adoption of computer and computerized information systems, including FMIT, DSS etc. To improve the utilization, the uptake of these kinds of technologies was studied in many areas.

It has been found in most reviewed studies that education level, farm size and productivity had positive correlation with adoption of new information technologies (IT), while age had negative association on the adoption. People with higher education level have more basic computer knowledge. Younger farmers use more IT than elderly farmers. This is perhaps because young people accept new things quicker than elderly. Also, the farmers attributes such as farmer's skills, learning style, personality, objectives and so forth were related to the result of DSS uptake (Wilson et al., 2001; Alvarez & Nuthall, 2006; Carrer et al., 2017).

Interestingly, Wilson et al. (2001) found that farmers who have more experience in farm management are more willing to try new technologies and easier reach the higher technical efficiency. However, Carrer et al. (2017), got an opposite result, i.e., a negative relationship between farmer's experiences and adoption of farm management information systems. This may relate to age factors because higher ages normally match with more experience but not with higher education.

Also, whether farmers have off-farm employment was an influencing variable. Farmers were exposed to new technologies by off-farm employment. They had a broader perspective which helped to improve the uptake, while farmers using on-farm employment showed a lower adoption (Putler & Zilberman, 1988; Woodburn et al., 1994). Another study amongst farms in Canada showed that the adoption of IT based tools in sustainable farming was influenced by the farmer's expertise and financial resources (Aubert et al., 2012).

In addition, farmers' perception of system performance was correlated with the actual uptake of an information system. Farmers cared about the features of usefulness, utility and the costs of implementation. If it was affordable, they were willing to adopt a DSS (Alter, 1976; Nuthall & Benbow, 1999; Rehman et al., 2007; Alvarez & Nuthall, 2006). Therefore, understanding farmers' views on whether DSSs can improve managing mycotoxin contamination in wheat is critical.

In conclusion, some factors have common features and similar correlations in previous studies, especially demographic variables. However, due to the diversity of cases, areas, groups, countries and even periods, different independent variables should be considered. In this survey, farmers are from different European countries, so their policy of crop growing, subsidy by the government, crop use, soil type and even culture and conditions are different.

However, most of studies have investigated management information systems in a broad sense, and limited literature reviews on the uptake of DSS by wheat farmers for managing the mycotoxin contamination can be found. Thus, the real situation of this specific case in these five countries is still unclear and many aspects are waiting to be discovered.

The aim of the study was to investigate the use of DSS for mycotoxin management of wheat, and how farm and farmer characteristics influence the uptake of such a DSS by wheat farmers. The study focused on wheat farmers from five European countries, including Serbia, the Netherlands, Austria, Italy and the UK, and investigated the correlation between farm and farm-related factors and uptake of DSS. By investigating the relationships, suggestions were given to help improve the acceptance of DSSs.

2 Methodology

As discussed above, the uptake of a decision support system to select appropriate measures against mycotoxin contamination in wheat can be influenced by farm characteristics and farmer characteristics. In this part, independent variables and questions set in the questionnaire were described.

2.1 Conceptual framework

As illustrated in Fig.1, these independent variables were assumed that have influence on using DSSs by respondents. The independent variables were separated into two groups and this conceptual framework formed the basis for the following empirical analysis.

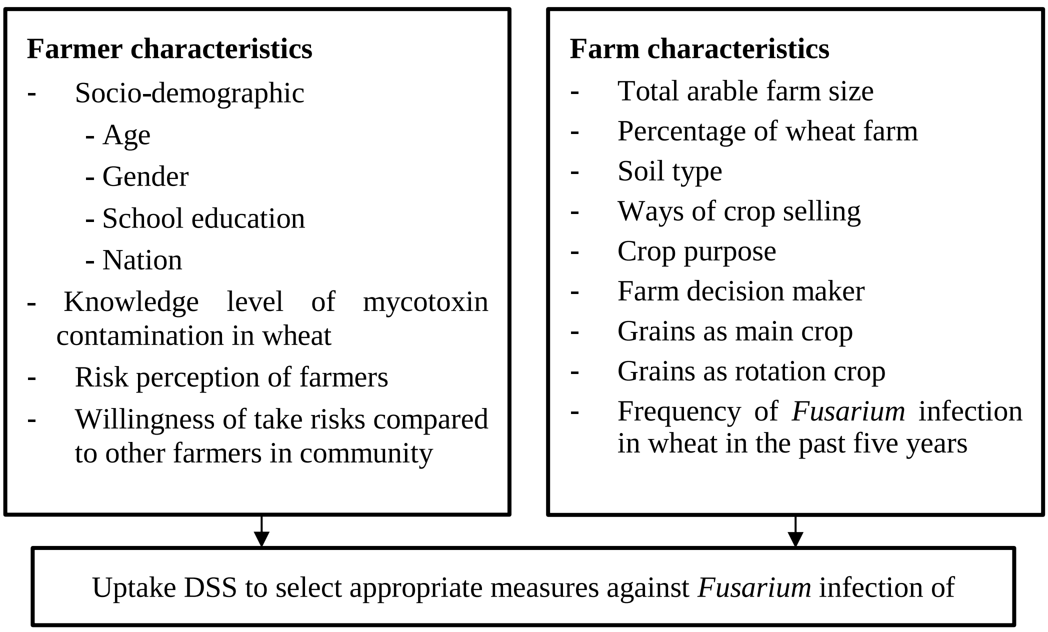

Fig. 1 Drivers of uptake of DSS by wheat farmers

2.2 Data collection

Data of five countries were collected in 2017 by distributing a standardized online questionnaire to wheat farmers via farmer-cooperation or organisations. Altogether, data from 292 respondents were finally selected and used in the analysis. There are 87 questionnaires filled in by farmers from Serbia, 120 from the Netherlands, 29 from the UK, 47 from Italy and only 9 from Austria.

There are 17 questions in the questionnaire used in the study. The answer of the question "Do you use a decision support system to select appropriate measures against *Fusarium* infection?" was regarded as the dependent variable and it was a dichotomous variable. Farmers stated that farmers use a DSS was expressed in '1' and not use a DSS was expressed in '0'.

Independent variables that were tested as potential predictive variables were sociodemographic in nature: age (1-5 scale); gender (male/female); school education (1-3 scale); knowledge level of mycotoxin contamination of wheat (1-3 scale); nation (5 countries). Besides the variables described above, the willingness to take risks regarding mycotoxin contamination compared to farmers in the same community (1-3 scale) and risk perception of farmers (1-3 scale) were considered. Risk perception was a combination of expectation of future and the expectation of consequence if *Fusarium* infection happened. The score of these two answers were multiplied and then grouped in five levels. These six independent variables were treated as categorical variables and were analysed in this study.

Farm characteristics were the second set of explaining variable aspect, containing the following information: total arable farm size (1-4 scale); percentage of wheat farm (1-4 scale); soil type (6 types); ways of crop selling (3 types); crop purpose (2 types); farm decision maker (2 types); frequency of serious *Fusarium* infection in the past five years (1-3 scale). Moreover, producing grains (e.g. wheat, barley, or maize) as main crop (yes or no), which means the most important crop in farm, and using grains (barley and maize) as pre-crop of wheat in rotation (yes or no) are another two variables, as crop rotation has been identified as one of the most effective cultural-control approaches.

2.3 Statistical methods

Data were analysed by using the software Excel 2016 and IBM SPSS Statistic 25 package. First, descriptive analysis of the data was performed. The distribution and frequency of variables in each country were described by tables and graphs. An overview of the data was represented, and potential outliers of data were checked.

Binary logistic regression model was applied to analyse the data. The uptake of DSS by farmers was the dependent variable (Y variable) in this model, where "0" stands for "no uptake of DSS" and "1" stands for "uptake of DSS".

To run the model, univariable analysis was used to make a pre-selection of the most important variables. All independent variables were run in univariable models and the

P-values were checked to identify the significant influencing variables. The variables with a P-value lower than 0.3 were selected and put in the multivariable analysis.

After pre-selection, stepwise backward selection using the maximum likelihood function method was used in the regression analysis to find the best fitting model to answer the research question. It started with all pre-selected variables and variable that had the least significance level were removed one by one until all variables were significantly correlated with dependent variable ($P \leq 0.05$). Then, the multicollinearity between independent variables was checked by Pearson Chi-square and the variables that were not independent to other variables were deleted ($P \leq 0.05$). After the final selection, the final model was created and explained.

3 Results

3.1 Descriptive analyses

Descriptive overviews of all samples from five countries are presented in this section, including the frequency of farmer characteristics and farm characteristics and the distribution of DSS users. The raw data distribution for all variables, the distribution of DSS users and DSS non-users in each country, and the similarity and difference between five countries are clearly showed via graphs and tables in Annex I.

Besides the frequency of samples, the results of univariable analysis of each dummy variable are presented in Tables 3.1.2(a) and Table 3.1.2(b). The groups which showed to have significant correlation with uptake of DSS were marked by asterisks, more specifically, “*”, “**” and “***” mean $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$, respectively, and not significant variables ($P > 0.05$) had no signal. The details of results of the univariable logistic regression models of each variable are presented in Annex II by tables.

3.1.1 The total sample distribution of five countries

The analysis considered data from 292 farmers in five European countries, of whom are 77 DSS users and 215 non-users. The frequency distributions of DSS users in different countries are presented in Table 3.1.1 and Fig.2.

Table 3.1.1 Distribution of DSS uptake by farmers in five countries

Uptake of DSS	Serbia (N=87)	NL (N=120)	Austria (N=9)	Italy (N=47)	UK (N=29)	In total (N=292)
No.	10	20	5	26	16	77
%	11.5	16.7	55.6	55.3	55.2	26.4

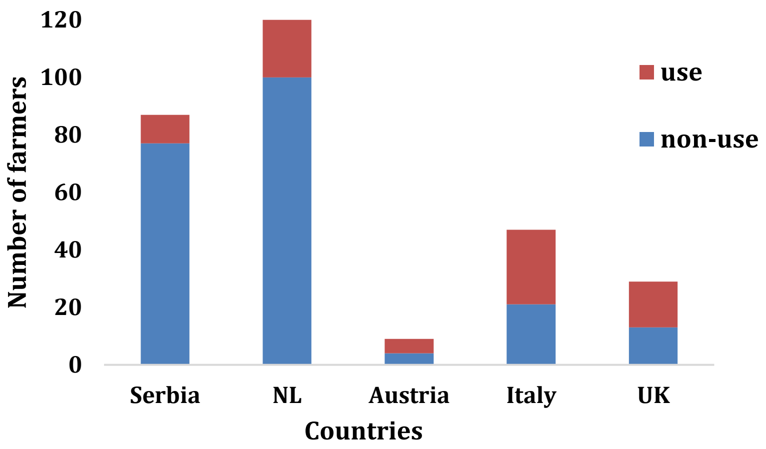

Fig. 2 Distribution of DSSs use and non-use farmers in five countries

The average percentage of DSS users is only 26.4%. Only 11.5% and 16.7% farmers adopt a DSS in Serbia and the Netherlands. While Austria, the UK and Italy describe more than half farmers using a DSS.

3.1.2 Results of contingency tables for DSS users and non-users and univariable results

Table 3.1.2 (a) shows the sample distribution and descriptive results for the farmer characteristics of the two groups of DSS users and non-users.

Table 3.1.2 (a) Distribution of the sample of farmer characteristics by DSS uptake

	Non-use (N)	Use [N (%)]	Total (N)
Sample	215	77 (26.4)	292
Age			
<34	49	7* (12.5)	56
35-44	29	9 (23.7)	38
45-54	32	29 (47.5)	61
55-64	28	12 (30)	40
>64	12	7** (36.8)	19
Gender			
Male	137	58 (29.7)	195
Female	12	6 (33.3)	18
School education			
Primary& secondary	32	17* (34.7)	49

After secondary	104	29*** (21.8)	133
University	13	18** (58.1)	31
Knowledge level			
Low	31	5** (13.9)	36
Medium	89	18*** (16.8)	107
High	84	52*** (38.2)	136
Nation			
Serbia	77	10*** (11.5)	87
The Netherlands	100	20*** (16.7)	120
Austria	4	5 (55.5)	9
Italy	21	26 (55.3)	47
UK	13	16*** (55.2)	29
Risk reception			
Low	72	26 (26.5)	98
Medium	90	30 (25)	120
High	50	21 (29.6)	71
Take risks			
Less	102	29 (22.1)	131
Same	78	31 (28.4)	109
More	34	17 (33.3)	51

Asterisks (*) indicate items that are significantly different from the not using group at the following levels: * P≤0.05, ** P≤0.01, ***P≤0.001, not significant (n.s.) P>0.05.

Farmers with age between 45 and 54 years old are the main group within total respondents. There are less respondents who use DSSs with age under 35 years old, while farmers aged between 45-54 have the largest proportion of DSS uptake.

Of the respondents, male farmers made up almost 91.6% of all respondents and only 8.4% are female. As there are different education system in different countries, the education level was classified in three groups, being the primary and secondary level, after secondary level and university level. Most of farmers had an education level of after secondary education.

The score of knowledge level of mycotoxin contamination in wheat was retrieved by five questions, including the following knowledge: 1. Harvest debris in the soil form a risk for *Fusarium* infection; 2. Able to recognize a *Fusarium* infection by black kernels; 3. *Fusarium* species can also be present in maize and barley; 4. *Fusarium* species produce mycotoxins like DON; 5. Mycotoxins could be harmful for humans. As the data showed, it is good to see that most farmers had a high knowledge level (48.7%) and there are only few farmers who are grouped in the low knowledge level class (12.9%). Farmers in higher knowledge level have a higher proportion of DSS users than farmers in lower knowledge level.

Risk perception is a combination of expectation of future and the expectation of consequence if *Fusarium* infection happened. The score of these two answers were multiplied and then grouped in five levels. Most of the farmers were in the medium class for risk perception, and there was no significant difference between all three groups, being low, medium and high.

Most of respondents were willing to take less risks than other farmers in the same community, and few farmers (17.5%) were willing to take more risk than others.

Table 3.1.2 (b) Distribution of the sample of farm characteristic by DSS uptake

	Non-use (N)	Use [N (%)]	Total (N)
Total hectare			
0-99	107	30 (21.9)	137
100-199	41	13 (24.1)	54
200-500	10	17 (63)	27
>501	8	5** (38.5)	13
Wheat percentage			
0-25%	67	26 (28)	93
26-50%	82	29 (26.1)	111
51-75%	11	8 (42.1)	19
76-100%	3	2 (40)	5
Soil type			
Clay	96	33 (25.6)	129
Loam	22	16 (88.9)	38
Loess	17	5 (22.7)	22
Sand	17	6 (26.1)	23
Chernozem	40	13 (24.5)	53
Other	19	4 (17.4)	23
Type of crop celling			
Collector or merchant	179	61 (25.4)	240
Directly to feed/food producer	24	8 (25)	32
Other	11	8 (42.1)	19
Type of crop using			

Human food	119	45 (27.4)	164
Feed or seed	93	31 (25)	124
Farm decision maker			
Respondent	70	41* (36.9)	111
With others/others	80	23 (22.3)	103
Grains as main crop			
No	120	34* (22.1)	154
Yes	80	40 (33.3)	120
Grains as rotation crop			
No	54	37** (40.7)	91
Yes	142	39 (21.5)	181
Past five years			
Never	84	31 (27)	115
Once	75	25 (25)	100
2-4 times	53	21 (28.4)	74

Asterisks (*) indicate items that are significantly different from the not using group at the following levels: * P≤0.05, ** P≤0.01, ***P≤0.001, not significant (n.s.) P>0.05

Table 3.1.2(b) presents the distributions of the sample farm characteristics. In this case, all farmers who answered the questions referred to conventional wheat rather than organic wheat farm.

Most farmers have total arable land smaller than 100 hectares, which accounted for over half respondents (59.3%). A low number of respondents had more arable land, so most of the farmers did not manage a huge farm. More detailed, the maximum land area in countries were different, they are 2500, 1450, 1250 and 2050 hectares in Serbia, the Netherlands, Italy and the UK, respectively.

Most farms used 26-50% of the farm arable land for wheat farming. Less respondents produce wheat larger than 50% of total area and least respondents (2.2%) use more than 75% arable land to produce wheat.

Table 3.1.2(b) above shows that most farmers produce wheat by clay. However, due to the different environment in countries, the soil types are different. In details, the clay was the main soil type in the Netherlands and Italy, while chernozem was the main soil in Serbia and the UK.

After harvest the wheat, most farmers sold their production via a collector or merchant (82.5%). It is good to mention that many farmers noted they will choose their cooperatives or higher bidder collector or merchant. There was a small group of respondents chose “other ways”, included in selling wheat directly to a feed or food producer, no selling for own using, cooperative company which have supply chain contracts, mills and seedlings, etc.

The wheat production can be used in three ways, for human consumption food, animal feed and seed. Most of farmers use for all as human food was still the domain.

Apparently, most of farmers make decision by themselves, participate the decision making by others or participating occupied a little bit lower percentage (48.13%). Farmers who make decision only by themselves showed a significant influence of DSS uptake, they are more likely to use a DSS.

Around 43.8% respondents produce grains as their main crop in farm, such as wheat, maize and barley. Farmers who do not use grains as main crop showed a negative influence on using a DSS. This may because non-grain crop produces very low or no mycotoxin. Farmers who produce other crops do not that need this system. Except for main crop, whether use grains as a prior rotation crop to wheat showed a high significant relationship. Farmers who do not use maize or barley as pre-crop are more likely to adopt a DSS. As using grains as pre-crop of wheat is bad to mycotoxin control, farmers who use a DSS may know more knowledge and manage their farm better.

3.2 Results of binary logistic regression model

3.2.1 Multivariable analysis

After running univariable binary logistic regression models, the potential relationships between the independent variables and uptake of DSS were investigated. Results were showed in Table 3.1.2 (a) and Table 3.1.2 (b) by asterisks signal.

After the preselection, ten variables with P-value lower than 0.4 were chosen to run the final model by stepwise backward method with likelihood ratio (LR) test. These 10 variables were: Age, School education, Knowledge level of mycotoxin contamination in wheat, Total hectare, Ways of crop selling, Decision maker, Grains as main crop, Grains as rotation crop, Take risks and Nation. The stepwise forward method with LR method was also used to run the final model. Result were similar as with using the backward method.

The model was defined in six steps and the final step model contained five independent variables: Age, Knowledge level of mycotoxin contamination in wheat, Decision maker, Grains as rotation crop and Nation. All of these had a P-value lower than 0.05 and the Nagelkerke R^2 was 0.540 in this step.

3.3.2 Multicollinearity check

After obtaining the (final) multivariable model, the multicollinearity between the five variables was checked to exclude variables that were not independent to other variables. As all variables were categorical variables, nominal or ordinal, a Pearson Chi-squared test was used to check if there was correlation between independent variables in the model.

The results showed that there were four significant relationships between the six variables. Age was associated with Grains as rotation crop with P-value of 0.040, however, the association was not very strong after checking the logistic regression, so both were kept in the final model. Nation was significant highly correlated with three variables with P-value lower than 0.001. They were Age, Grains as rotation crop and Knowledge level of mycotoxin contamination in wheat. Therefore, nation was removed from the final model and the final model was showed in Table 3.3.3.

After running a univariable binary logistic regression model by Enter method, the results of all variables were performed in the IBM SPSS statistic software. The P-value and the Exp(B) value of each variable are showed in the following section.

3.3.3 Results for DSS uptake tested by multivariable binary logistic regression

Table 3.3.3 Results for DSS uptake tested by multivariable binary logistic regression

Variables	OR (Exp(B))	95% Confidence interval	Sig. (P-value)
Age			
>64	reference		0.018*
<34	0.186	0.046-0.745	0.017*
35-44	0.507	0.131-1.965	0.326
45-54	1.059	0.303-3.695	0.929
55-64	0.604	0.157-2.328	0.464
Knowledge level			
High	reference		0.001***
Low	0.226	0.056-0.916	0.037*
Medium	0.247	0.114-0.536	0.000***
Decision maker			
With others or others	reference		
Respondent	2.469	1.210-5.037	0.013*
Grains as Rotation			
Yes	reference		
No	3.351	1.590-7.062	0.001***
Constant	0.600		0.404

(*P≤0.05, ** P≤0.01, ***P≤0.001, not significant (n.s.) P>0.05)

Table 3.3.3 indicates the final multivariable binary logistic regression model. EXP(B) value indicated that when the scale of independent variable was raised to one unit, the odds ratio was “EXP(B)” times greater and therefore farmers are “EXP(B)” times more likely to use a DSS.

The parameters of this model are: Omnibus test: Chi-squared = 50.712***; -2Log-Likelihood = 196.214.482; R2 (Cox and Snell) =0.227; R2 (Nagelkerke)=0.318; Hosmer-Lemeshow test: Chi-squared = 11.519, df =8, sign. 0.174 (n.s.); Classification (model): percentage correct: 77.2%.

4 Discussion

In this study, 17 farm and farmer characteristics were statistically significantly tested in a binary logistic regression model and tested for positive or negative effects of DSS uptake in wheat farming in Serbia and four EU countries.

The results of the analysis showed a high relevance of age, more specifically, the farmers who are younger than 34 years old are 0.19 times less likely to use a DSS than farmers who older than 64 years. One possible explanation is that the younger farmers are new farmers, with less experience of wheat farming, they might not know what the DSS is or are still learning how to apply it. However, there was no significant difference between farmers from 35 to 64 years old and farmers older than 64 years old. Older ages may indicate more experienced farmers on the one hand, and more stable partners and sophisticated management, on the other hand. They might be recommended to use a DSS by their peers and business partners.

Contrary to this study, a case study of a dairy farm showed that younger farmers are more likely to adopt new computer technology as youngers are more willing to accept new things (Alvarez et al., 2006). Possible the differences can be explained by the case (the DSS versus other computer technologies), and the core target people. The result may vary if it was asked about future willingness to use a DSS rather than use a DSS currently.

This study found that farmers' knowledge level of mycotoxin contamination in wheat has a high significantly positive influence on DSS uptake. When the knowledge level variable is decreased to one level, the odds ratio is around 0.24 and therefore farmers are 0.24 times less likely to use a DSS. This finding parallels the results of some studies in other fields. A case from Germany showed that farmers who have longer experience of crop farming and higher knowledge level had a positive influence on adopting precision agriculture technologies (Paustian & Theuvsen, 2017). It might be a mutual influence between DSS using and knowledge level. Farmers who knew more about risks and principles of wheat contaminations easily realized that using DSS to manage farm is a smart option. Conversely, due to uptake of DSS, farmers got more knowledge and information from this system when the system support suggestions.

Decision maker of a farm was confirmed as a significant factor, the farms that respondents themselves make decision of the farm were 2.47 times more likely to use a DSS than farms that managed by more than one decision makers or by other people. Other people included farm co-operators, partners and family members. Using a DSS will increase the costs of farming and it needs time and people to learn and operate. People who don't know the function of DSSs may not be willing to start using it, as it is time-consuming and labour-consuming to implement. If they have a lot of confidence of their own decisions, it could be more difficult to use a DSS.

Using crop rotation but no-grains as pre-crop is an important measure against *Fusarium* infection in farm. The study showed that the uptake of DSS is higher for farmers who use this measure, they were 3.35 times more likely to use a DSS than farmers who grow barley and maize as pre-crop of wheat. It is reasonable to explain that a DSS advises farmers to avoid to grow other grains prior to wheat, which indicates that farmers who use a DSS have more knowledge and avoid wrong farm management.

However, because few studies have been done on similar topics, a full comparison cannot be made. Hopefully, there will be more relevant studies in the future to find and identify more potential factors correlate to farmers behaviour and effectively improve the utilization rate.

5 Limitations

Several limitations of this study must be mentioned. The sample was provided by an online-questionnaire and comprised data from 272 wheat farmers from five European countries. Farmers needed to use smartphone, laptop or computer to access the questionnaire, which might cause a selection bias of samples. Also, there was a large standard deviation of the number of respondents between five countries, which made it hard to compare the similarity and distinction of them. There were many respondents via Serbia and the Netherlands, but a smaller number of observations from Austria, the UK and Italy. Especially in Austria, the number of samples were much smaller than in other countries. This might be because of language gap and difficulty of terms such as *Fusarium* infection and rotation system. It will not be clear whether a larger sample would have altered the conclusions.

The same reason could also lead to a lot of missing data. Many farmers did not finish all questions in the questionnaire, which might result into different results. The method was analysed all samples together, however, it cannot represent all the European wheat farmers.

The second limitation was methodology. As there were many missing data, when ran the binary logistic regression model, the software gave answer of “NA” assumption data or deleted this observation, so that the results came from a limited group of samples. Another point is that variables such as farm size, wheat percentage of farm and age were treated as categorical variables, while they were continuous variable originally. Changing the way in which it was classified may change the significance and intensity of the association between variables.

According to the disadvantages mentioned above, the following things can be improved in future research. On the one hand, getting possible observations from countries as many as possible so that the results will be more reliable and representative. Decreasing the number of missing values by taking an interview with farmers, talking with them face to face, explaining the question more carefully in the questionnaire, let farmers understand what DSSs is and how it helps them, on the other hand. Moreover, the reason of uptake or not uptake should be recorded, and more potential variables can be selected.

6 Conclusion

The study has identified several drivers of DSS uptake by 272 European wheat farmers. The results showed that there were ten empirical predictors of farmer characteristics and farm characteristics which had significant correlations with uptake of DSS, and four independent variables in the final binary logistic regression model. Age, knowledge level of mycotoxin contamination in wheat, respondents as decision maker in farm, and using non-grains as rotation crop showed to have a positive influence on the uptake of DSS. The empirical results that factors have an impact on DSS adoption are of management significance to crop industries, consulting firms and farmers. For developers and manufactures of decision support systems, this study provides insights into the characteristics of the core target group, wheat farmers. To encourage wheat farmers to adopt DSSs for choosing appropriate measures against mycotoxin contamination in wheat and managing farm more scientifically, changing the potential relationship based on the result of research could be useful.

The study also provides starting points for future research. There are limited studies that investigated the relationship between farmers and uptake of DSS. Not only wheat farmers, but also limited for other crops and other countries. In this study, the correlation between uptake of DSS and farm and farmer characteristics had found. However, the reasons and the attitudes of farmers are still not clear. Understanding farmers' perceptions can help increase DSS users.

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ANNEX I

Table 1 Distribution of farm characteristics and uptake of DSS in five countries

	Serbia			The Netherlands			Austria			Italy			UK		
Groups	Non-use	Use	Total	Non-use	Use	Total	Non-use	Use	Total	Non-use	Use	Total	Non-use	Use	Total
Total arable land (Hectare)															
0-99	41	5	46	53	13	66	3	4	7	8	6	14	2	1	3
100-199	0	0	0	27	2	29	0	1	1	0	4	4	5	4	9
200-500	11	2	13	4	2	6	0	0	0	0	5	5	2	6	8
501-2000	3	0	3	1	1	2	0	0	0	0	3	3	0	4	4
＞2000	2	0	2	0	0	0	0	0	0	0	0	0	0	1	1
Percentage of wheat area of the total arable land (%)															
0-25	32	4	36	27	2	29	3	2	5	7	13	20	1	3	4
26-50	20	4	24	49	10	59	0	3	3	1	2	3	8	11	19
51-75	2	0	2	0	6	6	0	0	0	0	0	0	5	1	6
76-100	0	0	0	5	0	5	0	0	0	1	2	3	0	0	0
Type of soil															
Clay	8	2	10	81	17	98	1	0	1	6	14	20	0	0	0
Loam	9	0	9	0	0	0	2	5	7	6	6	12	5	5	10
Loess	8	0	8	6	2	8	0	0	0	3	2	5	0	1	1
Peat	5	1	6	2	0	2	0	0	0	1	1	2	1	0	1

Sand	7	1	8	5	0	5	0	0	0	2	2	4	3	3	6
Chernozem	36	6	42	0	0	0	0	0	0	0	0	0	4	7	11
Other	0	0	0	6	1	7	1	0	1	3	1	4	0	0	0
Ways of crop selling															
collector or merchant	62	10	72	90	19	109	2	2	4	17	18	35	8	12	20
Directly to feed or food producer	12	0	12	8	0	8	1	1	2	0	3	3	3	4	7
Other	3	0	3	1	0	1	1	2	3	4	5	9	0	0	2
Crop purpose															
Food	62	7	69	31	2	33	1	2	3	21	22	43	7	10	17
Feed or seed	15	3	18	67	17	84	3	3	6	0	3	3	6	6	12
Farm decision maker															
Respondent	26	6	32	36	13	49	2	3	5	3	16	19	0	4	4
Others or with others	36	2	38	33	5	38	0	3	3	5	6	11	6	7	13
Crop produce															
Peas	6	1	7	7	1	8	0	0	0	0	6	6	3	3	6
Barley	28	2	30	40	9	49	5	4	9	6	11	17	10	14	24
Potatoes	13	2	15	87	14	101	0	2	2	0	0	0	0	3	3

Maize	74	9	83	13	5	18	4	5	9	6	12	18	3	3	6
Alfalfa	24	1	25	3	2	5	0	0	0	3	10	13	1	0	1
Onions	9	1	10	60	11	71	0	0	0	2	0	2	0	0	0
Carrots	3	1	4	16	2	18	0	0	0	0	0	0	0	0	0
Oats	8	0	8	3	0	3	0	0	0	2	4	6	3	6	9
Beans	4	1	5	4	0	4	0	0	0	1	2	3	9	5	14
Sugar beets	12	4	16	92	17	109	1	2	3	1	6	7	1	2	3
Grass	3	0	3	28	1	29	0	0	0	0	3	3	6	6	12
Rapeseed	10	0	10	0	3	3	2	3	5	1	3	4	8	10	18
Other	51	5	56	24	4	28	2	2	4	9	22	31	2	2	4
Wheat	71	9	80	97	20	117	4	5	9	20	26	46	3	16	19
Using grains as pre-crop of wheat															
Yes	49	4	53	1	0	1	2	5	7	16	19	35	12	10	22
No	18	5	23	96	16	112	1	0	1	3	6	9	1	6	7
Crop rotation in most important wheat field															
Alfalfa	1	1	2	3	1	4	0	0	0	1	0	1	1	0	1
Barley	17	1	18	25	3	28	0	0	0	11	11	22	1	2	3
Beans	35	7	42	30	8	38	1	4	5	7	13	20	4	6	10
Carrot	13	1	14	27	2	29	2	1	3	2	2	4	3	5	8
Grass	3	1	4	10	1	11	1	0	1	0	0	0	2	1	3
Maize	1	0	1	9	0	9	0	0	0	0	0	0	0	0	0
Oat	0	0	0	0	0	0	0	0	0	0	0	0	2	2	4

Other	5	0	5	6	1	7	0	0	0	0	0	0	0	0	0
Frequency of serious *Fusarium* infection in the past 5 years (0-5: never to five times)															
0	34	4	38	31	9	40	1	1	2	11	9	20	8	7	15
1	21	2	23	43	7	50	1	2	3	6	9	15	4	5	9
2	12	4	16	25	2	27	0	2	2	3	6	9	0	4	4
3	9	0	9	0	1	1	0	0	0	1	1	2	1	0	1
4	0	0	0	0	0	0	2	0	2	0	1	1	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Risk perception (addition of scores to “consequence” and “future”)															
1-5	24	8	32	29	7	36	1	5	6	7	4	11	6	3	9
6-10	30	1	31	47	8	55	2	0	2	10	12	22	3	7	10
11-15	16	1	17	19	5	24	0	0	0	3	9	12	0	6	6
16-25	5	0	5	2	0	2	0	0	0	0	1	1	1	0	1
Willingness of take risks compare to other farmers (1-5: less to more risks)															
Less	27	3	30	11	3	14	1	5	6	8	8	16	5	1	6
A bit less	12	3	15	47	5	42	1	0	1	4	7	11	5	11	16
Same	31	3	34	37	9	46	1	0	1	10	9	19	3	4	7
A bit more	3	0	3	12	1	13	0	0	0	0	1	1	0	0	0
More	4	1	5	2	1	3	1	0	1	0	0	0	0	0	0

Table 2 Distribution of farmer characteristics and uptake of DSS in five countries

	Serbia		the Netherlands		Austria		Italy		UK		Five countries
	Use	Total	Use	Total	Use	Total	Use	Total	Use	Total	Total
Farmer demographics											
Age											
<34	2	41	2	6	1	2	2	5	0	1	55
35-44	2	11	0	17	0	1	3	4	1	2	35
45-54	2	9	6	26	3	4	16	19	4	6	64
55-64	1	7	7	25	1	1	0	0	4	8	41
>64	1	2	3	13	0	0	1	2	2	2	19
Gender											
Male	6	58	18	84	5	8	19	27	10	18	195
Female	2	12	0	2	0	0	3	3	1	1	18
School education											
Primary &Secondary	3	27	10	39	1	1	12	18	3	7	121
After secondary school	5	40	8	48	4	7	0	0	5	8	125
University	0	2	0	0	0	0	9	11	3	4	29
Knowledge level of mycotoxin contamination in wheat											
Low	2	13	0	14	0	0	1	7	2	2	36
Medium	2	28	7	64	0	0	5	8	4	8	108
High	6	41	13	41	5	9	18	30	9	15	136

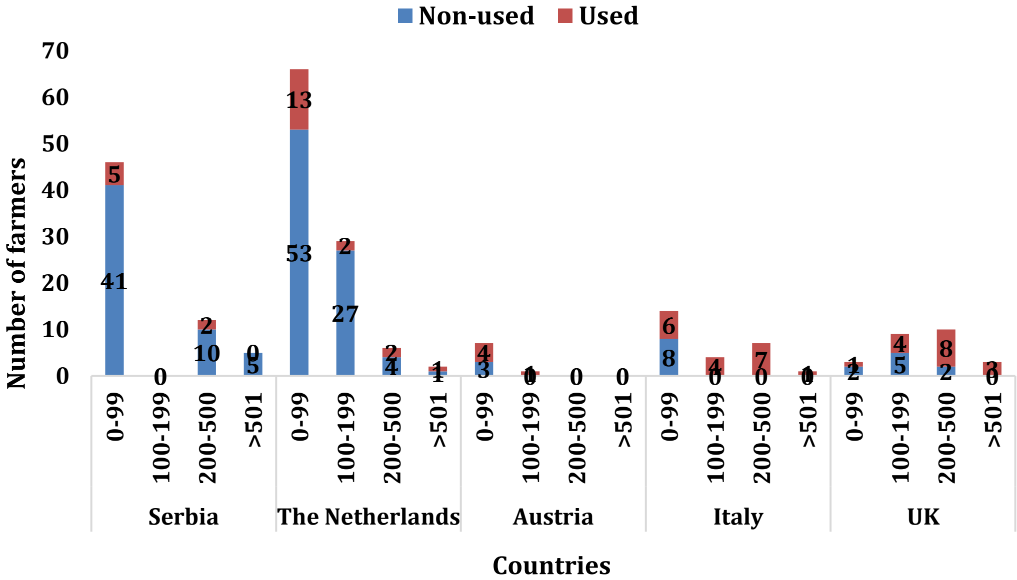

Fig. 3 Distribution of total arable land (hectare) of samples

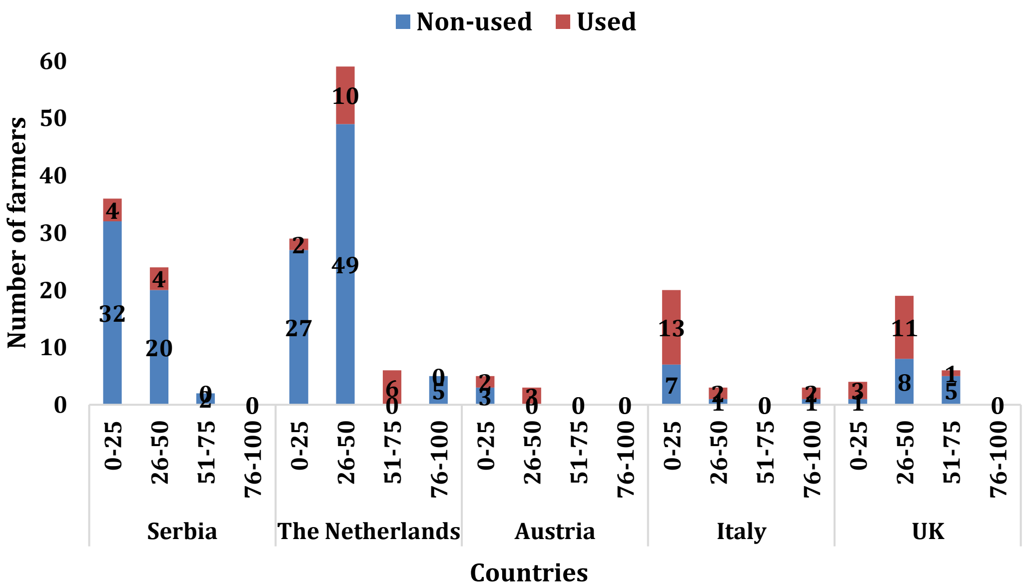

Fig. 4 Distribution of percentage of wheat farm of samples

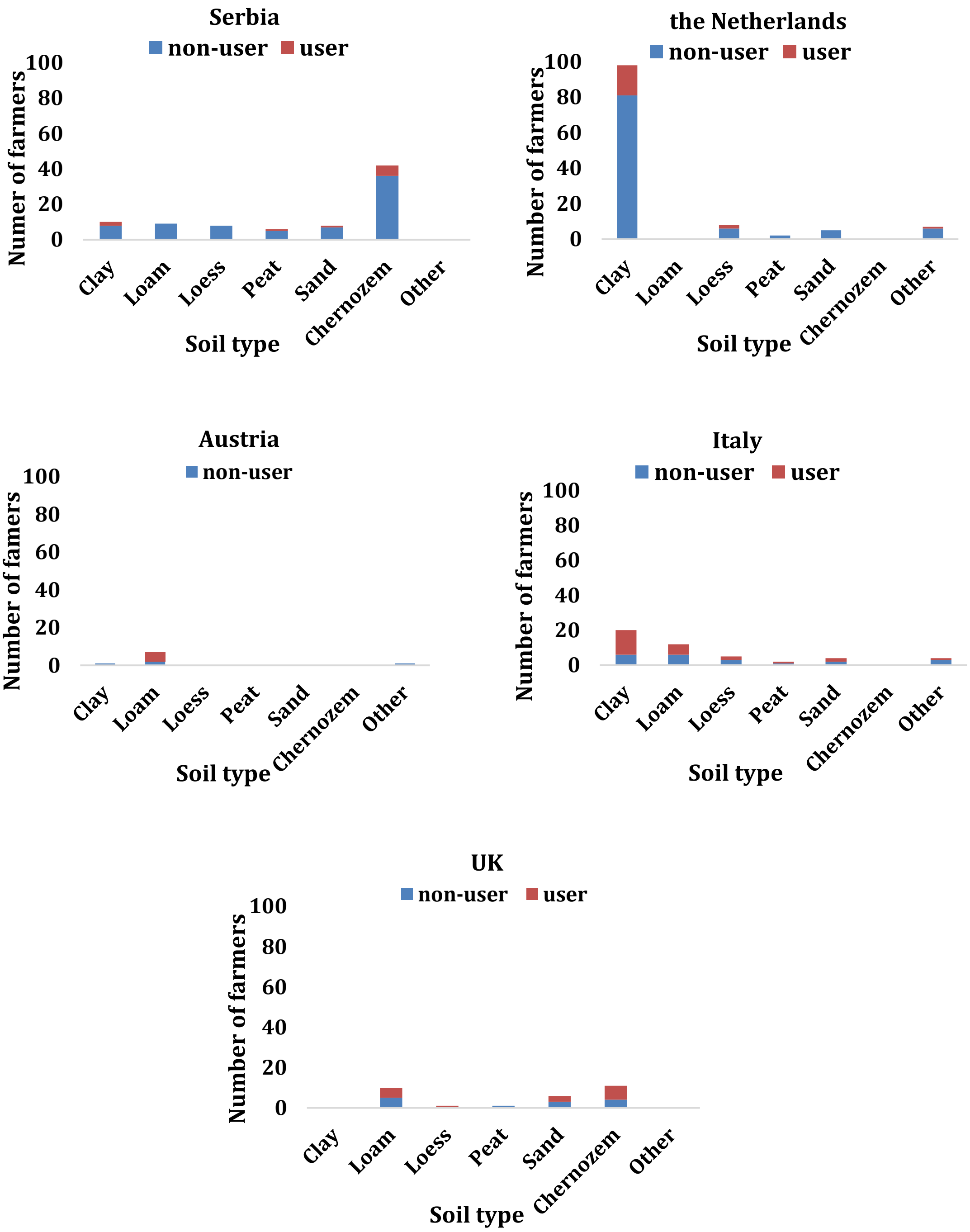

Fig. 5 Distribution of type of soil of samples

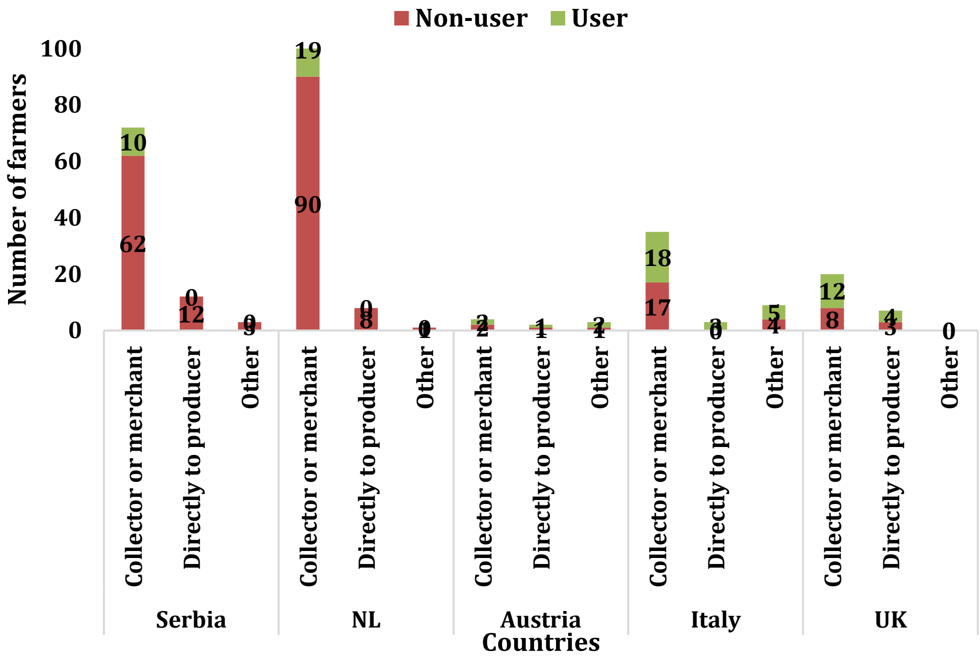

Fig. 6 Distribution of ways of crop selling of samples

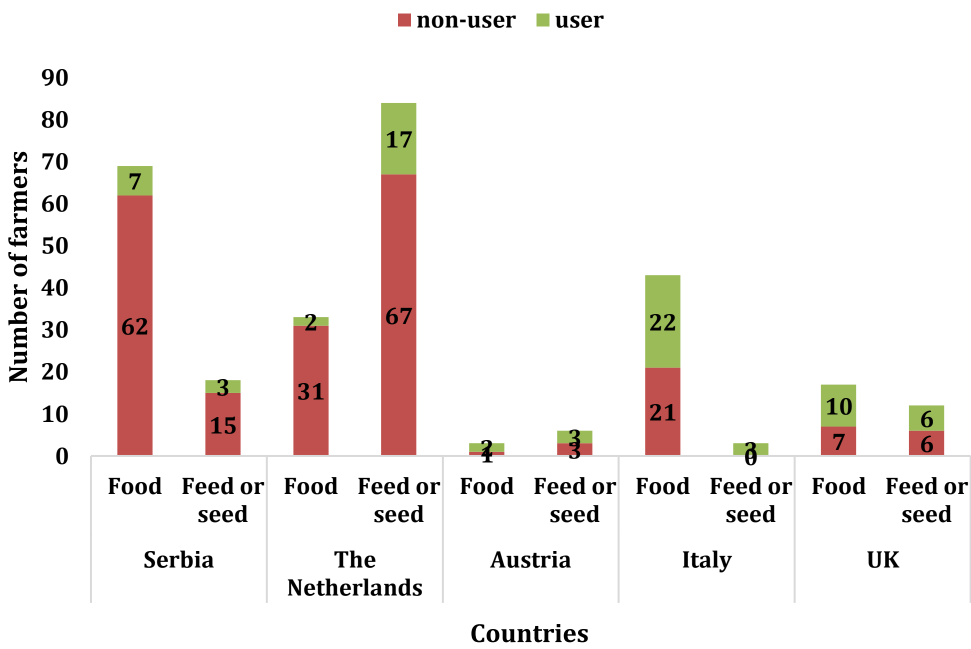

Fig. 7 Distribution of crop purpose of samples

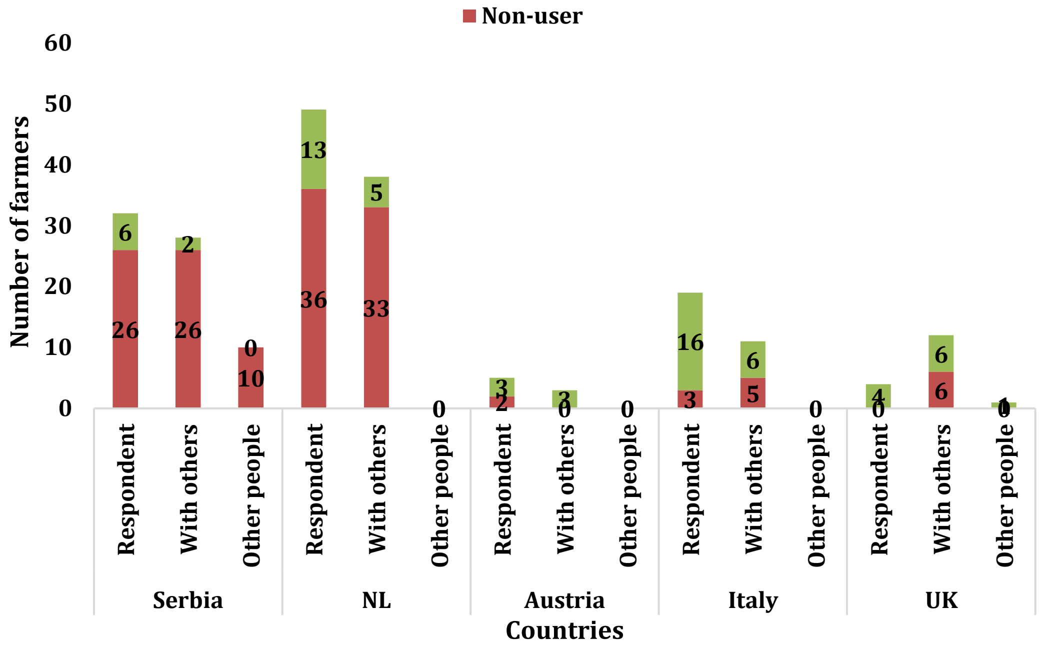

Fig. 8 Distribution of farm decision maker of samples

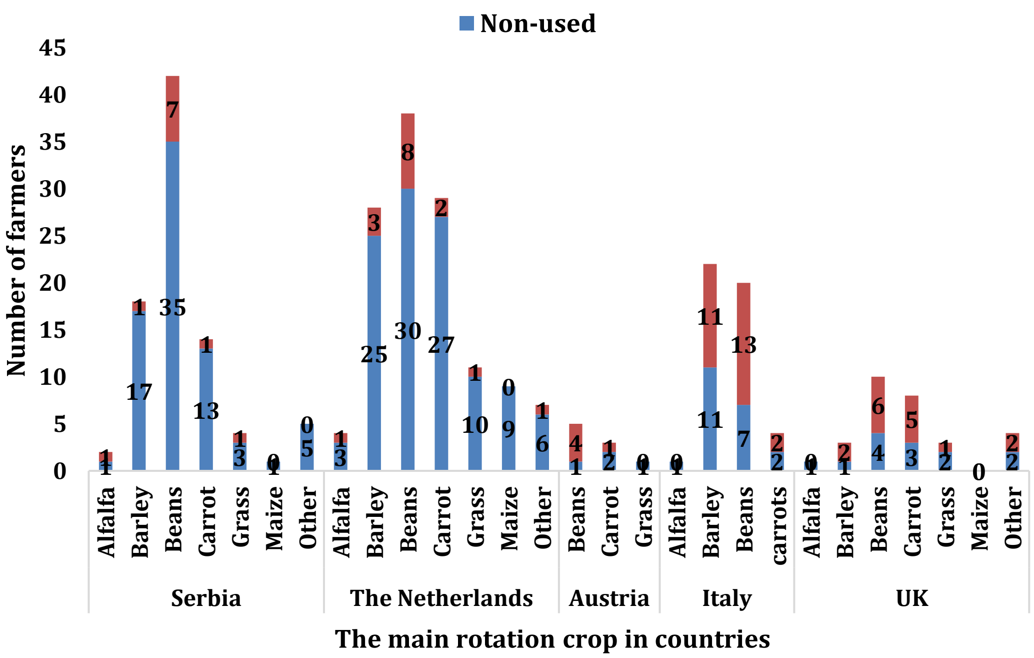

Fig. 9 Distribution of crop production of samples

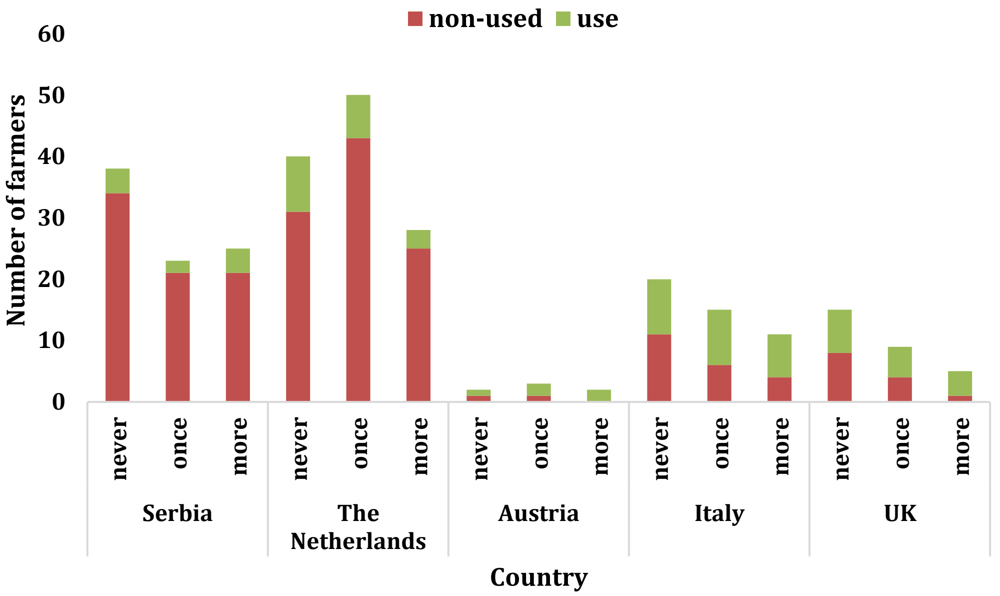

Fig.10 Distribution of frequency of *Fusarium* infection in the past five years of samples

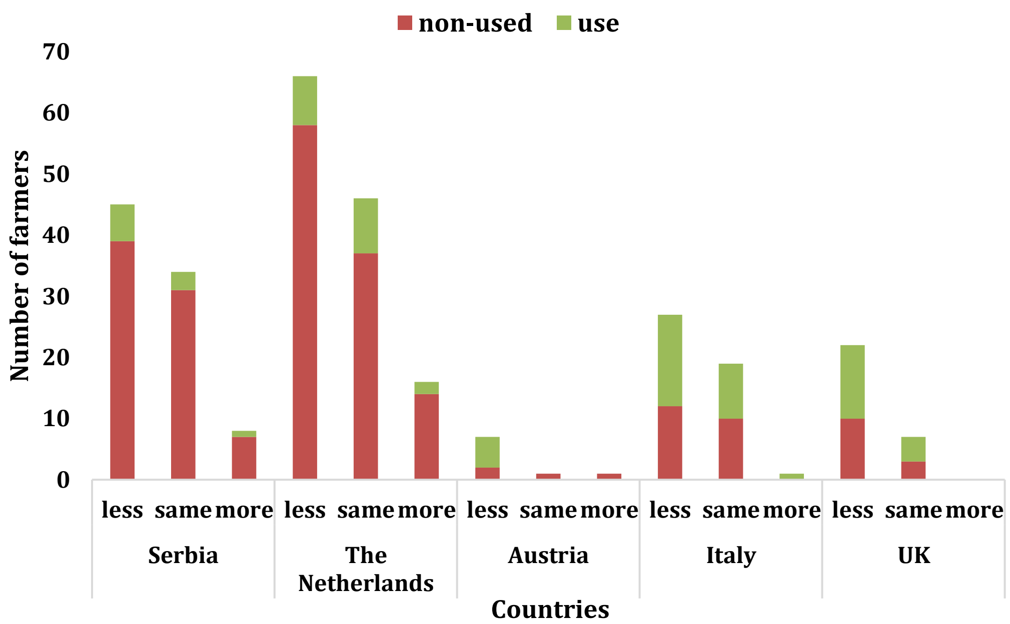

Fig. 11 Distribution of willingness of take risks of samples

ANNEX II

Table 3 Result of univariable analysis of age

	B	S.E.	Wald	Df	Sig.	Exp(B)
>64			16,706	4	,002	
<34	-1,407	,624	5,082	1	,024	,245
35-44	-,631	,610	1,071	1	,301	,532
45-54	,441	,540	,665	1	,415	1,554
55-64	-,308	,588	,275	1	,600	,735
Constant	-,539	,476	1,284	1	,257	,583

Age: ＞64 years old as reference.

Table 4 Result of univariable analysis of gender

	B	S.E.	Wald	Df	Sig.	Exp(B)
Male	-,166	,524	,101	1	,751	,847
Constant	-,693	,500	1,922	1	,166	,500

Gender: Female as reference.

Table 5 Result of univariable analysis of school education

	B	S.E.	Wald	Df	Sig.	Exp(B)
University			15,028	2	,001	
Primary and secondary	-,958	,472	4,123	1	,042	,384
After secondary	-1,603	,420	14,544	1	,000	,201
Constant	,325	,364	,799	1	,371	1,385

School education: University as reference.

Table 6 Result of univariable analysis of knowledge level

	B	S.E.	Wald	Df	Sig.	Exp(B)
High			16,640	2	,000	
Low	-1,345	,513	6,868	1	,009	,261
Medium	-1,119	,313	12,780	1	,000	,327
Constant	-,480	,176	7,387	1	,007	,619

Knowledge level: High as reference.

Table 7 Result of univariable analysis of total hectare

	B	S.E.	Wald	Df	Sig.	Exp(B)
>501 hectares			17,285	3	,001	
0-99 hectares	-,802	,606	1,748	1	,186	,449
100-199 hectares	-,679	,653	1,080	1	,299	,507
200-500 hectare	1,001	,696	2,069	1	,150	2,720
Constant	-,470	,570	,680	1	,410	,625

Total hectare: >501 hectares as reference.

Table 8 Result of univariable analysis of wheat percentage

	B	S.E.	Wald	Df	Sig.	Exp(B)
76-100%			2,310	3	,511	
0-25%	-,541	,942	,330	1	,566	,582
26-50%	-,634	,938	,457	1	,499	,530
51-75%	,087	1,024	,007	1	,932	1,091
Constant	-,405	,913	,197	1	,657	,667

Wheat percentage: 76-100% as reference.

Table 9 Result of univariable analysis of soil type

	B	S.E.	Wald	Df	Sig.	Exp(B)
Other.types			5,797	6	,446	
Clay	,542	,800	,458	1	,499	1,719
Loam	1,291	,841	2,354	1	,125	3,636
Loess	,386	,927	,173	1	,677	1,471
Peat	,105	1,101	,009	1	,924	1,111
Sand	,568	,909	,391	1	,532	1,765
Chernozem	,486	,838	,336	1	,562	1,625
Constant	-1,609	,775	4,317	1	,038	,200

Soil type: Other types as reference.

Table 10 Result of univariable analysis of type of crop selling

	B	S.E.	Wald	Df	Sig.	Exp(B)
Other			2,461	2	,292	
Collector or merchant	-,758	,488	2,416	1	,120	,469
Directly to food/feed producer	-,780	,619	1,591	1	,207	,458
Constant	-,318	,465	,470	1	,493	,727

Type of crop selling: Other as reference.

Table 11 Result of univariable analysis of crop purpose

	B	S.E.	Wald	Df	Sig.	Exp(B)
Human food	,126	,271	,216	1	,642	1,134
Constant	-1,099	,207	28,062	1	,000	,333

Crop purpose: Feed or seed as reference.

Table 12 Result of univariable analysis of farm decision maker

	B	S.E.	Wald	Df	Sig.	Exp(B)
Respondent	-,712	,308	5,350	1	,021	,491
Constant	,177	,459	,148	1	,700	1,193

Farm decision maker: With others/others as reference.

Table 13 Result of univariable analysis of Grains as main crop

	B	S.E.	Wald	Df	Sig.	Exp(B)
Non-grains as main crop	-,568	,274	4,287	1	,038	,567
Constant	-,693	,194	12,812	1	,000	,500

Grains as main crop: Yes as reference.

Table 14 Result of univariable analysis of grains as rotation crop

	B	S.E.	Wald	Df	Sig.	Exp(B)
Non-grains as rotation crop	,914	,280	10,684	1	,001	2,495
Constant	-1,292	,181	51,095	1	,000	,275

Grains as rotation crop: Yes as reference.

Table 15 Result of univariable analysis of frequency in past five years

	B	S.E.	Wald	Df	Sig.	Exp(B)
2-4 times			,258	2	,879	
Never	-,071	,333	,046	1	,831	,931
Once	-,173	,346	,249	1	,618	,841
Constant	-,926	,258	12,890	1	,000	,396

Frequency of *Fusarium* infection in past five years: 2-4 times as reference.

Table 16 Result of univariable analysis of take risks

	B	S.E.	Wald	Df	Sig.	Exp(B)
More			2,692	2	,260	
Less	-,565	,364	2,405	1	,121	,569
Same	-,230	,365	,395	1	,530	,795
Constant	-,693	,297	5,445	1	,020	,500

Willingness to take risks compare to other farmers: More as reference.

Table 17 Result of univariable analysis of risk perception

	B	S.E.	Wald	Df	Sig.	Exp(B)
High			,478	2	,787	
Low	-,151	,364	,190	1	,663	,860
Medium	,231	,335	,477	1	,490	,794
Constant	-,868	,260	11,129	1	,001	,420

Risk perception: High as reference.

Table 18 Result of univariable analysis of nation

Nation	B	S.E.	Wald	Df	Sig.	Exp(B)
Italy			45,878	4	,000	
Serbia	-2,249	,502	20,036	1	,000	,106
The Netherlands	-1,817	,447	16,557	1	,000	,163
Austria	,016	,768	,000	1	,984	1,016
UK	,006	,475	,000	1	,990	1,006
Constant	,208	,373	,309	1	,578	1,231

Nation: Italy as reference.

ANNEX III

Table 19 Results of multivariable analysis of variables with backward stepwise method

	B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I. for EXP(B)
Age >64			11,909	4	,018		
<34	-1,682	,708	5,648	1	,017	,186	,046-,745
35-44	-,679	,691	,966	1	,326	,507	,131-1,965
45-54	,057	,638	,008	1	,929	1,059	,303-3,695
55-64	-,504	,688	,536	1	,464	,604	,157-2,328
Knowledge level: High			14,589	2	,001		
Knowledge level: Low	-1,486	,714	4,338	1	,037	,226	,056-,916
Knowledge level: Medium	-1,399	,395	12,510	1	,000	,247	,114-,536
Decision maker: Respondent	,904	,364	6,176	1	,013	2,469	1,210-5,037
Non-grains as Rotation crop	1,209	,380	10,112	1	,001	3,351	1,590-7,062
Constant	-,510	,612	,697	1	,404	,600	

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