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Rural ICT Penetration, Bank Credit, and Agricultural Sector Performance: A Panel ARDL Analysis in Eastern Indonesia

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Abstract

The relationship between ICT, the financial sector, and output growth has been extensively studied, however, macro-economic studies with an emphasis on the role of rural ICT on agricultural performance are few and yield mixed findings. Additionally, past research has not given sufficient attention to how bank credit affects agricultural performance. This paper highlighted the dynamic effect of rural ICT penetration and bank credit on agricultural performance in Eastern Indonesia. We used secondary data taken from the Central Bureau of Statistics and the Financial Services Authority. The panel data covered 16 provinces of eastern Indonesia from the first semester of 2010 to the second semester of 2022 (2010S1–2022S2). Using the panel autoregressive distributed lag (ARDL) approach, the results showed that in the long run, rural ICT penetration and bank credit played a significant role in boosting agricultural performance. However, in the short run, the impact of rural ICT penetration and bank credit on agricultural performance was statistically insignificant. Finally, we recommended several important policies that can practically impact and contribute to improving agricultural performance.

Keywords

Agriculture, Rural ICT, bank credit, ARDL, Eastern Indonesia.

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Introduction

As an agricultural country, the Indonesian government has long paid significant attention to the development of the agricultural sector. This is illustrated by Indonesia's achievement of receiving an award from the International Rice Research Institute (IRRI) in recognition of a food-agriculture system resiliency and self-sufficiency in rice during 2019-2021 through the application of innovative rice technology. The agricultural sector has contributed greatly to the national economy—especially through creating employment and providing food for food security-making it an instrument of poverty alleviation and a source of livelihood for the population. However, as Indonesia's economic structure changes, the performance of the agricultural sector continues to face serious problems related to its declining contribution to GDP compared to the industrial and service sectors. The Central Bureau of Statistics reports that in 2010 the contribution of the agricultural sector to Indonesia's GDP was 13.93%, decreasing to 12.40% in 2022. In eastern Indonesia, the contribution of the agricultural sector to the GDP was 17.62% in 2010 and 16.36% in 2022.

Improving the performance of the agricultural sector requires the support of technological advancements, including information and communications technology (ICT) (Dzanku et al., 2021; Nakasone et al., 2014; Olmstead and Rhode, 2014). Currently, ICT is experiencing rapid development in various fields. This is indicated by the emergence of a global digital era with deep internet penetration that supports the use of smartphones, computers, laptops, tablets, and other digital technology devices. Indonesia has great potential for the development of its digital economy and is expected to become one of the countries with the largest digital economy achievements in the world (Kemenkoinfo, 2019). The use of ICT in all economic sectors will provide benefits for accelerating economic growth through reduced transaction costs or efficiency, ease of information, expanding markets, and improving productivity (Farooqi et al., 2020; Kpodar and Andrianaivo, 2011; Toader et al., 2018). The role of ICT penetration on the agricultural sector performance through mobile phone and internet access is expected to include access to real-time weather updates, market trends, and competitive price information to determine sustainable production. These things increase the productivity and growth of agricultural output in the long run (Dzanku et al., 2021; Nakasone et al., 2014). In addition, the use of the Internet can create more efficient and direct marketing channels, expand and enlarge market access, reduce transaction costs, facilitate access to financial institutions, and reduce monopoly power of merchants (Aker and Ksoll, 2016; Dzanku et al., 2021; Fafchamps and Minten, 2012; Goyal, 2010).

The nexus of ICT and agricultural performance has been investigated by several researchers. However, the previous empirical studies offered mixed results and lacked consensus. Several empirical studies find strong evidence to support the significant role of ICT in agricultural development performance and conclude that ICT plays a significant role in boosting agricultural production (Hopestone, 2014; Kaila and Tarp, 2019, Lio and Liu, 2006; Nakasone, et al., 2014; Nguyen, et al., 2023; Oyelalmi et al., 2022; Suroso et al., 2022). However, several other studies find that the role of ICT does not provide major benefits to agricultural performance, such as study of Evans (2018), which revealed a negative relationship between internet access and the development of the agricultural sector. Fafchamps and Minten (2012) found that commercial market applications of mobile phone technology and weather information had little or statistically insignificant effects on prices or farming practices. Similarly, Aker and Ksoll (2016) concluded that using ICT via mobile phones does not increase crop sales or farmer-level prices received.

Most of the farming methods in Indonesia still rely on traditional methods with low productivity. A reform effort to switch from traditional rural farming methods to more modern methods requires consistent levels of funding (Ellinger and Penson, 2014; Miller and Jones, 2010; Olmstead and Rhode, 2014). However, one of the crucial problems in agricultural development is the lack of budget to carry out production activities (Ellinger and Penson, 2014). To compensate for the lack of financing, farmers generally apply for loans at the nearest financial institutions, both formal and informal. The role of bank credit in the growth of the real economy including the agricultural sector can be reviewed from the theory and previous empirical studies. The finance-growth theory suggests that the size of the financial sector affects the real sector of the economy directly. This theory is based on banks' ability to connect people with extra money to people who need it through financial intermediation (Mishkin, 2013). Schumpeter in 1911 was the first to hypothesize that the financial sector is very important in determining the growth of the real economy. Other scholars noted that the financial system boosts growth via capital accumulation and innovation (Levine, 1997) while King & Levine (1993) found “innovation” as the primary link between finance and output growth.

The importance of bank credit to the real economy can also be seen from several previous studies which find the significant role of commercial banks in the progress of the private sector and increasing economic growth (Vaithilingam et al., 2003; Ajibola, 2015; Morina and Özen, 2020). Meanwhile, research by Gani and Bahari (2020) found mixed findings where bank loans only contributed significantly in the long term and were not effective in influencing the real economy in the short term. Special empirical emphasis on the relationship between bank credit or bank loans and agricultural performance reveals that the provision of affordable credit enhances organized production activities in rural areas and leads to increased output and employment opportunities (Saleem and Jan, 2018; Sethi and Acharya, 2018). Furthermore, the previous research reveals that the use of agricultural credit to fund agricultural production activities has a positive and significant impact on the agricultural performance (Ngong et al., 2022; Peng, et al., 2021; (Rehman et al., 2017); Kumar et al., 2017). In contrast, Chuke and Anyalechi (2018) found that the use of bank credit in the agricultural sector only played a small role in improving the agricultural development progress in rural areas.

The main purpose of this study is to investigate the dynamic effect of rural ICT penetration and bank credit on agricultural performance. This research is unique in two ways. Firstly, the agricultural sector in Eastern Indonesia plays a more substantial role in GDP (Gross Domestic Product) than in Western Indonesia. However, to the best of our knowledge, there has been no previous research that has examined the impact of rural ICT and bank credit on agricultural performance in Eastern Indonesia using a dynamic econometric model. Secondly, while there have been some qualitative studies on the impact of rural ICT on agricultural performance in Indonesia, our study is unique in that it employs the Panel ARDL model to examine this impact. This research is expected to make a significant contribution to the advancement of science and provide practical policy direction that can help enhance agricultural performance and improve the welfare of farmers, particularly in Eastern Indonesia.

The topic of this paper is an interesting issue that revolves around macroeconomic analysis with the following research questions. Firstly, does rural ICT penetration influence agricultural performance in Eastern Indonesia, both in the short and long term? Secondly, does bank credit affect agricultural performance in Eastern Indonesia, both in the short and long run? The specific objectives of this research are to investigate the influence of rural ICT penetration on agricultural performance, both in the short and long term and to investigate the effect of bank credit on agricultural performance in Eastern Indonesia, both in the short and long term. The remaining sections of this paper include materials and methods, results and discussion, and conclusions.

Materials and methods

This study utilized secondary data from the Central Bureau of Statistics and the Financial Services Authority. The panel data covered 16 provinces in Eastern Indonesia, ranging from the first semester of 2010 to the second semester of 2022 (2010S1-2022S2). The 16 provinces consist of East Nusa Tenggara, West Nusa Tenggara, West Kalimantan, East Kalimantan, South Kalimantan, Central Kalimantan, South Sulawesi, North Sulawesi, Southeast Sulawesi, Central Sulawesi, Gorontalo, Maluku, North Maluku, Papua, and West Papua. Stata version 17 software was used for data processing and analysis.

The dependent variable of this study is agricultural sector performance (lnAGR). The independent variables of this study are bank credit (lnCR) and rural ICT penetration. Rural ICT penetration is represented by the rural internet (INT) and rural mobile phone (MP) penetration rates. Education (lnEdu) is treated as a control variable. In the domain of ICT penetration measurement, there are various indicators that can be utilized. However, in the case of rural areas, this study exclusively focuses on two ICT measures, namely mobile phone and internet penetration. This approach is motivated by the fact that the vast majority of village residents in Indonesia rely heavily on mobile phones and the Internet as their primary means of communication and information exchange. On the other hand, other ICT tools such as fixed-line telephones and radios have seen a significant decline in usage and have been abandoned by the village population (BPS, 2022). Furthermore, the majority of ICT models implemented by local governments in rural development projects in Indonesia rely heavily on internet and mobile phone connectivity (Amin, 2018). Although television can also be considered an ICT measure, it is less mobile than mobile phones and may not be as effective in the context of agricultural development. Additionaly, computer usage in rural areas is restricted to specific tasks (BPS, 2022). Therefore, it is crucial for policymakers to consider the limitations of each ICT medium and design models that align with the specific needs of their target communities. Education is regarded as a control variable due to its critical role in realizing the potential of technology, securing bank loans, and enhancing agricultural productivity in Eastern Indonesia. Table 1 presents the names, symbols, measurements, units, and expected signs of the variables.

Panel unit root test

We need to conduct a panel unit root test before applying the panel autoregressive distributed lag

Variable name	Symbol	Measurement	Unit	Expected sign
Agricultural sector performance	lnAGR	Value-added of the agricultural sector	IDR billion	+
Rural internet penetration	INT	Rural internet users	%	+
Rural mobile phone penetration	MP	Rural mobile phone users	%	+
Bank credit	lnCR	Agriculture credit	IDR billion	+
Education	lnEDU	Mean years of schooling	Year	+

Source: Authors identification, 2023

Table 1: Operational variables.

(ARDL). The presence of non-stationary data or unit roots may cause spurious regression parameters. One characteristic of stationary data is that the data trend should be closer to its mean value or it has a consistent mean and variation over time (Asteriou and Hall, 2016; Hansen, 2017). The first purpose of the panel unit root test is to check whether the data is stationary or non-stationary. The second purpose is to determine the degree of integration. The data used can be identified as stationary in integration order at level I (0), first-difference I (1), or mixture I(0) and I(1). Application of the panel unit root test has advantages compared to standard time series data due to the larger number of observations and heterogeneity across provinces. Thus, it allows us to minimize bias and potentially yield more precise parameters (Hansen, 2022). Levin et al. (2002) state that the use of panel unit root tests is more efficient than time series unit roots.

Researchers employ different approaches to determine the panel unit roots. In this study, we followed the panel unit root test method suggested by Levin, Lin, and Chu (LLC) and Im, Pesaran, and Shin (IPS). In their study, Levin et al. (2002) devised a method based on Quah's generalization procedure that allows heterogeneity of individual deterministic effects (constant and/or linear time trends) and heterogeneous autocorrelation error structures, assuming the parameter is AR(1) homogeneous. Another assumption is that N and T tend to infinity, but T increases faster; thus, $N/T \rightarrow 0$. IPS is a good fit for our varied panel data because it can manage individual-specific effects and distinct residual serial correlations. Although this method is superior to LLC, it requires a large amount of time series (T).

Panel cointegration test

The cointegration test is a widely utilized procedure in dynamic econometric models that aims to determine the presence of a long-term relationship between variables. This study adopted the panel cointegration test developed by Pedroni (1999, 2004), which includes eleven statistical indicators that can aid in establishing the existence of a long-term relationship between variables. These statistical indicators are divided into two groups, namely within dimensions and between dimensions. The within-dimension group includes the ADF-statistic parametric panel, PP-statistic non-parametric panel, rho panel, and v-statistic panel, while the between-dimensions group includes the ADF-statistic group, PP-statistic group, and rho-statistic panel group, as noted by Neal (2014) and Asteriou and Hall (2016). By employing these statistical indicators, we can ensure that our panel autoregressive distributed lag (ARDL) model meets the necessary criteria and provides insightful results. The utilization of these indicators is crucial in achieving the desired outcome of the study, which is to determine the existence of a long-term relationship between the variables under investigation. As such, the panel cointegration test's utilization is paramount in ensuring the study's accuracy and reliability, making it a valuable tool in the field of econometrics.

Model specification

This study employed the panel ARDL (autoregressive distributed lag) to investigate the effect of rural ICT penetration and bank credit on agricultural performance in eastern Indonesia. Using panel ARDL provides many advantages, enabling us to estimate short-term and long-term coefficients dynamically which includes three types of estimators: pooled mean group (PMG), mean group (MG), and dynamic fixed effect (DFE). The application of the panel ARDL or the PMG estimator allows us to estimate short-term and long-term relationships including the speed of adjustment coefficient or the speed of the long-term equilibrium by allowing for heterogeneity of the short-term coefficient and error variance across provinces (Pesaran, et al, 1999). However, the coefficients of the long-run equilibrium relationships between variables are similar (homogeneous) across provinces. In contrast to PMG, the MG estimator produces a regression coefficient of short-term and long-term relationships that are heterogeneous for each province. Finally, the DFE estimator assumes that the short-term adjustment speed coefficient and the long-term coefficient must be identical for all cross-sections (Asteriou and Hall, 2016).

The formation of the basic model is as follows:

$$lnAGR_{it} = \beta_0 + \beta_1 INT_{it} + \beta_2 MP_{it} + \beta_3 lnCR_{it} + \beta_4 lnEDU_{it} + v_{it} \quad (1)$$

where *AGR* is the agricultural sector's performance, *INT* is the rural internet penetration rate, *MP* is the rural mobile phone penetration rate, *CR* is bank credit and *EDU* is education. The rural ICT penetration is represented by the *INT* and *MP* variables for province *i* at time *t*. l*nAGR, lnCR*, and l*nEDU* variables are the respective natural logarithms of *AGR, CR*, and *EDU. lnEDU* is treated as a control variable.

The MG model used to evaluate the long-run relationship between variables is as follows:

$$lnAGR_{it} = \theta + \beta_{0i} lnAGR_{i,t-1} + \beta_{1i} INT_{i,t-1} + + \beta_{2i} MP_{i,t-1} + \beta_{3i} lnCR_{i,t-1} + \beta_{4i} lnEDU_{i,t-1} + \varepsilon_{it} \quad (2)$$

Equation (2) explains that the estimation of the MG model assumes that both the short-term and long-term coefficients are heterogeneous across provinces. Therefore, selecting the optimum time lag using the Akaike Information Criterion (AIC) requires a larger number of periods (T) than the number of cross-sections (N).

The long-run relationship model using the PMG and DFE estimators can be written as follows:

$$lnAGR_{it} = \alpha_i + \sum_{j=1}^{o} \lambda_{ij} lnAGR_{i,t-j} + \sum_{j=0}^{p} \delta_{1ij} INT_{i,t-j} + + \sum_{j=0}^{q} \delta_{2ij} MP_{i,t-j} + \sum_{j=0}^{r} \delta_{3ij} lnCR_{i,t-j} + + \sum_{j=0}^{s} \delta_{44ij} lnEDU_{i,t-j} + \varepsilon_{it} \quad (3)$$

where, i represents the province (1, 2, 3…..16), *t* is the period of 2010S1–2022S2 and *o, p, q, r*, and *s* are the optimum time lags. αi is the provinces specific effect, and εit refers to the error terms. The model includes an error-correction term that denotes a short-run relationship, which can be written as follows:

$$\Delta lnAGR_{it} = \alpha_i + \phi_i (lnAGR_{i,t-1} - \lambda_1 INT_{i,t-1} - - \lambda_2 MP_{i,t-1} - \lambda_3 lnCR_{i,t-1} - \lambda_4 lnEDU_{i,t-1}) + + \sum_{j=1}^{o} \lambda_{ij} \Delta lnAGR_{i,t-j} + \sum_{j=1}^{p} \lambda_{1ij} INT_{i,t-j} + \sum_{j=1}^{q} \lambda_{2ij} MP_{i,t-j} + + \sum_{j=1}^{r} \lambda_{3ij} lnCR_{i,t-j} + \sum_{j=1}^{s} \lambda_{4ij} lnEDU_{i,t-j} + \varepsilon_{it} \quad (4)$$

The speed of dynamic change to long-term equilibrium for *lnAGR* due to changes in *INT*, *MP, lnCR*, and *lnEDU* is measured by ϕ_i, while λ_i indicates the long-run parameters. ϕ_i represents the existence of a long-run relationship. The presence of a cointegration relationship among *lnAGR, INT, MP, lnCR*, and *lnEDU* is revealed by a significant and negative ϕi coefficient. All ECM dynamics (*ε*) follow an independent and identical distribution assumption. The model can estimate coefficients for both stationary and non-stationary regressors and provide a reliable parameter estimation. Pesaran et al. (1999) revealed that the MG and PMG estimators are suitable for panel data analyses with large cross-sections (*N*) and time series (*T*). However, if homogeneity exists, the MG estimator is inefficient. When homogeneity exists, the PMG estimator based on the maximum likelihood is more efficient (Asteriou and Hall, 2016).

The optimal lag length and Hausman test

We applied the Hausman test to select the best estimator among MG, PMG, and DFE. When comparing the MG and PMG estimators, if the p-value of the Hausman test is greater than 0.05 (insignificant), then we conclude that the PMG estimator is more efficient and preferable under the null hypothesis (Asteriou and Hall, 2016). Furthermore, PMG is more efficient and preferred if the difference in estimation results between PMG and DFE is not significant or the null hypothesis is not rejected.

Results and discussion

Table 2 provides a comprehensive overview of the panel data, presenting statistics such as the mean, standard deviation, minimum and maximum values, and the number of observations for each variable. To improve clarity, all data was transformed into natural logarithms (ln), except for variables measured in percentage units (MP and INT). This approach ensures that the statistical information is more easily interpreted and understood.

By converting the data to natural logarithms, it is possible to compare the relative magnitudes of the variables more effectively. Furthermore,

Variable	N	Mean	Std. dev	Min	Max
lnAGR	416	2.014	0.652	0.661	3.593
INT	416	77.140	16.895	15.230	96.960
MP	416	35.025	23.755	2.580	93.300
lnCR	416	6.467	1.791	1.609	9.610
lnEDU	416	1.872	0.149	1.470	2.195

Source: Authors computation, 2023

Table 2: Descriptive statistics.

this technique has the added benefit of reducing the impact of outliers, which can distort the results of statistical analyses.

The data presented in Table 2 depicts the findings of a study that analyzed a set of variables. The study included a total of 416 observations (N) and aimed to identify the characteristics of the variables under consideration. The results of the statistical analysis indicated that *INT* exhibited the highest mean value, minimum value, and maximum value when compared to the other variables. To assess the degree of variation between the actual data and their mean values, the standard deviation was employed. The standard deviation of *MP* was found to be the highest at 23.775. Conversely, *lnEDU* exhibited the lowest standard deviation at 0.149 and also the lowest mean value at 1.872. The findings imply that *INT* was the most significant variable in this study, and the degree of variation in *MP* was markedly higher than that in *lnEDU*.

Table 3 shows a correlation matrix, which is a useful tool for predicting the direction and strength of correlation between variables and identifying multicollinearity issues. However, it has its limitations as it cannot establish cause-and-effect relationships between variables. Hence, it is essential to use inferential statistical techniques such as econometric models to evaluate the causality of these variables. By using such methods, we can gain a better understanding of the underlying relationships between variables, which helps us make informed decisions based on the results.

Table 3 presents the correlation matrix using Pearson's correlation coefficient for each combination of variables. All pairs of variables were positively correlated. The variables *lnAGR* and *lnCR* had the highest degree of correlation compared to other pairs of variables, indicating that *lnCR* (i.e., bank credit) as an independent variable was moderately and positively associated with the dependent variable *lnAGR* (agricultural performance). Moreover, the pairwise independent variables (*MP, INT, lnCR,* and *lnEDU*) had correlation coefficients of less than 0.70, which suggests that the relationships between independent variables do not present a multicollinearity issue. To ensure the accuracy of the data, it is necessary to conduct a test to examine the stability of the variables of interest. To accomplish this, a panel unit root test is employed to avoid the issue of spurious regression. This test was conducted utilizing two distinct approaches: the Levin, Lin, and Chu (LLC) method and the Im, Pesaran, and Shin (IPS) approach. The results of the test are presented in Table 4.

In Table 4, we can see the results of the panel unit root test using both the LLC and IPS approaches. The LLC statistical test indicated that variables l*nAGR, MP, INT*, and *lnCR* were significant at that level, while *lnEDU* did not reject the null hypothesis. However, all variables were significant at the first difference, indicating that they were

	lnAGR	*MP*	*INT*	*lnCR*	*lnEDU*
lnAGR	1.000				
MP	0.351	1.000			
INT	0.319	0.661	1.000		
lnCR	0.754	0.549	0.533	1.000	
lnEDU	0.325	0.407	0.499	0.421	1.000

Source: Authors computation, 2023

Table 3: Correlation matrix.

Variable	Levin, Lin, and Chu (LLC)		Im, Pesaran, Shin (IPS)	
	Level	First-difference	Level	First-difference
lnAGR	−4.535***	−34.886***	−0.336	−28.563***
MP	−9.914***	−2.557***	−10.557***	−1.195
INT	7.784***	−3.291***	10.493***	−0.869
lnCR	−1.724**	−9.324***	1.917	−9.063***
lnEDU	−0.194	−3.039***	6.358***	−2.581***

Note: *** and ** indicate the significance levels of 1% and 5%, respectively

Source: Authors computation, 2023

Table 4: Panel unit root test results.

stationary at the integration order of I(1). The IPS approach suggested a different outcome where *MP* and *INT* were stationary at the level, but not in the first difference. On the other hand, *lnAGR, lnCR*, and *lnEDU* did not reject the null hypothesis in the first difference. Therefore, we can conclude that all variables were stationary at the mixed integration order or combination I(0) and I(1), which confirms that the panel ARDL is suitable for analysis in this study. Subsequently, we conducted the Pedroni cointegration test to determine the presence of a long-term relationship between the variables. The results in Table 5 present valuable insights into their relationship.

The statistical analysis presented in Table 5 confirmed a strong long-term association between variables since 9 out of 11 indicators rejected the null hypothesis. We determined the optimal lag (*o, p, q, r, s*) through ARDL panel estimation to enable the estimation of short-term and long-term regression parameter estimates. The AIC indicator confirmed that the optimal lag for ARDL is (1, 1, 1, 1, 1), which was a crucial aspect of this process. We have obtained the outcome of the estimation of short-term and long-term relationships of the ARDL model in Table 6, which will be instrumental in our future analyses.

Table 6 summarises the results of the panel ARDL estimation which included PMG, MG, and DFE models. The Hausman test was adopted to select the best model and the results showed that PMG was superior to MG and DFE, showed

Indicator	Statistic	Prob.	Weighted statistic	Prob.
Within-dimension:				
Panel v-statistic	−1.083	0.861	−1.062	0.856
Panel rho-statistic	−8.886	0.000***	−7.483	0.000***
Panel PP-statistic	−26.652	0.000***	−24.056	0.000***
Panel ADF	−10.102	0.000***	−9.659	0.000***
Between-dimensions:				
Group rho-statistic	−4.948	0.000***		
Group PP-statistic	−28.837	0.000***		
Group ADF-statistic	−7.858	0.000***		

Note: *** indicates the significance level of 1%.
Source: Authors computation, 2023

Table 5: Panel cointegration test results.

Variable	PMG coefficient	t-stat	MG coefficient	t-stat	DFE coefficient	t-stat
Short-run						
ECT	−0.7400	−5.04***	−1.2929	−10.68***	−0.5346	−11.67***
ΔMP	−0.3564	−1.30	−0.5389	−4.38***	−0.2857	0.106
ΔINT	0.1024	0.594	0.1949	1.16	0.2946	2.07**
ΔlnCR	−0.0158	−1.11	0.1674	−1.69*	−0.0072	−0.52
ΔlnEDU	−0.0004	−0.00	0.135	0.6	−0.0188	−0.11
C	0.5233	3.88***	1.0324	0.055*	0.8196	5.62***
Long-run						
MP	0.5988	11.83***	0.7079	4.88***	0.4458	4.82***
INT	0.2114	11.60***	0.1686	2.68***	0.3456	6.97***
lnCR	0.0348	5.55***	0.0352	3.00***	0.0116	0.95
lnEDU	0.3235	5.22***	0.1757	0.47	−0.0229	−0.15
Hausman test: MG or PMG[1]		0.470	PMG or DFE[2]			0.011
P-value		0.977				0.991

Note: Dependent variable: lnAGR. The lag structure is ARDL (1, 1, 1, 1, 1)
[1] PMG is an efficient estimation than MG under the null hypothesis
[2] PMG is an efficient estimation than DFE under the null hypothesis
*** and ** indicate the significance level of 1% and 5%, respectively.
Source: Authors computation, 2023

Table 6: Short-run and long-run estimation results.

by the probability value (p-value) of the Hausman test was insignificant in both cases, supporting the appropriateness of the PMG estimator. In terms of PMG estimation results, we found no empirical evidence to support a short-term relationship; all the coefficients of the variables were statistically insignificant at all confidence levels. As expected, Table 6 demonstrated a valid and significant ECT, satisfying the requirements for long-term consistency and efficiency among the variables of interest. The ECT specification evaluates how long it takes to correct a short-term imbalance to achieve a long-term equilibrium among the variables of interest. The coefficient of ECT of −0.7400 showed that the deviation of variables from the short-run disequilibrium to the long-run equilibrium was significantly adjusted and corrected by 0.74% half-yearly in the provinces of eastern Indonesia.

Table 6 also presents the results of the long-term relationship of the PMG model which were inconsistent with the MG and DFE models. The results of PMG model estimation, in the long run, revealed that all of the independent (MP, INT, lnCR) and control variables (lnEDU) had a positive and significant impact on the performance of the agricultural sector in eastern Indonesia at the 1% significance level. The rural ICT penetration, as proxied by the rural mobile phone (MP) and rural internet (INT) penetration, played a significant role in boosting the agricultural sector's performance with coefficients of 0.5988 and 0.2114, respectively. This suggests that in the long run, a 1% increase in the rural mobile phone and rural internet penetration would lead to an increase of 0.60% and 0.21%, respectively, in the agricultural sector performance of the 16 provinces of eastern Indonesia. This finding is consistent with the findings reported by Nguyen et al. (2023), Kaila and Tarp (2019), Suroso et al. (2022), Lio and Liu (2006), Oyelalmi et al. (2022), Nakasone et al. (2014), and Hopestone (2014). However, it contradicted the findings of Evans (2018), Akinlo et al. (2021), Fafchamps and Minten (2012).

Bank credit also exerted a statistically significant and positive effect on the performance of the agricultural sector in eastern Indonesia. The PMG results demonstrated that a 1% increase in the percentage of bank credit values will improve agricultural performance by 0.03% and this improvement was significant at the 1% level of significance. The present study is based on empirical evidence that suggests a positive correlation between the expansion of farmers' access to bank credit and the long-term development of the agricultural sector in Eastern Indonesia. This finding concurs with the research conducted by Rehman et al. (2017), Ngong et al. (2022), and Kumar et al. (2017). However, Nwude and Anyalechi (2018) presented contradictory results, indicating that the use of bank credit in the agricultural sector has a limited impact on the developmental progress of the agricultural sector in rural areas.

After conducting a thorough analysis of the PMG estimation results, we found conclusive empirical evidence that confirms the existence of a long-term relationship between the use of information and communication technology (ICT) and bank credit in the rural agricultural sector. However, our findings did not support the existence of short-term impacts, implying that the use of ICT and bank credit may not provide immediate benefits to the rural agricultural sector. Nonetheless, our analysis suggests that the adoption of these tools can positively contribute to agricultural productivity in the long term, ultimately leading to benefits for farmers. Our findings are in line with the predictions of the Solow growth model or neo-classical theory, which suggests that increasing savings as a source of capital accumulation can result in higher output per capita in the long term. Additionally, our analysis indicates that the adoption of technology, including ICT, can make a significant and permanent contribution in the long run (Mankiw, 2017). To achieve successful agricultural development in Eastern Indonesia through the implementation of ICT and banking credit, it is crucial to provide adequate infrastructure, knowledge, and education for rural communities. Therefore, it is essential to garner support from the government, private sector, and investors. We can ensure that the agricultural sector in the region benefits from the adoption of these technologies, leading to long-term growth and progress.

Conclusion

This research paper focused on the impact of rural ICT penetration and bank credit on agriculture performance in eastern Indonesia. The study used panel data from 16 provinces in eastern Indonesia, covering the period from the first semester of 2010 to the second semester of 2022 (2010S1–2022S2). The panel ARDL approach was used to analyze the data. The empirical findings of this study suggested that rural ICT penetration played a crucial role in agricultural performance. The analysis demonstrateed that rural mobile phone and internet usage had significant coefficients of 0.5988 and 0.2114, respectively. The results are consistent with previous research. Moreover, the study revealed that bank credit had a positive and statistically significant effect on the performance of the agricultural sector in eastern Indonesia. The study found that a 1% increase in the percentage of bank credit values improved agricultural performance by 0.03%, and this improvement was significant at the 1% level of significance. The evidence suggests that expanding farmers' access to bank credit is crucial for the long-term development of the agricultural sector in eastern Indonesia. However, our findings did not support the existence of short-term impacts, implying that the use of ICT and bank credit may not provide immediate benefits to the rural agricultural sector.

Our study has identified several key policies that can significantly impact agricultural development and improve the welfare of farmers in rural areas. Firstly, the government should prioritize providing adequate internet infrastructure that covers all rural areas in Eastern Indonesia. This will greatly enhance the performance of the agricultural sector by improving connectivity and facilitating the economic activity, distribution, and marketing of products. In turn, this is expected to reduce the development gap between rural and urban areas, including between the eastern and western regions of Indonesia. Secondly, it is essential to provide farmers with easy access to financial services, such as bank credits. Inclusive banking credit is crucial for financing agricultural activities, which can stimulate farmers' productivity and income. The government should intervene by reducing interest rates, which are a significant capital cost and business burden for farmers. Thirdly, educating rural communities on the adoption and use of ICT can significantly increase agricultural productivity, financial management, and agricultural production. Therefore, the government should focus on providing education and knowledge related to the use of ICT for these purposes.

Based on our study, we recommend several important policies that can practically impact and contribute to improving agricultural development and the level of welfare of farmers in rural areas as follows: First, the government should emphasize providing adequate internet infrastructure that reaches all rural areas in eastern Indonesia because this will make a major contribution to improving the performance of the agricultural sector. The availability of adequate infrastructure in the eastern region of Indonesia will increase connectivity and improve the flow of economic activity, distribution, and marketing of products. It is expected to reduce the development gap between rural and urban areas, including between the eastern and western regions of Indonesia. Second, provide adequate and easy access for farmers to obtain financial services such as bank credit. Providing inclusive banking credit is an essential factor for financing agricultural activities, which can stimulate farmers' productivity and income. The government must intervene by reducing interest rates which are the capital costs and business burdens of farmers. Third, providing education and knowledge related to the adoption and use of ICT to increase agricultural productivity, financial management, and agricultural production for rural communities.

Recommendations for further research can be made based on these limitations. This study has some limitations related to its research methods and scope. Firstly, it only considers two measures of ICT penetration, rural mobile phone, and internet penetration, and excludes other measures such as fixed-line telephone, computers, radio, and television. Secondly, this study only uses panel data from the provinces in the eastern region of Indonesia, and future research should cover all provinces in the country. Lastly, the control variable in this research is limited to educational factors, even though agricultural development is also linked to production efficiency, competitive market prices, ease of marketing, and farmers' income.

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Developing a Functional User Interface for VR Simulations within Agricultural Equipment Contexts

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Abstract

This study investigates the optimization of VR simulation interfaces for agricultural machinery, emphasizing the critical role of skill development and targeted education in enhancing agricultural efficiency. By utilizing eye-tracking technology, the research evaluates user experience (UX) across two menu designs - panel and radial -in VR settings. Results highlight the significance of intuitive menu design in facilitating user navigation and information access, with the panel menu outperforming the radial menu in usability. Despite some preferences for the radial menu's features, the panel menu is favored for its user-friendly design and ease of access, particularly in agricultural simulations. The findings suggest that effective VR interface design, supported by focused training, can significantly improve operational efficiency in agriculture.

Keywords

UI, VR, Eye-tracking, panel menu, radial menu, usability, UX, agriculture.

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Introduction

By using VR simulators, researchers can safely test and refine human-machine interfaces without risking the safety of human workers. This approach allows for the optimization of new control systems, ensuring that they are user-friendly and efficient. Additionally, the use of VR simulators can provide valuable data on human behaviour and decision-making in complex scenarios, which can inform the design of safer and more productive construction equipment. In this way, the combination of human capital and technology can lead to improvements in both productivity and safety in the construction industry. In a study evaluating advanced human-machine interfaces for hydraulic excavators, researchers found that immersive VR simulations improve efficiency and ergonomics without causing mental or physical strain on operators (Morosi and Caruso, 2021; Makarov et al., 2021; Dhalmahapatra et al., 2021).

VR consists of a computer-generated virtual environment where the user can interact with the environment and objects. Well-designed VR can help people immerse themselves in what feels like a believable reality-like experience (Quesnel and Riecke, 2018). Although VR is not new, thanks to recent developments in immersive technologies, especially in visualization and interaction, VR is becoming increasingly attractive to scientists. The latest displays for VR head-mounted displays (HMDs), such as the HTC Vive or Oculus Rift, allow users to experience a high degree of immersion (Radianti et al., 2020) instead. The immersion describes the technical capabilities of a system; it is the physics of the system. The subjective correlate of embeddedness is presence. If a participant in VR perceives naturally using his or her senses, then the most straightforward inference the brain's perceptual system can make is that what is perceived is the participant's virtual environment (Slater and Sanchez-Vives, 2016).

Menus are an integral part of digital product user experience (UX), allowing users to easily navigate and find the features or content they need. It also gives users a sense of control over the app and makes it easier for them to interact with it. Studies have shown that a quality and intuitive menu can significantly improve a product's overall friendliness and usability and can be a critical factor in achieving success in the marketplace (Merritt and Zhao, 2021).

In the desktop application, the menu is created as a list of individual items to offer, where each item is associated with a specific command. Alternatives to this approach are pie menus, where each item is shaped like part of a pie and has the same proportion of the whole, making them efficient in terms of Fitts' law. These bids are usually designed to execute simple commands, with more complex tasks, such as multiple selections, which should be executed using other user interface elements (UI). These menus could be applied to VR, but the Fitts Act states that multiple aspects of VR offerings should be considered in development (Monteiro et al., 2019).

Fitts' law is used to evaluate human-computer interactions and to estimate movement time and difficulty index. However, Fitts' law is generally useful for measuring and estimating movement times between objects on the same axis or in the same dimension. In other words, the measurement axis can be either horizontal or vertical and cannot be used to measure both axes simultaneously (Nookhong and Kaewrattanapat, 2022).

User experience (UX) refers to a user when interacting with a product or service. This experience can be encountered in various activities, such as ordering food in restaurants, shopping, or commuting to work. However, the quality of the experience can vary depending on the context, as seen in the examples of a stressful morning car journey or a leisurely walk through a park. In contrast, usability is defined as the degree to which a particular entity can use a given system to achieve specific objectives effectively, efficiently, and satisfactorily within a well-defined context of use (Hassenzahl and Tractinsky, 2006). It encompasses three main factors related to the user's characteristics and objectives and the context of use: effectiveness, efficiency, and satisfaction. When evaluating usability, the goal is to ensure that aspects such as efficiency and effectiveness are consistent with the product under test (Quesnel and Riecke, 2018).

UI usability is essential because it assesses the product's pragmatic aspects related to the behavioural objectives that software must achieve. In the context of virtual reality (VR) games, usability evaluation should carefully consider the influence of VR features and gameplay goals (Radianti et al., 2020). For instance, a limited field of view can hinder the user's ability to step back and see the bigger picture in critical situations. This demonstrates the role of usability in achieving learning objectives in simulations and real-world situations. However, different games may have different requirements, and user testing on focus groups is necessary for game development. Previous studies have shown that usability also affects assessing factors that enhance learning (Fernández-Manjón et al., 2011). Therefore, usability evaluation is crucial in improving the overall user experience and achieving the desired outcomes in simulation training for participants to concentrate on the task, not the menu.

Various interaction techniques have been developed in virtual and augmented reality. While object selection, manipulation, travel, and pathfinding techniques are already in existing taxonomies and have been described in considerable detail, application control techniques still need to be sufficiently considered. However, these are needed by almost every mixed reality application, e.g., alternative objects or options. They are also needed for all kinds of real-world applications. For this purpose, there are many different techniques for selecting from three-dimensional (3D) menus (Dachselt & Hübner, 2006).

According to a study by Gebhardt et al. (2013), the most common approach for selecting a technique for VR menu ray-cast type. Users can directly point to the object for selection using a virtual ray cast, as a "laser pointer" does in the real world. Another method is to use a virtual fingertip to select from a menu. This uses a one-to-one mapping method, which is very intuitively similar to the real world. The limitation of this method is that the user experiences great difficulty in perceiving depth in the virtual environment. In addition, the user can only select from menus within arm's reach.

The most immersive VR systems typically include HMDs and handheld controls. HMDs are used in specific areas of medical practice and education, but their use proliferates. This kind of technology is also being applied in other various fields. Using a headset, the user can move and rotate in 3D space as if there they are. Also, the digital environment responds directly to the user's movements. HMD echnology can provide the user with complete immersion in the virtual environment (Salovaara-Hiltunen et al., 2019).

Our research mainly focused on developing and testing an effective user interface for virtual reality (VR) simulations in agricultural machinery environments based on previous research. Our study‘s objective was to optimize this UI‘s position and layout so that it could be tested afterward from the view of UX. Therefore, also compare and replicate the research but with augmentations from the way of our collective knowledge about the ideal position and coordinates of the panel menu, therefore using eye-tracking technology in the usability study.

We have not yet been able to identify a similar UX evaluation of VR technology used for simulations in agriculture, although similar machines are used. Therefore, research potential can be identified here.

The following sections summarize the necessary overview for familiarisation with the issue and introduce the essential background processes for the testing and data collection. We present the individual testing steps and then present the results with graphs and scale. We conclude with comments on the results and possible future research directions.

Materials and methods

Our paper also reports on a study conducted by Monteiro et al. (2019) on 51 participants who were presented with two different types of menus in a virtual reality environment. The menus were presented in four possible combinations and placed in two locations: fixed on a wall and attached to the user's hand. The study measured various factors, including menu usability, user satisfaction, interaction time, and the number of unnecessary steps. The results indicated that participants preferred the traditional panel menu in the virtual reality environment and performed better with it than with the radial menu. Therefore, the study highlights the importance of considering the type of menu and its location when designing menus for virtual reality environments.

Similar to the study conducted by Monteiro et al. (2019), our research involved a total of 50 participants. 40 was used to identify the appropriate menu position. A further 10 were used to test the actual environment. The object of the study was to identify a better solution between the two options. We look for errors and identify better solution based on their minimization. This allows us to rely on the methods presented by Nielsen (2012) and Virzi (1992), who present that it takes about five testers to identify 80% of usability errors.

Our sample included 18% women 82% men, with an average age of 24 years. Potential visual deficits were not addressed due to the focus of the study. 8 participants commonly wear glasses or contact lenses. None of the participants complained about any vision problems in the VR environment. 18 participants have used VR technology before, 2 of them work with it on a regular basis. The average length of the test trial and, thus, working in the VR environment lasted 24 minutes.

Thanks to the equipment available in our VR laboratory, we could utilize eye-tracking technology.

Eye-tracking interfaces use real-time eye movements as a mode of user interaction. This interface can be valuable when other interaction modes are unavailable or not preferred, such as when users have severe motor impairments or when their hands are occupied with other tasks. Although eye-tracking may not be as precise as using handheld controllers in VR, it can be much faster than traditional input devices (Špakov et al., 2014; Sibert and Jacob, 2000). Techniques for visualizing scan paths, such as heatmaps, are useful for analyzing the way subjects process information (Goldberg and Helfman, 2010). By using a fap that shows the degree of fixation accumulation, researchers can gain insights into the patterns of visual attention exhibited by subjects while performing a task (Wang et al., 2014). A heatmap can reveal which areas received the most visual attention and which areas were ignored during the task (Cai, Sharma, Chatelain and Noble, 2018).

Testing itself contained two testing processes. First, we focused on the panel menu and its position due to the more straightforward processing of the results from the scene. The first process of the testing had a general focus and helped to lock the menu in the proper position. The second process was first connecting the mentioned environment. Then select the machinery's attributes (model, color, equipment), in our case, a tractor.

The first testing consisted of several parts:

- Introduction;
- Introduction to the VR HW controls;
- Setting the menu parameters;

- Usability testing;
- Guided interview.

Participants were informed of the testing and reassured that they were not the ones being tested, but the environment and any missteps or controls were perfectly fine. VR technology was unfamiliar to most participants and made them a little nervous about interacting with the tester in a virtual space. Participants were familiarized with the technology and taught how to operate menus, which was a central part of the testing. The participants made decisions about parameters in a specific order:

1. Distance of the menu from the user;
2. The size of the menu;
3. Height of the menu from the ground;
4. Scroll left/right;
5. Rotation.

Before beginning the main tasks of the study, it was important for participants to become familiar with the research environment. To achieve this, participants were first given a set of simple tasks to complete, allowing them to become more comfortable with the research environment and the tasks that were to come.

During VR user interface testing, the Concurrent Think-aloud method (CTA) is often used. This method allowed us to test different aspects of the user interface and get immediate valuable feedback from users. Once the UI testing is complete, there is a short phase during which the tester interacts with the test user to gain further insights into their experience of using the product. This process is called a guided interview or Retrospective Think-aloud (RTA) and is usually conducted immediately after testing (Prokop et al., 2020).

The equipment we used has the I-VT fixation, a classification algorithm based on velocity, which identifies eye movements by analyzing the velocity of directional shifts of the eye (Olsen, 2012).

After usability testing, the respondent completed a questionnaire using the standardized System Usability Scale (SUS) method, which consisted of 10 sentences to evaluate various aspects of usability. The questionnaire used a Likert scale to assess ease of use, confidence, inconsistencies, and need for technical assistance. SUS scores provide a measure of overall usability and are considered a valuable evaluation tool (Brooke, 1996, p. 194).

Measurement results are reported in Unity units, where 1 unit corresponds to 1 meter in real space. The default menu position was 1.5 meters above the virtual floor and 5 meters from the user. The results can be divided into two categories: relevant and irrelevant. The relevant parameters are the height of the menu located on the Y-axis and the distance of the menu from the user on the X-axis. The less relevant parameters are the slope of the menu along the Z-axis and the size of the menu. Participants were most comfortable with menu positions between 1.16-1.86 meters from the virtual floor. Regarding the distance from the user, the ideal intervals ranged from 4.7 to 5.2 meters. Less than half of the participants changed the default menu position.

The second testing process, as mentioned before, was based on the study conducted by Monteiro et al. (2019). In this research, the authors compared the panel and radial menus. Thanks to the virtual reality laboratory, which includes eye-tracking HMD Vive pro eye, we were able to get diverse data. We compared a static panel menu with a radial menu positionally locked to the hand. Participants used a ray cast to control the panel menu and a touchpad for the radial menu, with finger tracking.

The second testing (for both menus) consists of several parts:

- Introduction;
- Introduction to the VR HW controls;
- Usability testing;
- Guided interview;
- SUS

Menu parameters were taken from the first testing process. We took coordinates and made a panel menu, which corresponds with the panel menu from the study by Monteiro et al. (2019). The changes were made on the base of Fitt's law; we adjusted the buttons to a space in the body of the menu for shorter distances between buttons. The radial menu was based on the research of Salkanovic et al. (2020), which was the implementation and analysis of pie menus for mobile touch devices. Then we start the usability testing of both menus. Tasks were assigned in a specific order for the participant to perform:

1. Change the color of the tractor to red;
2. Change the type of the tractor to New Holland;

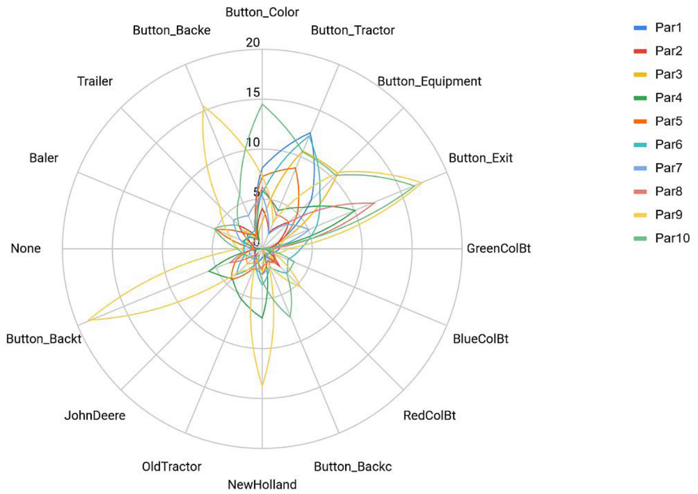
3. Change the equipment to a trailer;
4. Change all parameters mentioned before based on preferences, and please share experiences with a menu out load.

We collected heatmaps from every button in the radial menu and panel menu. We also collected the total fixation duration of participants looking at the buttons, then the first fixation time and first fixation length.

Results and discussion

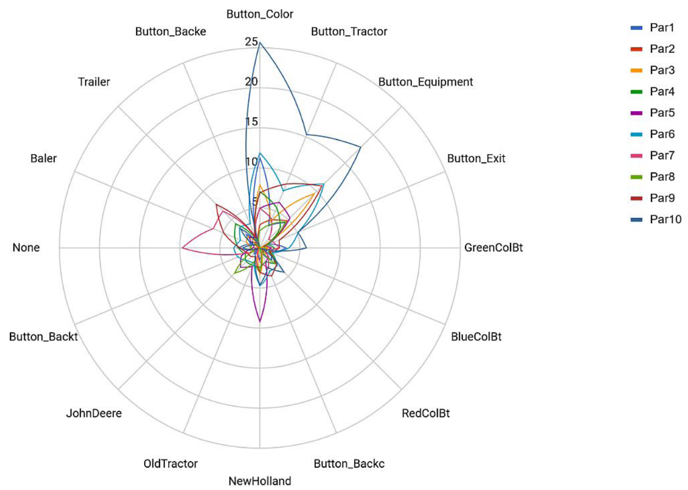
The testing demonstrated the value of using VR technology in user experience research. As VR technology continues to gain popularity, it presents exciting opportunities for improving simulations and other types of content. Although we know that the test sample of our participants was not significant, we believe this study is a gate to our more complex research in the future.

In terms of eye-tracking results, the heatmaps show that most participants only focused on the part of the button for the panel menu buttons. Most of the buttons in the panel menu had two or fewer points of higher concentration. In comparison, heat maps on buttons of the radial menu had a much more vast field and usually more than 2 points of higher concentration. When we look at the data of total duration on the buttons, we can say that participants spend much more time looking at buttons of the radial menu (see Figures 1, 2), which tells us the dispersion on the graph, where the middle line shows us duration in seconds. Most participants spend more than 5 seconds concentrating on the buttons. On the other hand, when testing the panel menu, most of the participants fit up to 5 seconds.



Source: own processing

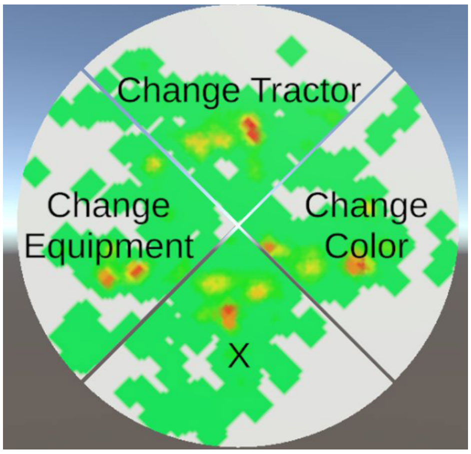
Figure 1: Total duration in seconds (Radial menu).



Source: own processing

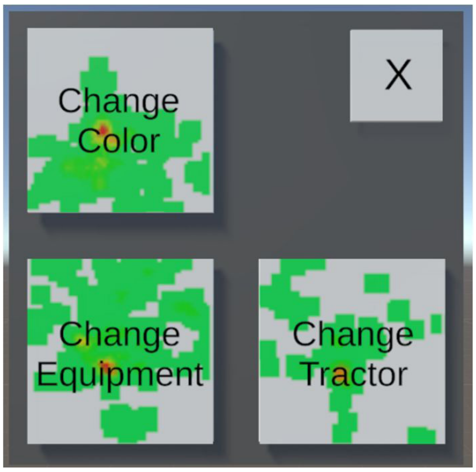
Figure 2: Total duration in seconds (Panel menu).

Observing both data sets, we can say that even though both menus do not have some great value, in most cases, the results are better for the panel menu. Furthermore, these results correspond to the obtained heat maps (see Figures 3, 4).



Source: own processing

Figure 3: Heat map (Radial menu).



Source: own processing

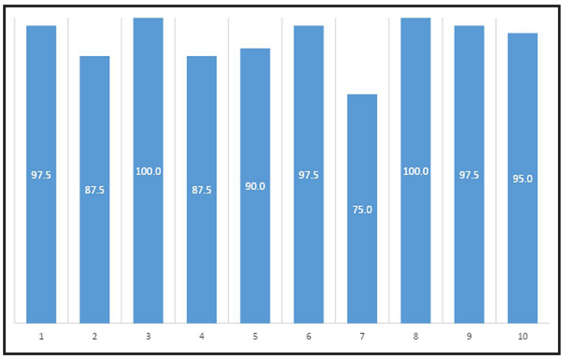
Figure 4: Heat map (Panel menu).

During the CTA and RTA, participants consistently mentioned that the panel menu was easier to handle, visually appealing, and intuitive. They appreciated having the menu close to the point of interest (the tractor). However, the radial menu was also deemed functional but difficult to handle, especially when switching between the menu and tractor or raising the hand. Even though some participants compared the handling of the radial menu to phone-like activity, they did not consider it for an advantage.

The SUS value is scored on a scale from 0 (worst) to 100 (best), with scores below 68 considered below average and scores above 68 considered above average (Bangor, Kortum and Miller, 2008).

In our study, the arithmetic means SUS score of all 10 participants was 92 for the panel menu and 71 for the radial menu.

This indicates that both menus are above average in terms of usability. Mainly the panel menu indicates a significantly above-average score, even for individual participants (see Figure 5). Where the bottom line shows the participant and the column shows the score.



Source: own processing

Figure 5: Individual panel menu SUS survey results (SUS score).

Conclusion

Our project focused on enhancing the user interface of virtual reality simulations for heavy machinery, recognizing the importance of specialized education and skill development in agricultural techniques. Therefore, our efforts were aimed at advancing the VR simulation interface specifically for use in agricultural machinery contexts. To assess the user experience effectively, we utilized eye-tracking technology, with a special focus on evaluating the design and usability of both panel and radial menus.

Our findings revealed that both panel and radial menus were rated highly for usability, though the panel menu was notably superior. Heat maps showed that users tended to interact with only certain buttons on the panel menu, while the radial menu's usage was more evenly spread. Additionally, it was observed that users spent more time engaging with the radial menu's buttons.

Feedback from Concurrent Think-aloud (CTA) and Retrospective Think-aloud (RTA) methods consistently favored the panel menu for its intuitiveness, visual appeal, and ease of use, attributed to its strategic placement near the user's focal point, the tractor. On the other hand, despite being functional, the radial menu was found to be less user-friendly, especially in tasks requiring the user to alternate focus between the menu and the tractor or to perform actions like raising the hand. Our research indicates a preference for the panel menu in terms of usability and overall user experience, notwithstanding certain benefits of the radial menu as noted by participants.

Our study delved into the challenges of applying traditional usability and UX research methods to VR environments, highlighting difficulties in navigation compared to standard computer interfaces. We recognized the potential for enhancing VR interaction in agriculture by adapting established methodologies for VR settings. While thoroughly examining these alterations was outside our scope, it presents a valuable direction for future studies. This exploration is particularly relevant when considering tools like the User-Technological Index of Precision Agriculture (UTIPA). The index is based on evaluating technological advancement and applicability for agricultural practice (Masner et al., 2019). That could benefit from improved VR UX to support precision agriculture communities.

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Are Organic Farms Less Efficient? The Case of Estonian Dairy Farms

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Abstract

The paper investigates the technical efficiency of conventional and organic dairy farms in Estonia in the period 2006–2015 using Farm Accountancy Data Network. We analyse self-selection into organic farming using the propensity-score-matching approach and explicitly test the hypothesis that organic and conventional farms apply homogeneous technology. We find that organic farms are less efficient. However, the difference in technical efficiency between organic and conventional farms decreases substantially when the technical efficiency assessment incorporates the use of the appropriate technology. The lack of growth of technical efficiency over time indicates that there might be a lack of knowledge in organic milk production that hinders its development. Since technical efficiency increases with farm size, it is important that organic dairy farms increase their scale.

Keywords

Production function, technical efficiency, milk production, propensity score matching.

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Introduction

The adoption of organic farming practices has gained increasing attention both in policy and scientific circles. According to the organic farming paradigm, a farm is a balanced unit, wherein production-, environment-, and human activities are integrated (Tzouvelekas et al., 2001; Mareth et al., 2016). Organic livestock production is associated with several limitations compared to conventional systems. In most cases, it also assumes organic crop production on the farm. During summers, cows need to be grazed, which is a constraint for larger farms. There is usually not enough grassland around the holding and grazing many cows requires additional labour. In organic livestock production natural insemination is preferred to artificial insemination, and the use of hormones or other preparations for heat synchronization is not allowed. The use of veterinary medicine for preventing disease is prohibited. After curing animals with medical preparations, the sale of milk is banned for twice as long as in conventional systems. Feed for animals must not contain GMOs, antibiotics, growth stimulators, or hormone preparations. Calves must be fed with natural milk for three months (Leming et al., 2011; Palts and Vetemaa, 2012; Nehring et al., 2021).

The difference in productivity of conventional and organic production systems may be due to technological differences, technical inefficiency, or both. Critics of organic production claim that conventional farms are clearly winners in terms of crop yield efficiency, while organic farm advocates claim that organic farms are more energy efficient (De Ponti et al., 2012). The milk yield of dairy cows on organic farms is on average 30% less than on conventional farms in the EU (European Parliament, 2018).

The profitability of organic agriculture can be attributed to several factors. First, organic farmers do not rely on synthetic fertilizer and pesticide inputs, which can be costly. In addition, organic foods enjoy a price premium over conventionally produced foods, meaning that organic farmers can often get more for their yield (Kumbhakar et al., 2009). However, the more restricted use of specific inputs in organic production increases costs, makes organic farms less productive, and, unless higher output prices compensate for lower productivity, reduces their profitability. Seufert et al. (2012) showed that crop yields are typically smaller in organic farms than in conventional farms, but the difference in some cases may be very small.

A wealth of literature has evaluated the factors affecting the TE of EU dairy farming (e.g., Madau et al., 2017; Čechura et al., 2021; Kroupová Žáková and Trnková, 2020). Most of the TE comparisons between organic and conventional farms utilize data about traditional inputs (land, materials) and outputs (milk, grain, etc.) and assume that the same technology is used (e.g., Tzouvelekas et al., 2001, Kumbhakar et al., 2009). Pietola and Oude Lansink (2001) point out that the choice to transition to an organic production system might be more likely among conventional farms that have lower productivity. Sipiläinen and Oude Lansink (2005) suggested that when comparing conventional and organic farms several factors need to be controlled for, including farm location, to avoid selection bias. Other studies have suggested that organic dairy farms have lower TE compared to conventional farms (Oude Lansink et al., 2002; Ricci Maccarini and Zanoli, 2004; Djokoto, 2015).

One of the key issues of efficiency analysis is the technological heterogeneity among farms. This is especially important if we want to compare the performance between organic and conventional farms. The issue of technology choice (conventional dairy farms converting to an organic system or vice versa) has been considered already by Breustedt et al. (2011). Nehring et al. (2021). They found that both conventional and organic larger dairy farms had higher TE, and that size of the farm was related to its economic viability. Kargiannis et al. (2012) found that conventional and organic farms are similarly efficient considering their production technologies.

Estonia is a good case study to compare the TE of organic and conventional dairy farms. Dairy is one of the main production branches in Estonian agriculture with the highest average milk yield per cow in the EU. The competitiveness of organic production systems is an increasingly prominent area of interest as the EU's Farm-to-Fork Strategy has defined the aim of increasing the share of area that is organically farmed of total utilized agricultural area to 25 per cent by 2030 (European Commission, 2020). EU Member States such as Austria and Estonia (22 per cent) have almost reached this target (Moschitz et al., 2021).

The aim of the paper is to contribute to the literature to the debate on of the TE of organic farms using Estonian dairy sector as an example. We pay special attention on the differences in technology between organic and conventional farms using treatment effect approach. Whilst pervious studies have focused on the Western European countries, our attempt is the first to analyse a highly efficient dairy sector in a Central and Eastern European country.

Materials and methods

Methodology

The first step in our investigation is to estimate TE. Since the pioneering work of Aigner et al. (1977) and Meeusen and van den Broeck (1977), efficiency measurement using stochastic frontier models has become a standard approach of applied economists. However, traditional efficiency models assume that all firms face a common frontier, and the only differences result from the intensity of input use (Tsionas, 2002; Alvarez et al., 2012). As our aim is to estimate TE for dairy farms and to compare organic and conventional farms, the assumption of common technology is strong. To account for unobserved heterogeneity, conventional panel data models such as fixed-effects or random-effects models are suitable (Pitt and Lee, 1981; Schmidt and Sickles, 1984). However, these models have the following limitations: (i) the treatment of the inefficiency term as time-invariant, which raises a fundamental identification problem, and (ii) they fail to distinguish between cross-individual heterogeneity and inefficiency (Abdulai and Tietje, 2007; Greene, 2005). To account for these limitations, Greene (2005) proposes two stochastic frontier models that are time-variant and that distinguish unobserved heterogeneity from the inefficiency component. These models are called 'true' fixed-effects (TFE) and 'true' random-effects (TRE) models. However, as pointed out by Greene (2005), TFE models might produce biased individual effects and efficiency estimates because the presence of the individual effects creates an incidental parameter problem. In contrast, TRE models produce unbiased inefficiency estimates, therefore we apply a TRE model in line with that of Kostlivý and Fuksová's (2019). The TRE model can be specified as:

$$y_{it} = \alpha + \mathrm{f}(x_{it}, \beta) + w_i + v_{it} - u_{it}, \quad (1)$$

where y_{it} is the log of output (revenue) for farm i at time t; α is a common intercept; $\mathrm{f}(x_{it}, \beta)$ is the production technology; x_{it} is the vector of inputs (in logs); β is the associated vector of technology parameters to be estimated; v_{it} is a random two-sided noise term (exogenous production shocks) that can increase or decrease output (ceteris paribus); and $u_i > 0$ is the non-negative one-sided inefficiency term. The parameters of the model are estimated with the maximum likelihood (ML) method using the following distributional assumptions:

$$u_{it} \sim N^+(0, \sigma_{it}^2) = N^+\left(0,\ exp\left(w_{u0} + z'_{u,it} w_u\right)\right) \quad (2)$$

$$v_{it} \sim N^+(0, \sigma_v^2) \quad (3)$$

$$w_{it} \sim N^+(0, \sigma_w^2) \quad (4)$$

The term u_i in the Equation (1) measures technical inefficiency in the sense that it measures the shortfall in output from its maximal possible value given by the stochastic frontier ($f(x_{it}, \beta) + v_{it}$). The estimation of u_i contains the specific heterogeneity; to disentangle these effects we applied the JLMS technique (Jondrow et al., 1982). This implies calculating the conditional distribution of u_{it} given $\varepsilon_{it} = v_{it} - u_{it}$ for each observation.

Mayen et al. (2010) emphasize two important methodological issues when comparing the TE of organic and conventional farms: self-selection into organic farming, and formal testing of the homogeneous technology assumption. They propose using a matching approach instead of a Heckman-type model to address the self-selection issue. Following their suggestion, we employ propensity score matching (PSM) to predict the probability of a farm being an organic farm based on observed covariates for both organic and conventional farms. The method balances the observed covariates between the organic group and conventional farmers based on the similarity of their predicted probability of being organic farmers. The aim of PSM matching is to find a comparison group of organic farmers from a sample of conventional farmers that is closest (in terms of observed characteristics) to the sample of organic farmers. Estimating the treatment effects based on the propensity score matching (PSM) requires two assumptions. The first is the Conditional Independence Assumption (CIA), which states that for a given set of covariates participation is independent of potential outcomes. A second condition is that the average treatment effect for the treated (ATT) is only defined within the region of common support. This assumption ensures that treatment observations have comparison observations "nearby" in the propensity score distribution. Following Mayen et al. (2010) we perform a formal test to resolve the potential endogeneity problem and test the validity of the assumption of homogeneous technology using an organic dummy in the production frontier.

Data

For the purpose of the empirical analysis we used data from the Estonian Farm Accountancy Data Network (FADN), which was obtained from the Estonian Agricultural Research Centre. The database consists of an unbalanced panel of dairy farms for the period 2006–2015.

The production function $f(x_{it}, \beta)$ in our models is specified with the following input variables: *Labour* is hours of labour used on the farm, measured as total number of hours worked, including management, family, and hired workers; Land is agricultural area in hectares; *Variable inputs* is variable farm inputs, measured by total specific costs (variable costs), deflated by the consumer price index (CPI) to 2006 Euro prices; *Capital* is farm-fixed and capital costs, also deflated by the CPI to 2006 Euro prices; and $t(1;...;\ 10)$ is a time trend. Farm total output (*Output*) in euros was used as an output variable, which was deflated by the producer price indices of agricultural products for agricultural goods.

The z-variables in this study are the following: *Share of rented land* is the share of rented land of the farmer's total agricultural land in a year; *Share of paid labour* is the share of paid labour in total labour input. *Farm size* is the size of the farm classified according to FADN size groups.

Summary statistics and the statistical significance of tests on equality of means for continuous variables and equality of proportions for binary variables of organic and conventional farms are reported in Table 1. There are significant differences in farm characteristics between conventional and organic farms. Calculations indicate that, on average, organic farms are smaller in terms of output and input use and receive smaller subsidies than conventional farms. Other characteristics are also significantly different, except for the age of farmers. However, the matched conventional farms exhibit similar characteristics to the organic farms.

	Conventional			Organic			Matched conventional[a]		
	N	Mean	Std. Dev.	N	Mean	Std. Dev.	N	Mean	Std. Dev.
Production function variables									
Output (euros)	1834	295743.9	636586.8	289	33260.4***	53014.9	289	115891.7	350027.7
Capital (euros)	1834	70292.1	145277	289	17111.2***	31833.9	289	31063.9***	93155.9
Variable inputs (euros)	1834	208876.2	471940	289	29685.1***	37763.5	289	76318.5	212012.9
Land (hectare)	1834	413.3	709.6	289	171.1***	182.5	289	190.9***	390.8
Labour (AWU)	1834	10.5	17.6	289	2.9***	2.8	289	4.8	9.8
Heteroskedasticity variables in the inefficiency function									
Share of rented land	1830	0.5	0.31	289	0.54***	0.32	289	0.55	0.34
Share of paid labour	1834	0.45	0.43	289	0.27***	0.37	289	0.26	0.37
Heteroskedasticity in error component variables									
Farm size	1834	7.58	2.64	289	6.14***	1.52	289	5.99***	2.3
Additional variables for PSM analysis									
Age (year)	1820	53.4	11.5	289	53.7	10.9	289	53.4	11.9
Owner (0/1)	1834	0.7	0.46	289	0.86***	0.35	289	0.83	0.37
Natura 2000 (0/1)	1834	0.08	0.27	289	0.20***	0.4	289	0.14	0.35
Total subsidies (euros)	1834	62255	105879	289	31370***	32643	289	31425	74129

Note: Asterisks denote a statistically significant difference with the organic mean at the 1 percent (***) level,

[a] The subsample of conventional farms matched to organic farms on the basis of the estimated PSM analysis

Source: Own estimations, data: Farm Accountancy Data Network (Estonia)

Table 1: Descriptive statistics of variables.

Results and discussion

Self-selection test

First, we test whether there is a reason to consider self-selection into organic farming for the full sample. Thus, we employ a Durbin-Wu-Hausman (DWH) test of the endogeneity of the organic dummy variable included in the Equation (1). The resulting chi-squared statistic from an F test is 6.46 with 1 degree of freedom (p-value = 0.011). Therefore, we reject the null hypothesis that the organic dummy is exogenous at the 5% level.

PSM analysis

We start with a description of the results of matching procedures. We selected the age of farmers, ownership, total agricultural subsidies, economic farm size, the share of paid labour in total labour, and the share of rented land in total agricultural land, located in Natura 2000 areas, and county dummies to control for regional heterogeneity as the covariates to ensure appropriate similarity between organic and conventional farms without violating the assumption of common support.

The first challenge in PSM analysis is to identify the appropriate matching algorithm. The most used matching algorithms that involve a propensity score are the following: Nearest Neighbour Matching, Radius Matching, Stratification Matching, and Kernel Matching. As the quality of a given matching technique depends strongly on the dataset, the selection of a relevant matching technique is based on three independent criteria: i) standardized bias (Rosenbaum and Rubin, 1985); ii) a t-test (Rosenbaum and Rubin, 1985); and, iii) joint significance and pseudo R2 (Sianesi, 2004). Our estimations suggest that the various methods produce very similar results, but nearest-neighbours (N1) matching is the best matching algorithm in all cases[1].

Table 2 presents the probit estimates of the organic propensity equation. The model has a McFadden pseudo R^2 value of 0.205, and 87.05% of the cases are correctly classified. Some variables are statistically significantly associated with being an organic dairy farm. Farms with a greater share of rented land and those located in Natura 2000 areas are more likely to be organic. On the other hand, farm size is negatively associated with organic production. Some county dummies are also highly significant.

We use the probit estimates to generate a propensity score – i.e., the predicted probability of being organic – for each farm. We then create a subsample of conventional farms by selecting for each organic farm the conventional farm with a propensity score

[1] We applied the STATA psmatch2 programme developed by Leuven and Sianesi (2012).

closest to that of the organic farm. The resulting subsample of matched conventional farms consists of 289 farms. These farms are on average less than half the size of the original conventional dairy sample in terms of outputs and use of inputs (Table 2). Compared to the organic farms, the matched conventional dairy farms are still statistically different in terms of capital and input use and farm size.

Variable	coefficients
Age	-0.006
Owner	0.056
Farm size	-0.179***
Natura 2000	0.510***
Share of rented land	0.270*
Share of paid labour	-0.033
Total subsidies	0.000
County dummies	
39 Harju	1.420***
44 Hiiu	0.907***
49 Ida-Viru	0.516*
51 Järva	-0.371
57 Lääne	0.054
59 Lääne-Viru	-0.148
65 Põlva	-0.312
67 Pärnu	0.313
70 Rapla	-0.537*
74 Saare	0.835***
78 Tartu	0.848***
82 Valga	0.066
84 Viljandi	0.545*
86 Võru	0.078
constant	-0.629
N	2108
Pseudo R^2	0.205

Note: Asterisks denote statistical significance at the 10% (*), 5% (**), and 1% (***) levels.
Source: Own estimations, data: Farm Accountancy Data Network (Estonia)

Table 2: Probit estimates of the propensity to produce organic milk.

In the next step we employed a balancing property test (t-test) to check statistically the comparability of the two groups of farms in terms of observable covariates (Caliendo and Kopeinig, 2008). Our estimations confirm that the matching algorithm that was applied considerably increased the comparability of the two farms groups, making counterfactual analysis more realistic (Appendix, Table A 1). After matching, the differences between the two groups in terms of covariates became insignificant.

We apply a DWH test of the endogeneity of the organic dummy variable included in equation (1) over the PSM subsample. The resulting c hi-squared statistic from an F test is 1.901 with 1 degree of freedom (p-value = 0.168). Thus, we cannot reject the null hypothesis that the organic dummy is exogenous, and we conclude that the PSM approach appropriately generates a subsample of conventional farms to which organic farms are randomly assigned.

Stochastic frontier analysis

We chose a translog specification of the $f(x_{it}, \beta)$ function in the empirical analysis because of its flexibility. We used log values for the input variables in the translog production function. Prior to taking logs, the x-variables were scaled (divided by their geometric means). Table 4 presents the results of the stochastic frontier models estimated on the full sample and the PSM subsample of dairy farms. We estimate two different models for each sample. First, we assume that both organic and conventional dairy farms have the same production technology. Second, we estimate a model that allows the organic and conventional production technologies to differ. Using the model for both the full sample and the PSM subsample that allows for different technologies, we test the restriction that the organic intercept and slope shifters are jointly equal to zero. The resulting chi-squared statistic from a Wald test is 4.53 and 4.45 with 5 degrees of freedom for the full sample and PSM subsample (p-value = 0.033 and 0.034). Thus, we reject the null hypothesis that the organic intercept and slope shifters are jointly equal to zero at conventional significance levels. In other words, we reject the hypothesis of a homogeneous technology for organic and conventional dairy farms.

Because all variables have been normalized by their respective sample mean prior to taking logarithms, the first-order estimates β_i can be interpreted as partial production elasticities, showing how much the output would increase in percentage terms if the use of the respective input was increased by 1%. Table 3 shows that variable inputs have the largest partial production elasticity in all models (0.61–0.77). Labour inputs have second highest elasticity in the full sample, whilst capital inputs play a more important role in the PSM subsample. The elasticities of capital and variable inputs are higher in the PSM subsample compared to those of the full sample. Interestingly, the time variable is insignificant for all specifications, implying the lack of changes in technological progress.

The share of rented land and the share of paid labour has a statistically significant effect on the statistical variances. As the share of rented land (share of paid labour) increases, inefficiency variance increases (decreases). When farm size increases, inefficiency variance decreases.

To assess TE differences between organic and conventional dairy farms we evaluate the stochastic frontiers at the means of discretionary inputs for all farms. The means and standard errors of the TE measured under different methodological assumptions are presented in Table 4, (columns 2-5).

	Full sample		PSM subsample	
	1 same technology	2 different technology	3 same technology	4 different technology
Capital	0.129***	0.134***	0.217***	0.224***
Variable inputs	0.643***	0.607***	0.774***	0.706***
Land	0.066***	0.105***	-0.124	-0.094
Labour	0.201***	0.179***	0.157*	0.176**
Capital* Variable inputs	-0.131***	-0.187***	-0.123	-0.157*
Capital*Land	-0.065*	-0.085**	-0.032	-0.088
Capital*Labour	0.059	0.104**	0.014	0.071
Variable inputs*Land	-0.142***	-0.070	-0.547***	-0.436**
Variable inputs*Labour	-0.238***	-0.229***	-0.512***	-0.551***
Land*Labour	0.316***	0.119	0.595***	0.538***
time	0.001	0.002	-0.003	0.004
time*Capital	-0.009	-0.003	0.029	0.029
time*variable input	0.027***	0.028***	-0.038	-0.036
time*Land	-0.003	-0.009	-0.010	-0.005
time*Labour	0.004	0.003	0.053**	0.048**
time[a]	0.004**	0.003**	0.007	0.006
Capital[a]	0.057***	0.075***	0.070**	0.093***
Variable input[a]	0.120***	0.118***	0.360***	0.317***
Land[a]	0.066**	0.104***	0.211*	0.208
Labour[a]	-0.062	0.014	-0.014	-0.003
organic		-0.291***		-0.436***
Capital*organic		0.031		0.008
Labour*organic		0.127*		-0.052
Land*organic		-0.145*		0.088
Variable inputs*organic		-0.026		-0.135
constant	12.448***	12.476***	12.491***	12.575***
Usigma				
Share of rented land	1.263***	0.708***	1.317***	1.376***
Share of paid labour	-2.180***	-2.060***	-1.346***	-1.411***
constant	-2.877***	-2.759***	-2.490***	-2.568***
Vsigma				
Farm size	-0.505***	-0.513***	-0.412***	-0.455***
constant	0.541**	0.482**	-0.554	-0.312
Theta				
constant	0.251***	0.225***	0.262***	0.250***
N	2307	2095	567	567
Log simulated-likelihood	-781.2324	-548.033	-345.553	-334.688

Note: Asterisks denote statistical significance at the 10% (*), 5% (**), and 1% (***) levels.
[a] The authors apply the Stata sfpanel command developed by Belotti et al. (2013).

Source: Own estimations, data: Farm Accountancy Data Network (Estonia)

Table 3: Results of SFA models.

Column 6 of the Table 4. displays the difference in the mean technical efficiency of organic and non-organic farms. Column 7 presents the significance of the Kruskal-Wallis test. The null hypothesis of the test is that the difference in TE means is not statistically significant. For the full sample, when we assume homogeneous technologies (row 4, Table 4), we find that the organic technology is 7.7% less productive than the technology used by conventional farms. The difference in TE decreases to 5.3% but it remains statistically significant when allowing for different technologies (row 5, Table 4.). This means that the best-practice organic farms are not able to produce as much as conventional dairy farms operating at the production frontier. In both cases, the significant Kruskal-Wallis p-values reject the mean equality null hypothesis, concluding that non-organic farm TE means are significantly higher than that of their organic counterpart, regardless of the assumptions we make on technology.

When weLat two rows of Table 4. present TE estimates corrected for self-selection bias, that is efficiency estimated on the PSM subsample. Where webut assume homogeneous technology, we find the TE of organic farms to be 76.2%, which is six percentage points lower than for conventional farms (row 7, Table 4.). The difference between average TE on organic and conventional dairy farms is still statistically significant at the 0.01 level, and is larger in magnitude under the homogeneous technology assumption than otherwise. It follows that Thus, a false assumption of homogeneous technology causes a downward bias in the estimate of TE on organic farms relative to that on conventional farms (row 7, Table 4.).

Finally, we estimate TE for each farm based on the estimated frontiers for the PSM subsample assuming different technology and compare the TE of organic and conventional dairy farms. Measured against the appropriate frontier, we find that average technical efficiency is 71.9 % on organic farms and 75.7 % on conventional farms. A Kruskal-Wallis test suggests the difference in mean TE is not statistically significant (row 8, Table 4.).

Discussion

In Estonia, only 2% of dairy cows are raised using organic production systems, while 22% of the utilized agricultural area is organic. One of the reasons for the small share of organic dairy farms in Estonia may be the dominant size of dairy farms. The Estonian dairy sector is dominated by relatively large conventional farms (Viira et al., 2015; Luik and Viira, 2016). Our results confirm that larger farms are less likely to be organic in Estonia, which may be related to difficulties with applying certain organic production practices (e.g., grazing) in large diary units.

We use PSM to compile a valid set of conventional farms for comparing TE on organic and conventional dairy farms. Matching improved significantly the comparability of the organic and conventional farms. However, matched conventional dairy farms used more capital and variable inputs compared to similar organic farms. While variable input use could be associated with differences in intensity of production, the differences in capital may refer to a lower level of investment and older production facilities on organic farms. For organic farms, this could be an advantage in the short term, but in the longer term raises question about their economic viability.

Most earlier studies that compared the productivity of organic and conventional farms found that organic farms have lower productivity (Kumbhakar et al., 2009; Mayen et al., 2010; Oude Lansink et al., 2002; Tiedemann and Latacz-Lohmann, 2011). Sipiläinen and Oude Lansink (2005) found a 10% efficiency gap between organic and conventional dairy farms, and Kumbhakar at al. (2009) found that organic farms were 5% less efficient than conventional farms.

	conventional farms		organic farms			
	Mean	Std. Dev.	Mean	Std. Dev.	difference in means	Kruskal-Wallis
Full sample						
same technology	0.828	0.002	0.751	0.009	0.077	0.0001
different technology	0.828	0.002	0.775	0.009	0.053	0.0001
PSM subsample						
same technology	0.762	0.007	0.703	0.011	0.059	0.0009
different technology	0.757	0.007	0.719	0.011	0.038	0.2385

Source: Own estimations, data: Farm Accountancy Data Network (Estonia)

Table 4: Means and standard deviations of technical efficiency.

We find that the organic farms are on average about 8% less technically efficient than conventional farms if we assume that they use homogeneous technology. If we assume that the technology on organic and conventional farms differs, the TE of organic farms is 5% lower than on conventional farms. Therefore, we can make an unambiguous conclusion about the heterogeneity of technology on organic and conventional farms. In this case, however, the difference in TE decreases, but remains statistically significant. This confirms that the best-practice organic farms are not able to produce as much as conventional dairy farms operating at the production frontier. In this, our results are consistent with other findings (Kumbhakar et al., 2009).

This productivity difference could explain why Estonian dairy farms prefer conventional production practices. However, productivity differences are not as high as differences in yields (De Ponti et al., 2012; Seufert et al., 2012). This suggests that if the policy aim is to increase organic dairy farming, additional support is needed. However, if the aim is to increase the share of organic farms among dairy farms, one should also consider the time needed for adjustment. Sipiläinen and Oude Lansink (2005) found that after the conversion to organic farming, farm efficiency increases for 6-7 years, indicating the presence of a learning effect. An increase in the TE of organic farms was also found by Kostlivý and Fuksová (2019). The presence of a learning effect justifies the conversion subsidies for organic farms.

After evaluating TE for each farm, and comparing the results of organic and conventional dairy farms, we find that average TE is 71.9% on organic farms and 75.7% in conventional farms. This difference in mean TE was not statistically significant. One of the erroneous assumptions that can be made when comparing organic and conventional dairy farms is the assumption of homogeneous technology. If one acknowledges that organic and conventional dairy farms use different technology, the differences in TE become insignificant. This suggests that more attention should be paid to technology differences in organic and conventional production systems.

The choice of an organic system is influenced by number of factors, including personal preferences. Organic farming might also be preferred by society, thus social norms might be a factor that affects the technology choice of farmers. As part of the EU Farm-to-Fork Strategy, organic farming will be promoted, and at least 25% of the EU's agricultural land shall be under organic farming by 2030 (Purnhagen et al., 2021). While Estonia (22%) has almost reached the target of 25% (Moschitz et al., 2021), there is still much room for an increase in organic milk production in Estonia. To achieve this, additional economic incentives are needed (Uuematsu and Mishra, 2012).

Conclusion

In recent years the number of organic farms and share of organic land of all utilized agricultural area has increased in Estonia. Despite this, the share of organic dairy farms remains small, and the average milk yield per cow is lower on organic farms than traditional ones. In this context, we compared the TE of organic and conventional dairy farms using FADN data from 2006–2015. The findings showed that organic and conventional farms differ in size and technology. Therefore, organic dairy farms have a different production frontier to conventional farms. It is important to acknowledge this difference in future studies that compare organic and conventional agricultural production.

Our results reveal that there has been a lack of technological progress in organic dairy farming in Estonia. While it has previously been shown that after conversion from conventional to organic farming there is a transition or learning period during which TE increases, the lack of progress in the Estonian case indicates that there might be a lack of knowledge related to organic milk production that hinders the development of this type of farming, which may also discourage conventional dairy farms from converting to organic production. This situation requires the attention of policy makers.

According to our findings, TE increases with farm size. Therefore, it is important that organic dairy farms also increase their scale and become more efficient. In addition to farm payments that compensate productivity differences, it is therefore also important to implement policy measures that facilitate the development of organic farms.

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Appendix

Variable	Unmatched	Mean		t-test	
	Matched	Treated	Control	t	p > t
Age	U	53.723	53.394	0.648	0.91
	M	53.723	53.38	0.36	0.718
Owner	U	0.858	0.706	5.40	0.000
	M	0.858	0.844	0.47	0.636
Natura 2000	U	1.204	1.077	6.90	0.000
	M	1.204	1.192	0.36	0.717
Farm size	U	6.138	7.571	-9.01	0.000
	M	6.138	6.175	-0.22	0.822
Share of rented land	U	0.543	0.504	2.09	0.037
	M	0.5436	0.533	0.38	0.706
Share of paid labour	U	0.270	0.446	-6.55	0.000
	M	0.270	0.280	-0.30	0.763
Total subsidies	U	31370	62384	-4.93	0.000
	M	31370	32718	-0.29	0.769
39.id_county	U	0.186	0.014	14.85	0.000
	M	0.186	0.144	1.38	0.169
44.id_county	U	0.034	0.015	2.28	0.023
	M	0.034	0.035	-0.08	0.937
49.id_county	U	0.051	0.042	0.69	0.488
	M	0.051	0.058	-0.37	0.711
51.id_county	U	0.020	0.088	-3.97	0.000
	M	0.020	0.028	-0.59	0.557
57.id_county	U	0.048	0.062	-0.94	0.347
	M	0.048	0.063	-0.81	0.421
59.id_county	U	0.027	0.112	-4.45	0.000
	M	0.027	0.043	-1.02	0.309
65.id_county	U	0.010	0.036	-2.33	0.020
	M	0.010	0.014	-0.46	0.645
67.id_county	U	0.169	0.155	0.61	0.545
	M	0.169	0.180	-0.34	0.733
70.id_county	U	0.041	0.164	-5.52	0.000
	M	0.041	0.059	-0.98	0.326
74.id_county	U	0.179	0.078	5.60	0.000
	M	0.179	0.175	0.14	0.888
78.id_county	U	0.055	0.018	3.82	0.000
	M	0.055	0.049	0.31	0.759
82.id_county	U	0.038	0.058	-1.43	0.154
	M	0.038	0.034	0.21	0.838
84.id_county	U	0.062	0.044	1.33	0.185
	M	0.062	0.052	0.50	0.620
86.id_county	U	0.058	0.067	-0.56	0.577
	M	0.058	0.041	0.94	0.346

Source: Own estimations, data: Farm Accountancy Data Network (Estonia)

Table A1: Comparison of farm groups without and with matching

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Aid, Domestic Governance, and Agricultural Growth in Developing Countries

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Abstract

This study departed from other agricultural aid-growth studies by measuring growth as the annual growth rate of agricultural value added and accounting for the moderating role of governance on the aid-growth effect. Using data on a panel of 117 developing countries from 1996 to 2020, aid negatively influenced agricultural growth. Governance had a negative but insignificant independent effect on growth. However, the interaction of governance with aid turned the aid-growth effect from a significant negative to a statistically insignificantly positive effect. Since the low level of governance produced the positive interaction effect, of the aid-growth relationship, escalation of (good) governance could produce a strong effect.

Keywords

Agricultural aid, agricultural growth, aid-effectiveness, developing countries, governance.

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Introduction

The agricultural sector's growth is two to four times more effective in raising incomes among the poorest than other sectors, accounting for four per cent of global gross domestic product (GDP), and in some developing countries, representing more than 25% of GDP (International Development Agency, 2021). These notwithstanding, developing economies still rely on food imports with scarce foreign exchange with the associated logistical challenges. Supply shocks to the global food system such as the reduction in grain supplies from Ukraine and Russia due to the Russia-Ukraine conflict are evidence. Aside from foreign investment, developing countries have received foreign aid in the form of grants or loans at favourable rates, whose purpose is to finance programmes to improve living conditions in recipient countries (Alabi, 2014; Shaibu and Shaibu, 2022). Some of the specific uses include improved seeds and soils, roads to connect food production centres to markets, agribusiness credit and private sector investments, and training and technology transfer (Alabi, 2014). This helps start-up projects in sectors or areas that have been left behind (Shaibu and Shaibu, 2022).

The debate on aid effectiveness is not settled. Some have argued that aid enhances growth (Stiglitz, 2002; Stiglitz and Charlton, 2006). The proponents explain that financial flows in the form of development aid substitute for the lack of national savings that subsequently increase the stock of capital, which encourages investment by reducing rates and costs of loans. Thus, aid improves the living conditions and health of workers in the receiving countries, which transmits to the productivity and performance of employees in addition to promoting the exchange of knowledge and technology between rich and poor countries (Yahyaoui et al., 2019). Burnside and Dollar (2000, 2004) and Isham et al. (1997) noted that the positive effect of aid on growth is contingent on policies and institutions. Additionally, rampant inflation, unsustainable budget deficit or a situation of trade closure increases the risk of foreign support policies failing and requiring internal reform. On the other hand, Bauer and Yamey, (1982), Boone (1996), Mallik (2008) and Young and Sheehan (2014) have found a negative effect of aid on growth. They attributed this in large part to the lack of responsibilities of public officials seeking their interests in an environment of heavy corruption and bureaucracy (Yahyaoui et al., 2019). Others have taken a middle ground, that aid does not affect growth (Adedokun, 2017; Dowling and Hiemenz, 1982; Mosley, 1980; Singh 1985; Stiernstedt, 2010). The neutral effect can turn into a positive effect with the role of good governance (Adedokun, 2017; Stiernstedt, 2010). Governance is a complex interaction system between the structures, features and processes characterised by transparency, responsibility, and involvement (USAID, 2002). Viewed also as executive, economic, and political authority, it regulates the affairs of a country at every level. This includes articulating thoughts and exercising civil liberties (Awan et al., 2018; UNDP, 1997). The use of governance tools such as transparency, responsibility, and involvement must enhance the distribution and utilisation of foreign aid. In developing countries where corruption and poor governance is a concern for development partners, good governance in foreign aid will reduce corruption, encourage investment and ultimately, growth. The aid-growth effects described relate to the total economy. As the agricultural sector is the world's largest employer and with international goals to double income for smallholders (World Bank, 2022a), what is the effect of agricultural aid on agricultural growth in developing countries? Does governance moderate the aid-growth effect as in the case of Adedokun (2017) and Stiernstedt (2010)?

Hansen and Tarp (2001) split the aid-growth studies into three. The first is influenced by the Harrod-Domar model (Harrod, 1939; Domar, 1946), and the two-gap Chenery-Strout (Chenery and Strout, 1966) extension (Arndt, Jones, and Tarp, 2010). Underlying the Harrod-Domar model is a stable linear relationship between growth and investment in physical capital. If all aid is invested, one can calculate the aid required to attain a targeted growth rate. In this vein, the aid-growth relationship is positive. The second set of studies investigated the aid-investment-growth link directly and not through savings. This should lead to a positive link between aid and investment. The first two positions were, however, criticised. Easterly (1999, 2003) noted that growth is less related to physical capital investment than often assumed by the Harrod-Domar and two-gap approach. Also, the problem of endogeneity surfaced. That is, more aid will be induced by poor economic performance. Insights from new theories of economic growth also influenced the research agenda. The third recognised endogeneity and possible non-linear relationship between aid and growth (Veiderpass and Andersson, 2011). Other studies have noted the importance of the policy and governance environment within which aid-growth relationship occurs (Adedokun, 2017; Burnside and Dollar, 2000; Stiernstedt, 2010). The role of governance in managing foreign aid is expected to positively impact the aid-growth effect (Rodrik, 2000). Adedokun (2017) explained that good governance reduces rent-seeking activities and corruption, and thus encourages investment leading to growth.

Some gaps exist in the agricultural aid-growth literature. First, existing agricultural growth studies have measured agricultural growth as output, input utilisation and total factor productivity (Alabi, 2014; Gebremariam, 2018; Ighodaro and Nwaogwugwu, 2015; Kaya, Kaya, and Gunter, 2012; Shaibu and Shaibu, 2022; Waya, 2020). The estimated relationship does not adequately reflect the rate of change of the dependent variable due to aid. Second, although Aljonaid et al. (2022) measured growth as the annual growth of agricultural GDP, the study focused on sub-Saharan African countries. Third, neither the independent role of governance nor the interactive effect of the aid-growth effect was investigated in the agriculture studies. We fill these gaps by firstly, appropriately defining agricultural growth as change over time, measured as the annual growth rate of agricultural GDP. Secondly, we focus on developing countries. Thirdly, while we assess the effect of aid and governance independently on agricultural growth, we also studied the interaction effect of governance on the agricultural aid-agricultural growth relationship.

In filling these gaps, we used data on a panel of 117 developing countries from 1996 to 2020. Aid negatively influenced agricultural growth. The moderating effect of governance turned the negativity of the aid-growth effect into a positive but statistically insignificant one. Further enhancement in governance could cause a desirable significant effect.

Materials and methods

Models and modelling

Based on the objectives and the existing literature on the total economy (Abbas et al., 2022; Adedokun, 2017; Akramov, 2012; Djokoto, 2023a; Maruta et al., 2020; Mwakalila, 2019; Nwaogu and Ryan, 2015; Stojanov et al., 2013, 2019; Stiernstedt, 2010), we specify two equations:

$$GROWTH_{it} = \alpha_0 + \alpha_1 AID_{it} + \alpha_2 GG_{it} + \alpha_3 FDI_{it} + \\ + \alpha_4 DI_{it} + \alpha_5 INFRA_{it} + \alpha_6 INFLA_{it} + \alpha_7 TO_{it} + \\ + \alpha_8 POPG_{it} + \alpha_8 L.LNAGDP_{it} + \epsilon_{it} \quad (1)$$

To take account of the moderation role of *GG* on the growth effect of aid, an additional variable is created, the interaction of *AID* and *GG* to produce *AID x GG*. This is introduced into Equation 2 to yield Equation 3.

$$GROWTH_{it} = \beta_0 + \beta_1 AID_{it} + \beta_2 GG_{it} + \\ + \beta_3 AIDxGG_{it} + \beta_4 FDI_{it} + \beta_5 DI_{it} + \beta_6 INFRA_{it} + \\ + \beta_7 INFLA_{it} + \beta_8 TO_{it} + \beta_9 POPG_{it} + \\ + \alpha_{10} L.LNAGDP_{it} + \varepsilon_{it} \quad (2)$$

α_k and β_j are parameters to be estimated. *i* and *t* are respectively cross-section and time dimensions of the data, respectively. ε_{it} and ϵ_{it} are idiosyncratic error terms. The moderation of governance on the aid-growth effect is β_3.

GROWTH is agricultural growth, measured as the annual growth rate of agricultural value added in 2015 prices. This is the growth of real agricultural GDP. Economic growth has been measured similarly in the literature (Abbas et al., 2022; Maruta et al., 2020; Nwaogu and Ryan, 2015; Stojanov et al., 2013, 2019). *AID* is the net official development assistance and official aid received in current US dollars for all of agriculture, forestry, and fishing as a ratio of agriculture value added in current US dollars as used in the literature (Alabi, 2014; Djokoto et al., 2022; Gebremariam, 2018; Waya, 2020). *GG* is governance, measured with six indices, namely, political stability, corruption, government effectiveness, rule of law, regulatory quality and voice and accountability and composed into a single index as the average rank of each country in the panel for each year (Asongu and Nwachukwu, 2016; Boţa-Avram et al., 2018; Davis, 2017; Sarpong and Bein, 2021; Stojanović et al., 2016). The context of governance in this study relates more to domestic governance than international relations. *FDI* is foreign direct investment inflow into agriculture. Owing to limited observations at the data source, *FDI* was defined as 1 if the country received foreign direct investment in any year and 0 otherwise (Djokoto, 2023b). Foreign capital augments domestic agricultural capital. This should influence agricultural growth. The sum of equity capital reinvested earnings and other *FDI* capital is *FDI* (FAOSTAT, 2023a). DI is a domestic investment in agriculture, defined as gross fixed capital formation in agriculture to agricultural GDP. According to FAOSTAT (2023b), this covers costs such as the total value of a producer's acquisitions, disposals of fixed assets during the accounting period plus certain additions to the value of non-produced assets realised by the productive activity of institutional units. This is relevant for production. The proxy for infrastructure (INFRA) is the sum of mobile and fixed phone subscriptions per 1000 people. The original data was per 100 people. The expression in terms of 1000 people is necessary to reduce the size of the values to be comparable to those of the other variables. Infrastructure forms the backbone of an economy. *INFLA* is the annual growth rate of the consumer price index, inflation. An increase in inflation reduces the purchasing power of consumers and vice versa and can affect agricultural growth. *TO* is trade openness, computed as the sum of exports and imports divided by the gross domestic product, all measures for the agricultural sector. Beyond globalisation, trade is essential in providing both raw materials and semi and finished products for the agricultural sector. Thus, *TO* has implications for agricultural growth. *POPG* is the annual growth rate of the population of both sexes. Aside from providing manpower for the economy including the agricultural sector, population growth contributes to the market for agricultural products. Thus, POPG must have implications for agricultural growth. *L.LNAGDP* is the initial level of agricultural GDP. This is different from the one-year lag of *GROWTH*.

Data

Data on *AID, FDI, DI*, and ingredients for computing TO were obtained from FAOSTAT (2023c), whilst data on *GG, INFRA, INFLA* and *POPG* were sourced from the World Bank (2023). The variables, descriptions, measurement, and sources are summarised in Table 1. The data covered 1996 to 2020 for 117 developing countries listed in the appendix. The availability of *GG* data from 1996 limited the start date of the data else all others started from 1991. The observations totalled 2,645.

Variable	Description	Measurement	Source
GROWTH	Agricultural growth	Annual growth rate of agricultural value added in 2015 prices.	FAOSTAT (2023c)
AID	Aid to agriculture	Net official development assistance and official aid received in current US dollars for all of agriculture, forestry, and fishing as a ratio of agriculture value added in current US dollars	
FDI	Foreign direct investment inflow into agriculture.	FDI was defined as 1 if the country received foreign direct investment in any year and 0 otherwise.	
L.LNAGDP	Agricultural GDP	Initial level of agricultural GDP	
DI	Domestic investment in agriculture	Ratio of gross fixed capital formation in agriculture to agricultural GDP.	
GG	Governance indicator	Measured with six indices, namely, political stability, corruption, government effectiveness, rule of law, regulatory quality and voice and accountability and composed into a single index as the average rank of each country in the panel for each year.	World Bank (2023)
INFRA	Infrastructure	sum of mobile and fixed phone subscriptions per 1000 people.	
INFLA	Inflation	Annual growth rate of the consumer price index	
TO	Trade openness	The sum of exports and imports divided by the gross domestic product, all measures for the agricultural sector.	
POPG	Population	The annual growth rate of the population of both sexes.	

Source: FAOSTAT (2023c), World Bank (2023)

Table 1: Variables, descriptions, measurement, and sources.

Estimations and tests

Equations 1 and 2 were estimated using fixed effects (FE) and random effects (RE) estimators. The Hausman test (Hausman, 1978) was used to choose between the two. Appropriate tests were applied to test the possible violations of classical linear regression assumptions. Heteroscedasticity in the FE model was tested using the Modified Wald test for groupwise heteroskedasticity in the fixed effect regression model (Greene, 2000). In the case of RE, the Breusch and Pagan Lagrangian multiplier test for random effects (Breusch and Pagan, 1980) was employed. The Wooldridge test for autocorrelation in panel data (Wooldridge, 2002) was applied for both the FE and RE models. The variance inflation factor (VIF) was applied to test for multicollinearity. In line with the theoretical literature (Veiderpass and Andersson, 2011), endogeneity was suspected between *AID, FDI* and *DI* on one hand and *GROWTH* on the other hand. Hence, the general method of moments (GMM) was applied to equations 1 and 2 as a solution (Arellano and Bond 1991; Arellano and Bover, 1995). This approach was chosen because it is robust to heteroscedasticity and serial correlation (Anatolyev, 2005; Wooldridge, 2001).

Results and discussion

Background of the data

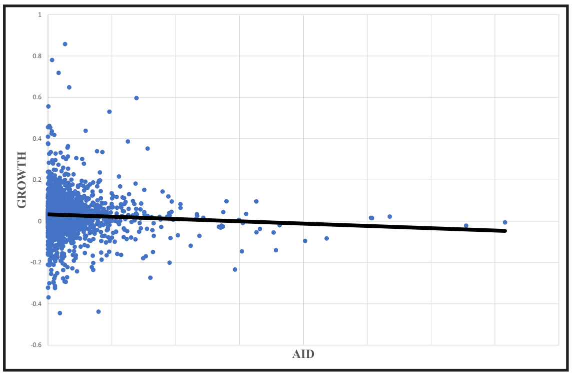
Agricultural growth recorded a minimum of -0.4449 (Central African Republic in 2013) and a maximum of 0.8573 (Palestine in 2004) (Table 2). The mean of 0.0300 coincided with that of Egypt, in 2013 and Indonesia in 2010. Some countries received zero aid whilst the country with the highest aid-to-agricultural GDP is Saint Kitts and Nevis with 0.7158 in 1998. This is not surprising because the Small States are heavily dependent on aid (Collier and Dollar, 1999, Narteh-Yoe et al., 2022) due to external shocks over which they have little or no control (World Bank, 2022b). The average of the governance indicator is 32.0980. This is less than half of the maximum of 74.0037 for Barbados in 2000. The minimum of 0.8818 is for Iraq in 2004.

Based on the literature, we assessed the non-linearity of the *AID- GROWTH* relationship. The trend line of the scatterplot of growth and aid

Variables	Observations	Mean	Standard deviation	Minimum	Maximum
GROWTH	2,645	0.0300	0.0857	-0.4449	0.8573
AID	2,645	0.0283	0.0476	0	0.7158
FDI	2,645	0.2378	0.4252	0	1
DI	2,645	0.0944	0.0531	0.0019	0.4318
INFRA	2,645	6.1717	5.2170	0	23.6958
INFLA	2,645	0.0944	0.8341	-0.1811	41.4511
TO	2,645	1.1468	2.4273	0	45.1502
POPG	2,645	0.0188	0.0125	-0.0514	0.1809
GG	2,645	32.1278	16.7760	0.8818	74.0037
AID x GG	2,645	1.0394	2.5557	0	41.9216
L1.LNAGGDP	2,528	21.1264	2.1426	14.9560	27.6940

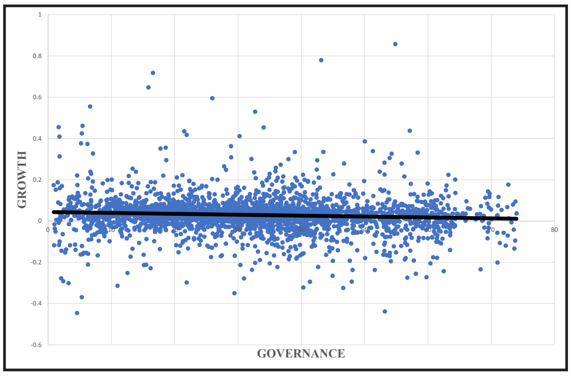
Source: Authors' elaboration

Table 2: Descriptive statistics.



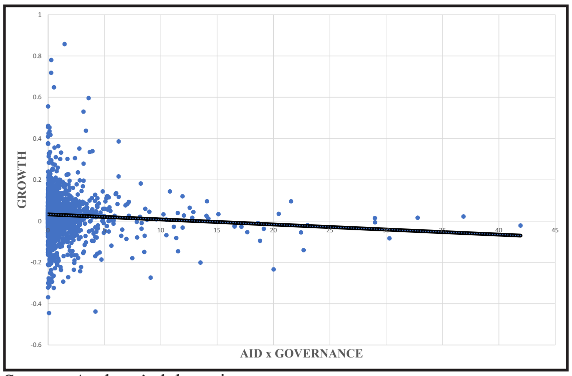
Source: Authors' elaboration

Figure 1: Scatter plot and trendline of growth and aid for developing countries.



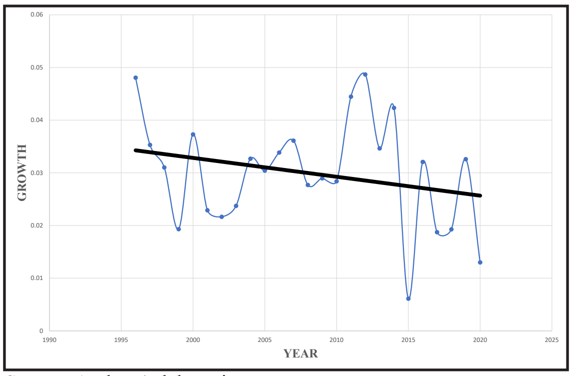
Source: Authors' elaboration

Figure 2: Scatter plot and trend line of growth and good governance of developing countries.



Source: Authors' elaboration

Figure 3: Scatter plot and the trend line of growth and interaction of aid and good governance in agricultural developing countries.



Source: Authors' elaboration

Figure 4: Scatter plot and the trend line of growth and interaction of aid and good governance in agricultural developing countries.

(*AID-GROWTH*) has a negative slope (Figure 1). That of growth and governance (*GG- GROWTH*) is also negatively sloping (Figure 2) but gentler than the previous. That of *AIDxGG -GROWTH* is also negatively sloping (Figure 3) but the strength of the slope appears to be between the other two (Figures 1 and 2). We did not find the non-linearity as pointed out by Veiderpass and Andersson (2011). From 1996 to 2020, growth has been declining based on the trend line in Figure 4. As the relationship captured by the trend lines is bivariate, the role of other variables that are known to explain growth is accounted for and reported in the next section.

Results

The results of the FE (model 1) and RE (model 2) are presented in Table 3.

	(1)	(2)
VARIABLES	*GROWTH*	*GROWTH*
AID	-0.0827* (0.0432)	-0.0784* (0.042)
GG	0.0002 (0.0004)	0.0002 (0.0002)
FDI	0.0006 (0.0058)	0.0035 (0.0055)
DI	-0.1381* (0.078)	-0.0636 (0.0647)
INFRA	0.0027** (0.0006)	-0.0006 (0.0004)
INFLA	-0.0191** (0.0094)	-0.0154* (0.0091)
TO	-0.0034** (0.0014)	-0.0027 (0.0013)
POPG	0.2565 (0.2341)	0.4046* (0.2151)
L1.LNAGGDP	-0.0280*** (0.0051)	0.0058** (0.0024)
Constant	0.6115** (0.1065)	0.1588*** (0.0517)
Model diagnostics		
Observations	2,527	2,527
Countries	117	117
F test	4.9300***	21.0800**
Heteroscedasticity test	3.3e+05 ***	0
Serial correlation test	4.0090**	
Multicollinearity test (VIF)	1.92	
Specification test (Hausman)	30.0100**	

Source: Authors' elaboration

Table 3: Fixed and random effects estimations and robustness of estimates of AID.

The Greene (2000) test for heteroscedasticity showed that the variances are not constant in the FE. For the RE model, the null hypothesis of the Breusch and Pagan (1980) test could not be rejected. Applying Wooldridge's test for autocorrelation in panel data (Wooldridge, 2002), the null hypothesis of no first-order serial correlation was rejected. Regarding multicollinearity, the highest VIF is 1.92, far less than the threshold of 10. The null hypothesis of the Hausman test (Hausman, 1978), the differences in coefficients are not systematic, was rejected. Thus, the FE is preferred to the RE. Notwithstanding preference for the FE, the estimates of *AID* and *GG* are similar in magnitude and statistical significance in the FE and RE models. This suggests the robustness of the key estimates to the estimators. Macroeconomic variables tend to present endogeneity problems. To account for this, the GMM was applied as it controls not only for endogeneity but is also robust to serial correlation and heteroscedasticity found in model 1 (Anatolyev, 2005; Wooldridge, 2001).

Table 4 presents an assessment of the robustness of the estimates of *AID* to the control variables. For models 3 – 12, the coefficient of *AID* is 0.10 with a negative sign. The standard errors range from 0.014 to 0.016. As a result, the null hypothesis that the estimates are statistically indistinguishable from 0 is rejected at least at a 1% level of probability. Thus, the estimates of *AID* are robust to estimators and control variables.

As noted earlier, some total economy studies have recognised the influences of governance on the aid-growth relationship. To assess this in the case of the agricultural sector, model 21 is estimated and the robustness of the estimates of *AID, GG*, and *AID x GG* to the control variables is assessed in models 13 – 20 (Table 5). The estimates of the three variables appear to be similar across all the models: magnitude, sign, and statistical insignificance of the coefficients.

	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
VARIABLES	*GROWTH*	*GROWTH*	*GROWTH*	*GROWTH*	*GROWTH*	*GROWTH*	*GROWTH*	*GROWTH*	*GROWTH*	*GROWTH*
L.GROWTH	-0.06950*** (0.01439)	-0.06953*** (0.01439)	-0.06913*** (0.01445)	-0.06972*** (0.01463)	-0.07083*** (0.01445)	-0.06927*** (0.01386)	-0.06997*** (0.01398)	-0.06870*** (0.01436)	-0.12383*** (0.01535)	-0.11068*** (0.01631)
AID	-0.18893*** (0.0235)	-0.18852*** (0.0235)	-0.18831*** (0.02345)	-0.19025*** (0.02333)	-0.18870*** (0.02305)	-0.20287*** (0.02432)	-0.18810*** (0.0231)	-0.18756*** (0.02359)	-0.17089*** (0.02926)	-0.17062*** (0.02886)
FDI		0.00698* (0.00423)								0.00529 (0.00454)
DI			-0.03012 (0.12668)							-0.06063 (0.11297)
INFRA				-0.00013 (0.00101)						0.00431*** (0.0009)
INFLA					-0.01335** (0.00607)					-0.02285*** (0.00809)
TO						-0.01834*** (0.00634)				-0.01641** (0.00708)
POPG							0.25429 (0.23926)			0.08799 (0.21298)
GG								-0.00019 (0.00054)		-0.00017 (0.00047)
L.LNAGGDP									-0.12843*** (0.0144)	-0.13166*** (0.01665)
CONSTANT	0.03720*** (0.00144)	0.03541*** (0.00171)	0.04020*** (0.01219)	0.03805*** (0.00665)	0.03835*** (0.00143)	0.05459*** (0.0062)	0.03237*** (0.0047)	0.04405** (0.0175)	2.79613*** (0.29676)	2.87415*** (0.34456)
Model diagnostics										
Observations	2,411	2,411	2,410	2,411	2,411	2,411	2,411	2,411	2,411	2,410
Countries	116	116	116	116	116	116	116	116	116	116
Prob. (AR(2))	0.5503	0.5595	0.563	0.5479	0.5386	0.4997	0.545	0.5544	0.0725	0.1042
Prob. Sargan	0.3036	0.3126	0.3107	0.3002	0.3341	0.2905	0.31	0.2964	0.6027	0.7264
Instruments	47	48	48	48	48	48	48	48	48	55

Note: *** p<0.01, ** p<0.05,*** p<0.10. Values in parenthesis are robust standard errors.

Source: Authors' elaboration

Table 4: Robustness of AID estimates to control variables.

	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)
VARIABLES	*GROWTH*	*GROWTH*	*GROWTH*	*GROWTH*	*GROWTH*	*GROWTH*	*GROWTH*	*GROWTH*	*GROWTH*
L.GROWTH	-0.06874** (0.01435)	-0.06875*** (0.01435)	-0.06858*** (0.01443)	-0.06883*** (0.01460)	-0.07017*** (0.01442)	-0.06906*** (0.01387)	-0.06930*** (0.01397)	-0.12317*** (0.01532)	-0.11076*** (0.01628)
AID	-0.13807 (0.14680)	-0.13887 (0.14699)	-0.14350 (0.14561)	-0.13614 (0.14761)	-0.13498 (0.14569)	-0.20639 (0.15371)	-0.13755 (0.14630)	-0.21448 (0.16487)	-0.23690 (0.17252)
GG	-0.00021 (0.00054)	-0.00023 (0.00054)	-0.00025 (0.00055)	-0.00020 (0.00054)	-0.00024 (0.00054)	-0.00014 (0.00052)	-0.00023 (0.00054)	-0.00013 (0.00046)	-0.00020 (0.00047)
AIDxGG	-0.00091 (0.00255)	-0.00090 (0.00255)	-0.00079 (0.00252)	-0.00097 (0.00256)	-0.00098 (0.00254)	0.00021 (0.00266)	-0.00090 (0.00254)	0.00076 (0.00278)	0.00121 (0.00294)
FDI		0.00701* (0.00424)							0.00533 (0.00454)
DI			-0.04126 (0.12981)						-0.05455 (0.11180)
INFRA				-0.00005 (0.00101)					0.00431*** (0.00088)
INFLA					-0.01357** (0.00609)				-0.02265*** (0.00806)
TO						-0.01851*** (0.00629)			-0.01620** (0.00705)
POPG							0.25227 (0.22858)		0.08070 (0.21185)
L.LNAGGDP								-0.12892*** (0.01426)	-0.13184*** (0.01654)
CONSTANT	0.04444** (0.01734)	0.04327** (0.01741)	0.04979*** (0.01726)	0.04411** (0.01893)	0.04649*** (0.01730)	0.06064*** (0.01795)	0.04013** (0.01749)	2.81262*** (0.29501)	2.87962*** (0.34174)
Observations	2,411	2,411	2,410	2,411	2,411	2,411	2,411	2,411	2,410
Countries	116	116	116	116	116	116	116	116	116
Prob. (AR(2))	0.5559	0.5648	0.5679	0.5559	0.5422	0.4998	0.5495	0.0737	0.1045
Prob. Sargan	0.2925	0.3025	0.2987	0.2910	0.3250	0.2653	0.2980	0.6031	0.7284
Instruments	49	50	50	50	50	50	50	50	56

Note: *** p<0.01, ** p<0.05,*** p<0.10. Values in parenthesis are robust standard errors.

Source: Authors' elaboration

Table 5: Robustness of estimations for moderating effect of governance to control variables.

Discussion of control variables

The coefficients of *FDI, DI* and *POPG* are not consistent across all six models (Table 6).

	(12)	(21)
VARIABLES	*GROWTH*	*GROWTH*
L.GROWTH	-0.11068*** (0.01631)	-0.11076*** (0.01628)
AID	-0.17062*** (0.02886)	-0.23690 (0.17252)
GG	-0.00017 (0.00047)	-0.00020 (0.00047)
AIDxGG	-	0.00121 (0.00294)
FDI	0.00529 (0.00454)	0.00533 (0.00454)
DI	-0.06063 (0.11297)	-0.05455 (0.11180)
INFRA	0.00431*** (0.00090)	0.00431*** (0.00088)
INFLA	-0.02285*** (0.00809)	-0.02265*** (0.00806)
TO	-0.01641** (0.00708)	-0.01620** (0.00705)
POPG	0.08799 (0.21298)	0.08070 (0.21185)
L.LNAGGDP	-0.13166*** (0.01665)	-0.13184*** (0.01654)
CONSTANT	2.87415*** (0.34456)	2.87962*** (0.34174)
Model diagnostics		
Observations	2,410	2,410
Countries	116	116
Prob. (AR(2))	0.1042	0.1045
Prob. Sargan	0.7264	0.7284
Instruments	55	56

Note: *** p<0.01, ** p<0.05,*** p<0.10. Values in parenthesis are robust standard errors.

Source: Authors' elaboration

Table 6: Final estimations of aid on agricultural growth and the mediating role of governance.

The results of *INFRA* suggest a positive effect on agricultural growth. This is expected as infrastructure facilitates input supply, production, and marketing of agricultural produce. Although this proxy, subscription of fixed and mobile phone lines per 1000 people is for the total economy and not for agriculture alone, with changes in technology, there is high penetration of mobile phone technology. Thus, the positive sign of INFRA is understandable. Inflation (INFLA) hurts agricultural growth, consistent with Kaya et al. (2012) but contrary to the findings of Adedokun (2017). Inflation reduces the purchasing power of the domestic currency. A decrease in the purchasing power of the currency would reduce investment, and how much food consumers can purchase which will ultimately reduce agricultural growth. *TO* is negative and statistically significant. This departs from the positive and statistically significant effect found by Adedokun (2017). The coefficient of the initial level of agricultural *GDP* (*L.LNAGGDP*), is negative and significant statistically. This means that as the initial agricultural GDP declines, agricultural output grows. This is logical because the increase in growth suggests current output is greater than the previous output.

Discussion of aid and governance effects on growth

The magnitude of the *AID-GROWTH* effect is negative and statistically significant. This implies a one US dollar increase in aid to agriculture will decrease agricultural growth by 0.17% (Table 7).

Effect	Student t-test	Wald test
Aid	-0.17062*** (0.02886)	34.9516***
Interaction effect of governance on aid-growth effect	0.0012 (0.0029)	0.1712

Note: *** p<0.01, ** p<0.05,*** p<0.10. Values in parenthesis are robust standard errors.

Source: Authors' elaboration

Table 7: Estimates of the growth effect of aid and the moderating role of good governance.

Aid in the form of financial resources is completely fungible whilst that as material could also be used for purposes other than what is intended. In the presence of corruption, which is high in some developing countries, both financial and material aid does find its way into anon-agricultural uses. The tendency to divert agricultural aid is further fuelled by the high level of poverty in developing countries. Although these areas may still be within the economy, as long these are not within the agricultural sector, the effect of agricultural aid would not be realised, hence the negative effect. The negative effect conforms to the relationship in Figure 1. As shown in Figure 3, growth decreased over time from 1996 to 2020. Thus, although *AID* may have increased, growth decreased. This is consistent with the use of agricultural GDP growth at constant 2015 prices as the dependent variable. It is worth noting that Adedokun (2017) and Stiernstedt (2010) found a negative but statistically insignificant effect, whilst Aljonaid et al. (2022) reported a positive effect. Kaya et al. (2012) found a positive effect of agricultural aid on economic growth in developing countries.

The magnitude of the interaction effect has turned positive following the moderation with governance. However, the magnitude is statistically indistinguishable from zero. The positive sign can be attributable to the influence of governance. The almost flat curve of the governance-growth relationship (Figure 2) may have influenced the results. Although the curve in Figure 3 slopes negatively and gently, the influence of the control variables and the governance factor caused the switch in sign. The statistical insignificance is due to the high standard errors of the GG coefficient in model 21. Whilst the effect of governance, a national indicator switched the sign of the interaction of the aid-growth effect, the influence is not sufficient to produce a statistically significant coefficient in the agricultural sector. Considering that the low mean governance rank of 32 produced a positive moderating effect, an enhanced level of governance can result in a statistically significant effect. The positive sign of the interaction effect is in line with the assertions of Rodrik (2000), albeit insignificant in our case. Developing countries can thus promote governance. Following this, its moderating effect is beneficial to the aid-growth relationship but weak. Our finding is consistent with the positive effect of Adedokun (2017) but departs from it based on the statistical significance. However, Stiernstedt (2010) found a positive and significant effect of the moderation role of governance.

Conclusion

This study departed from other agricultural aid-growth studies by measuring growth as the annual growth rate of agricultural GDP and accounting for the moderating role of governance on the aid-growth effect. Aid negatively affected growth. Governance had a negative but insignificant independent effect on growth. Consequently, aid is not a good stimulus for agricultural growth just as governance is not. However, the influence of governance turned the aid-growth effect from negative to positive albeit still statistically insignificant. Considering that developing countries generally measure low on governance, which produces a positive but insignificant effect, significant enhancement in governance could have a significant effect. . Governments in developing countries must accelerate governance beyond the current levels. As corruption has been concern in developing countries, reducing corruption through enhanced good governance would have a collateral effect on the aid-growth nexus. Infrastructure should be enhanced. This will not only benefit the agricultural sector but the larger economy. Although the agricultural growth has been associated with some level of inflation, reducing inflation, which is a macroeconomic goal, will also enhance agricultural growth. Further research can explore the agricultural aid-growth effect for transition countries. As this study used agricultural aid, recognising other types of agricultural aid could be interesting.

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A Crude Palm Oil Industry Concentration and Influencing Factors: A Case Study of Indonesia as the World's Largest Producer

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Abstract

The Crude Palm Oil (CPO) industry is one of the plantation commodities that has a strategic role in Indonesia's economic development. The number of companies and CPO production is always increasing, but the concentration of the industry that always decreases every year makes it important to analyze the factors that affect the concentration of the CPO industry in Indonesia. The data period used in this study was from 2001 to 2020. In this study, data sources were obtained from the Central Bureau of Statistics (BPS) Indonesia, Word Bank, and UN Comtrade. The data analysis method used is regression analysis of the Error Correction Model (ECM). The results showed that technical efficiency has a negative and significant relationship both in the long and short term to the concentration of the CPO industry. Competitiveness in the long term has a positive and significant relationship, while in the short term it is negative but not significant to the concentration of the Indonesian CPO industry. In the long run, the relationship between RSPO and Indonesia's CPO industry concentration tends to be negative but not significant, while in the short term it shows a significant influence. World CPO prices, both long-term and short-term, provide a positive and significant correlation to the concentration of the Indonesian CPO Industry. Indonesia's CPO exports in the long and short term have a negative and significant effect on the concentration of the Indonesian CPO industry.

Keywords

Error Correction Model (ECM), Crude Palm Oil (CPO), Industrial concentration, competitiveness, technical efficiency, policy.

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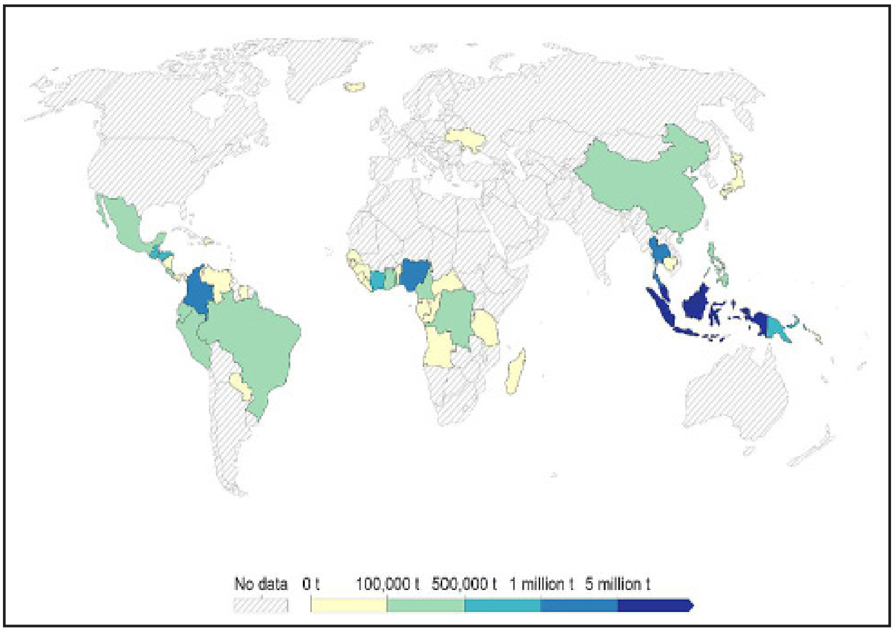
Introduction

Crude Palm Oil (CPO) is an important vegetable oil in the global fats and oils market and its industry is also one of the leading global agricultural industries (Ahmed et al., 2015). World CPO production has grown steadily and relatively faster than oil-producing crops Vegetable Other. Industry Crude Palm Oil (CPO) is one of the plantation commodities that has a strategic role in Indonesia's economic development. Based on Figure 1, Indonesia as the world's largest CPO producer controls 56 percent of total global exports, export capacity is 72 percent of total production in 2020. This industry is able to absorb the production of smallholders, improve the welfare of independent oil palm farmers, and increase foreign exchange earnings for the country (Tiku and Bullem, 2015). Palm oil products and derivatives have been utilized by various industrial sectors, ranging from the food, beauty, pharmaceutical, to energy industries (Ministry of Industry, 2022). Indonesia's CPO export destination countries such as India, China, Pakistan and Bangladesh are very dependent on CPO which is the region where most of the world's population is located (Ali, 2019).

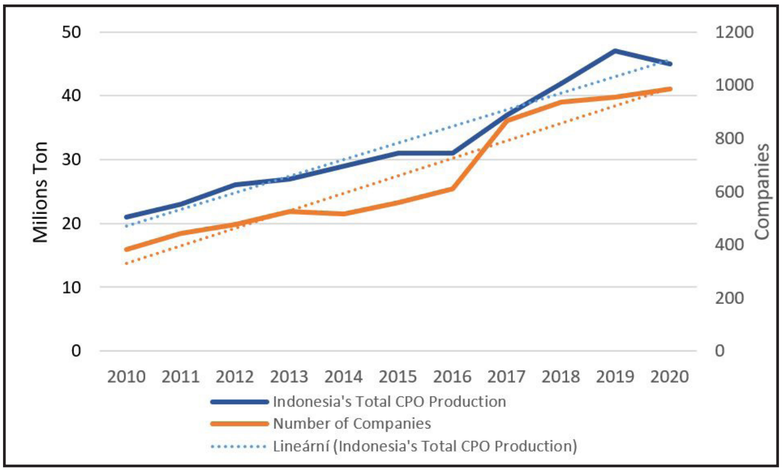
According to Carlton and Perloff (2005) and Scherer (1980), one of the determining factors of industry concentration is the number of sellers. Based on Figure 2, the number of companies and Indonesia's CPO production always increases. The more sellers there are in the CPO Industry the lower the concentration of the industry and the more balanced the market forces.

Industry concentration is also closely related to international competition. Industry concentration is important in international competition for several



Source: Food and Agriculture Organization of the United Nations

Figure 1: World CPO producer.



Source: Central Bureau of Statistics (2022)

Figure 2: Number of companies and total production of indonesian CPO.

reasons (Porter, 1990). First, it creates different requirements for success in different industries. Industries of concentration interest create ongoing barriers to entry in areas such as technology, specific skills, access, and reputation. Changes in concentration, can create genuine opportunities for competitors from a country to penetrate new industries (Surugiu, 2015). The effect of competitiveness on industrial concentration has been studied previously by Ergashxodjaeva et al., (2018) and Pomarici et al. (2021) which results in competitiveness affecting concentration.

The improvements in technical efficiency and economies of scale that occur in the CPO industry can Impact on industrial concentrations. When CPO companies are more efficient and have economies of scale, they can produce more products at lower production costs. This can help lower CPO prices globally and make it difficult for small, less efficient competitors to compete. As a result, large companies with high technical efficiency and economies of scale will become major players in the CPO industry, and industry concentration may be lower as small competitors find it difficult to survive. The influence between technical efficiency and industrial concentration has been studied by Setiawan et al. (2012).

The concentration and performance of the CPO Industry has always been an interesting study in empirical analysis, especially in terms of supporting sustainability through policy implementation. Porter (1990), and Carlton and Perloff (2005) suggests that policies can affect the concentration of an industry. In addition, the findings were also revealed in the study Dechezlepr (2017) and Lu et al. (2015). The CPO industry is faced with various challenges, including negative impacts on the environment and human rights violations. Therefore, efforts are needed to overcome this problem and promote sustainable and environmentally friendly CPO production. One of them is the development of sustainable certification policies through the Roundtable on Sustainable Palm Oil (RSPO) as a form of implementation of global standards for sustainable palm oil since 2008. The high cost of implementing RSPO can negatively impact the concentration of the CPO industry.

Some research results mention that product prices greatly affect industry concentration, this finding by Bonny (2017) and Clapp (2021). The CPO industry is a very competitive market and CPO prices are one of the main factors in determining a company's profits and market share. Companies that can offer lower CPO prices can have a competitive advantage and tend to have a larger market share, while companies with higher CPO prices may struggle to compete and tend to have a smaller market share. Therefore, fluctuations in CPO prices can affect the concentration of the CPO industry and determine the survival of companies in the CPO industry.

The concentration of the industry is strongly influenced by the export capacity of the product. High export capacity enables the company to export products to international markets and expand market share. Thus, the domestic market will not be the only market that companies in the CPO industry can tap into. In the long run, high export capacity can encourage the entry of new players into the CPO industry, which can reduce industry concentration. This has been researched by Awalludin et al. (2015) and Tanner et al., (2017). Therefore, we answer the following questions:

What is the concentration of Indonesia's CPO industry?

How does the effect of technical efficiency, competitiveness, RSPO policy, CPO price, and CPO Export affect the concentration of Indonesia's CPO industry?

Literature review

According to Bain (1956), concentration ratios are an important element in studying market structure. It signifies the extent to which companies in the industry hold market power. Companies with a high level of market power have the ability to raise prices and earn high profits in the process. Market share is often used to illustrate the level of market power a company has in an industry (Loecker et al., 2020). In analyzing the behavior of firms in the market, particularly as seen in oligopoly industries, firms compete with each other in building market power by gaining more market share. By increasing their market share, established companies prevent the entry of potential entrants following the studies contributed by Geras'kin and Chkhartishvili (2017), Tandra et al. (2022) and Hu et al. (2014).

According to Carlton and Perloff (2005), there are two models of approach in market research; the first is the Structure, Conduct and Performance (SCP) approach, which is generally used to describe market models. In the approach of the traditional New-Harvard SCP model, each component interacts with each other, as, market performance depends on market behavior. Furthermore, the market structure depends on fundamental factors, namely demand and production, including demand, substitution, seasonality, economic growth rate, location, number of orders, development methods and technologies, raw materials, product consistency, product elasticity, location, economies of scale and economic reach. The basic conditions of structure, conduct, performance affect government policy.

Economists have used a number of alternative centers in measuring industrial levels. To assist users in making informed choices among available alternatives in Lipczynski et al. (2017) suggests a number of general criteria that a particular concentration measure must meet if it is to adequately reflect the most important characteristics of the company's size distribution.

The issue of measuring market concentration has always attracted the attention of the scientific and professional community. According to Pavic et al. (2016), in a market economy, some firms do not have the ability to influence the price of their products, while other firms have the ability to influence the prices of their products.

In theory and practice, different measures of market concentration are known. Some of the steps are very simple and easy to understand, and therefore used very widely using the concentration ratio (CR). Concentration ratio provides a useful and practical indicator of market strength (Wang and Shailer, 2015). Since these indices are market-based values, they are much more useful when a company's strength in the market is determined along with other data (Ukav, 2017).

By Bikker and Haaf (2002), if the value of CR = 0 percent, the market is in a state of perfect competition, if it is between 0-50 percent, the market is perfectly competitive towards oligopoly, if CR is 50-80 percent, the market is identical to oligopoly, if CR 80-100 percent belongs to oligopoly towards monopoly, and if CR is equal to 100 percent-monopoly market. Furthermore, according to Tremblay (2012) if the CR value is between 0-40 then it is classified as a perfectly competitive market.

Naldi and Flamini (2014) it uses concentration ratio to measure how a quantity is distributed among a number of subjects (individuals or aggregates, such as households or firms). Market concentration is an important indicator to see market structure and level of competition, one of which is research Nendissa et al., (2019) analyze the CR4 of beef cattle farming industry. Research Napasintuwong (2017) analyzed the concentration of the corn seed industry and found that the market share of corn seeds in Thailand is quite concentrated with a tendency towards oligopolistic competition. Deconinck (2020) analyze the market concentration in China's seed and agricultural biotech market. Baker and Friel (2016) researched the concentration of the ultraprocessed food market in Asia. Research Outreville (2015) examine the relationship between market structure and performance in the wine sector using data from two Canadian provinces.

Materials and methods

The scope of this research is the Crude Palm Oil (CPO) industry. The industry category in this study is from the 2020 Indonesian Business Field Standard Classification (KBLI) with code 10432. The data period used in this study was from 2001 to 2020. The data used in this study are secondary data, including Indonesian CPO industry data, such as Indonesian CPO export data, the number of Indonesian exports, Indonesian cooking oil prices, while the international data used include world CPO exports, world exports, international CPO prices, and the Roundtable on Sustainable Palm Oil (RSPO) policy. In this study, data sources were obtained from the Central Bureau of Statistics (BPS) Indonesia, the Commodity Futures Trading Supervisory Agency (BAPPEPTI), Wordbank, UN Comtrade, the Ministry of Industry of the Republic of Indonesia, as well as factual supporting data from books and journals.

The data analysis method used is regression analysis of the error correction model (ECM). The use of this technique aims to explain whether or not there is an influence of the independent variable on the dependent variable in the short and long term (Banerjee et al., 2016). The ECM model is a model used to find long-term and short-term equilibrium regression equations and whether or not a model is consistent. The regression model used is as follows:

Long-term equation model:

$$CR4_t = \beta_0 + \beta_1 E_t + \beta_2 RCA_t + \beta_3 RSPO_t + + \beta_4 PCPO_t + \beta_5 PCO_t + \beta_6 XCPO_t + e_t \quad (1)$$

Short-term equation model:

$$\Delta CR4_t = \beta_0 + \beta_1 \Delta E_t + \beta_2 \Delta RCA_t + \beta_3 \Delta RSPO_t + + \beta_4 \Delta\_PCPO_t + \beta_5 \Delta\_PCO_t + \beta_6 \Delta\_XCPO_t + + \beta_7 ECT_t + e_t \quad (2)$$

where:

e = technical efficiency,
RCA = competitiveness,
$RSPO$ = Roundtable on Sustainable Palm Oil Policy,
$PCPO$ = CPO Price,
PCO = Cooking Oil Price,
$XCPO$ = Indonesian CPO Exports, Constant, Regression direction coefficient,
and ECT = Error Correction Term,
e = error term.
β_0 = intercept; $\beta_{1,2,3,4,5,6,7}$ = Coefficient of regression direction; and ECT = Error Correction Term

Variable	Definition	Formula	Source
Concentration Ratio Four Biggest Firm (CR4)	A measure of market concentration that calculates the combined market share of the four largest companies in a given industry.	$CR_n = \sum_{i=1}^{n} \frac{X_i}{T_j}$	Central Bureau of Statistics Indonesia
Technical Efficiency is measured using the Stochastic Frontier Analysis method	Econometric methods are used to measure the technical efficiency of an organization or company by considering uncontrollable factors such as environmental factors, government policies, and luck factors. In stochastic frontier analysis, technical efficiency is measured by comparing the actual output produced with the expected or optimal output.	$\ln Y_t = \beta_0 + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \beta_3 \ln X_3 + + \beta_4 \ln X_4 + \beta_5 \ln X_5 + (Vi\text{-}Ui)$ Information: $\ln Y_t$ = Total amount of production; β_0 = Constant; β_i = Elasticity of production of the I^th CPO manufacturing factor of production; $\ln X_1$ = Labor; $\ln X_2$ = raw material; $\ln X_3$ = Capital; $\ln X_4$ = fuel oil; $\ln X_5$ = Electricity; $Vi\text{-}Ui$ = error term (Vi is the noise effect, Ui is the effect of technical inefficiencies in the model.	Central Bureau of Statistics Indonesia
Competitiveness (RCA)	Competitiveness is the ability of companies, regions, countries, or between regions to increase income by utilizing productive and sustainable labor and other resources to face competition by maximizing the potential of their superior products (Porter, 1990: 6).	$RCA = \left(\frac{X_{IK}}{X_{IM}}\right) / \left(\frac{X_{WK}}{X_{WM}}\right)$	UN Comtrade
Roundtable on Sustainable Palm Oil (RSPO)	RSPO is certified to promote sustainable palm oil production by developing and promoting environmentally friendly, social, and economic practices.		
International CPO Price	International CPO price refers to the price of crude palm oil traded on the international market		World Bank
Packaged Cooking Oil Price	The price of Indonesian packaged cooking oil refers to the price of cooking oil packaged in ready-to-use packaging and produced in Indonesia.		Central Bureau of Statistics Indonesia
Indonesia's CPO Export Value	Indonesia's CPO export value is the total value of all palm oil (CPO) exports made by Indonesia in a certain period of time. This value includes the selling price of CPO and its derivative products, minus export costs such as shipping costs, insurance, and export duties.	CPO Export Value = CPO export volume x CPO Export Price - Export Cost	UN Comtrade

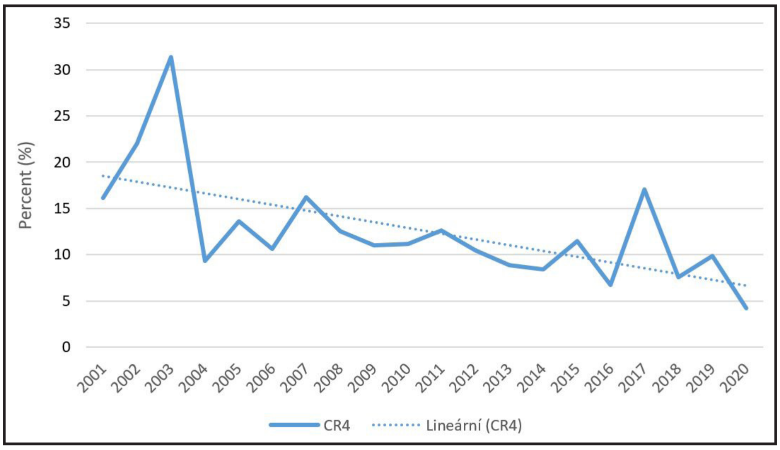
Source: Indonesian Central Bureau of Statistics, Worldbank, UN Comtrade, 2023

Table 1: Variable operational definition.

Results and discussion

Industrial concentration (CR4)

Based on Figure 3, industrial concentration (CR4) always decreases every year. The increasing number of companies entering the CPO industry and the tighter competition can cause a decrease in industry concentration (Frenken et al., 2014). This happens because the existence of new competitors can reduce the market share of existing companies and encourage healthier competition among CPO companies (Hidayat et al., 2023). The Indonesian government has issued several regulations and policies aimed at encouraging the existence of smaller and more sustainable CPO companies (Singh and Setiawan, 2013). One example is the smallholder oil palm policy which provides opportunities for oil palm farmers to manage their own oil palm plantations. This can reduce the dominance of large companies and increase the number of smaller CPO companies.



Source: Data Processed, Central Bureau of Statistics Indonesia, 2001-2020

Figure 3: CR4 Movement of Indonesian CPO industry in 2001-2020.

The increasingly unconcentrated CPO industry can have a negative impact on production efficiency, land and environmental exploitation, and labor welfare (Otieno et al., 2016; Abdul-hamid et al., 2021). One of the impacts of the increasingly unconcentrated CPO industry is the lack of efficiency in production (Avdelas et al., 2021). When the concentration of the CPO industry is getting lower, it means that more producers are competing in the market (Gosens and Lu, 2014). This causes producers to tend not to have strong control over the selling price of their products, making it difficult for them to set higher prices. This condition makes producers try to reduce production costs in order to remain competitive in the market.

The CPO industry is also known for its overexploitation of land. The CPO industry is often associated with overexploitation of land, especially in terms of deforestation and forest degradation (Kyere-Boateng and Marek, 2021). In general, the land used for oil palm plantations is natural forest that is logged and converted to plantation land (Khatun et al., 2020). This practice can cause damage to ecosystems and loss of natural habitats for flora and fauna, including endangered species such as Sumatran tigers and orangutans. Deforestation and forest degradation can also have a negative impact on the global climate, as tropical forests store large amounts of carbon in biomass and soil (Bustamante et al., 2016). When forests are cut down, carbon stored in soil and biomass can be released into the atmosphere, causing greenhouse gas emissions that contribute to climate change. In addition, the CPO industry is also often criticized for excessive use of pesticides and herbicides, which can pollute soil and water and negatively impact human health and the environment (Pretty and Bharucha, 2014). Therefore, efforts need to be made to reduce the use of harmful chemicals in CPO production, including by promoting environmentally friendly and sustainable agricultural practices.

The labor problem is also a result of the increasingly unconcentrated CPO industry. In the increasingly unconcentrated CPO industry, there are usually many small companies or individuals involved in the production process. However, due to the large amount of production and the need for a considerable amount of labor, often the workers involved in the CPO industry are employed illegally and do not have adequate legal protection (Azhar et al., 2017). The impact of the lack of legal protection and labor rights includes frequent cases of labor exploitation, low wages, and working in unsafe and unhealthy conditions (Min et al., 2019). In addition, there are also problems such as forced labor and child labor that are the result of the lack of supervision and regulation of the increasingly unconcentrated CPO industry (Abrams and Selfa, 2022). Labor issues related to the CPO industry can also have an impact on the sustainability of the industry. If these problems are not immediately addressed, there will be a decrease in productivity and quality of production, which in turn can affect the competitiveness of the CPO industry in the global market. Therefore, appropriate measures are needed to address labor issues in the CPO industry, such as adequate legal protection for workers and stricter regulations to prevent illegal practices and labor exploitation.

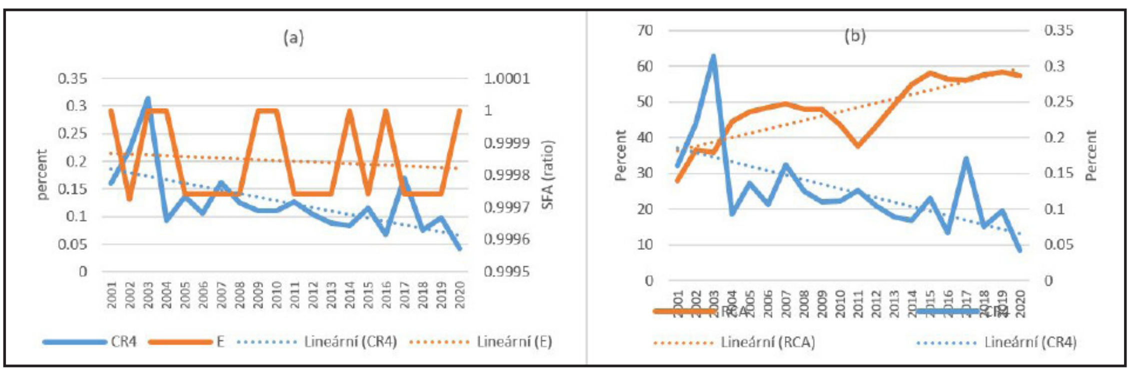
Movement of variables independent of industry concentration

Based on Figure 4a, the technical efficiency of the Indonesian CPO industry has a downward trend every year or is getting farther away from value 1 which means that the industry is increasingly inefficient. Although Indonesia is the largest CPO producer in the world, the technology used in CPO production in Indonesia is still relatively lagging when compared to other countries (Iskandar et al., 2018). This may affect the technical efficiency of the CPO industry and reduce the concentration of the CPO industry. Changing government policies, such as tax or regulatory changes, can affect the technical efficiency of the CPO industry and the concentration of the CPO industry (Papilo et al., 2022). This condition supports and is in line with the analysis in the previous section.

The movement of the competitiveness variable (RCA) of the CPO industry in Indonesia tends to fluctuate in the period 2001-2020 (Figure 4b), although there is an increasing trend over the study period. It can be seen that the highest increase in the competitiveness of the CPO industry in Indonesia occurred in 2014 with a percentage increase of 10.31 percent. While the highest decline occurred in 2011 with a percentage decrease of 15.7%. This happened because the price of CPO in the international market decreased in 2011 (Gan and Li, 2014). This can have a negative impact on the competitiveness of the CPO industry in Indonesia, and reduce the concentration of CPO.

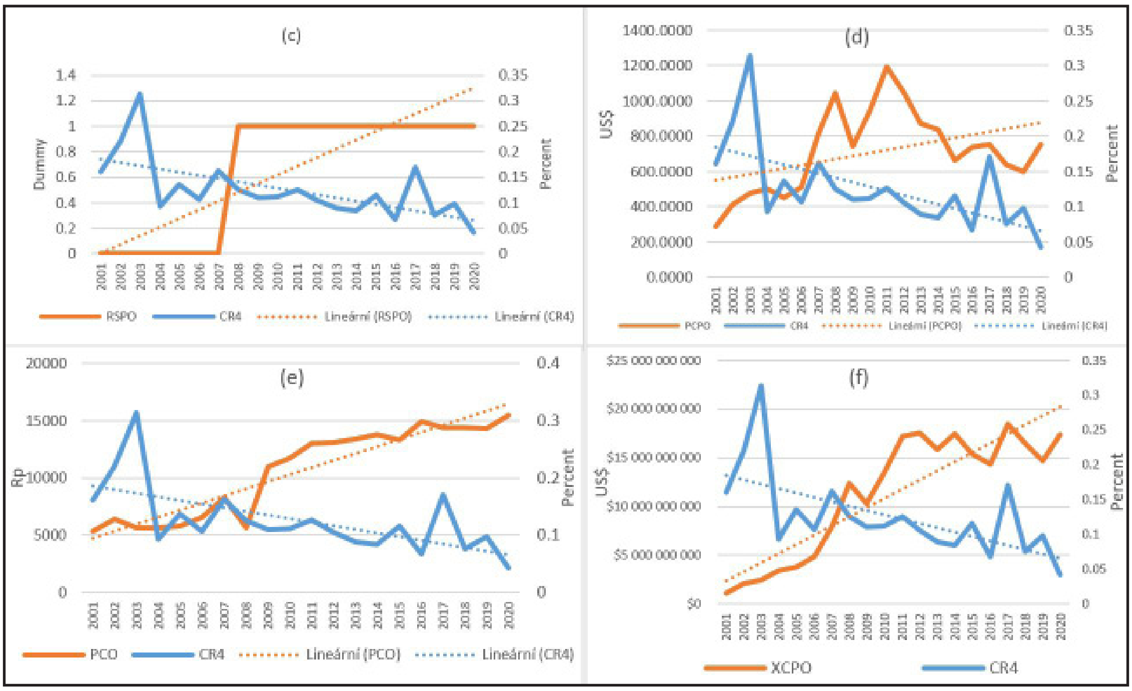
Several policies in overcoming environmental issues caused by palm oil production include the development of sustainable certification through the Roundtable on Sustainable Palm Oil (RSPO) as a form of implementation of global standards for sustainable palm oil since 2008 (Schouten and Glasbergen, 2011). Based on Figure 4c in 2008, when RSPO was introduced into the CPO industry, the concentration of the CPO industry decreased slightly. The RSPO requires that palm oil producers must meet certain sustainability standards in their production, such as not damaging the environment and complying with human rights. Implementation of these requirements entails additional time and costs for producers, and leads to temporary production reductions or production cuts in some companies that are unable to meet sustainability standards (Angulo-Mosquera et al., 2021).

Based on Figure 4d, in years where the concentration of the CPO industry rises, CPO prices tend to rise. This is due to the increase in demand for CPO when the CPO industry is growing and increasing production. The highest increase in CPO prices in 2011, this happened because increased demand from countries such as India and China became the main factor in the increase in CPO prices (Zulqarnain et al., 2020). Both countries are the largest consumers of crude palm oil in the world. World crude oil prices also increased in 2011, which affected the increase in CPO prices. World CPO prices can fluctuate because they are influenced by several factors such as global demand, production, currency exchange rates, and competition with other vegetable oils. High or low demand and production can affect the availability of CPO supply and ultimately affect prices. In addition, currency exchange rates can also affect CPO prices because world CPO trading is carried out in US dollars (Halimatussadiah et al., 2021). Competition between CPO and other vegetable oils can also affect CPO prices (Johari et al., 2015). If the price of other vegetable oils is cheaper, then consumers tend to switch



Source: Indonesian Central Bureau of Statistics and World Bank, data processed (2001-2020)

Figure 4: movement of variables independent of industry concentration. (To be continued).



Source: Indonesian Central Bureau of Statistics and World Bank, data processed (2001-2020)

Figure 4: movement of variables independent of industry concentration. (Continuation).

to these vegetable oils and influence the price of CPO. Therefore, changes in these factors can affect fluctuations in world CPO prices.

The highest increase in cooking oil prices in 2016 occurred because the increase in world crude oil prices in early 2016 affected the increase in packaged cooking oil prices in Indonesia. World crude oil is the main raw material for making packaged cooking oil. The increase in fuel oil prices in 2016 also affected the increase in the price of packaged cooking oil. The increase in fuel prices causes an increase in transportation and distribution costs, thus affecting the increase in the price of final products. Fluctuations in the rupiah exchange rate against the US dollar also affect the increase in the price of packaged cooking oil. If the rupiah exchange rate weakens against the US dollar, then the price of imported packaged cooking oil will rise because import costs to be paid in dollars become more expensive. In addition, it can be seen that the concentration of the CPO industry has an opposite trend to the price of cooking oil (Figure 4e). This can be explained by the fact that cooking oil is a derivative product of CPO. The higher the concentration of the CPO industry, the more CPO produced, so the supply of cooking oil also increases (Mosarof et al., 2015). The increase in supply can cause cooking oil prices to fall if demand does not increase along with the increase in supply, but if demand remains high, then cooking oil prices can rise along with the increase in CPO industry concentration.

Indonesia's CPO exports show an increasing upward trend from year to year as seen from Figure 4f, although there are fluctuations in certain years. In 2020, Indonesia's CPO export value reached $17.36 billion, a significant increase from 2019 which reached $14.72 billion. The highest increase in CPO exports occurred in 2017. 2017 was a year where international market demand for CPO was quite high, especially from countries such as India, China, and the European Union (Naylor and Higgins, 2017). This causes CPO producers in Indonesia to increase their production and increase CPO exports. The Indonesian government provides policies to encourage CPO exports, such as reducing CPO export taxes and providing incentives for CPO producers (Naylor and Higgins, 2018). This policy increases CPO exports and encourages the growth of the CPO industry in Indonesia. This positive trend shows that Indonesian CPO is still an important export commodity and has the potential to continue to grow in the future. However, as exports increase, concentrations tend to decrease. Indonesia's increasing CPO exports can be caused by several factors such as increasing international market demand, increasing CPO production in Indonesia, and government policies in supporting exports. Meanwhile, the decline in the concentration of the Indonesian CPO industry can be caused by factors such as policy changes in CPO industry regulations, the entry of new competitors in the CPO market, and changes in global market conditions that affect CPO prices.

Econometric analysis

- Descriptive statistics

Table 2 is the result of analysis for 6 variables, namely CR4, RCA, RSPO, PCPO, PCO, and XCPO, each of which has 20 observations. Statistical values such as mean, median, maximum, minimum, and standard deviation are also presented.

Based on Table 2, it can be seen that the mean and median values in each variable are not always the same, thus indicating that there is an unsymmetrical distribution of data (skewness) on some variables. In addition, the standard deviation value that varies in each variable also shows different variations or distribution of data. RSPO variables have a minimum value of 0 and a maximum of 1, indicating a large variation in the data. While the RCA variable has a narrower range of values compared to other variables, with a minimum value of 27.98183 and a maximum of 58.23941.

- Unit root test

From Table 3, it can be seen that all variables have been stationer at first different, because all variables have a probability of less than alpha α = 5 percent (significant).

- Cointegration test

This cointegration test (Table 4) is performed to find out if there is a long-term relationship between the dependent variable and the independent variable and is intended to test whether the resulting regression residual is stationary or not.

	CR4	RCA	RSPO	PCPO	PCO	XCPO
Mean	0.125723	47.88960	0.650000	6.622167	9.192500	22.89165
Median	0.110826	48.14995	1.000000	6.621791	9.425000	23.35587
Maximum	0.313670	58.23941	1.000000	7.084537	9.650000	23.64176
Minimum	0.042256	27.98183	0.000000	6.110501	8.590000	20.80107
Std. dev.	0.059899	8.613335	0.489360	0.272098	0.415868	0.869800
Observations	20	20	20	20	20	20

Source: Eviews (2022)

Table 2: Descriptive statistics.

Variable	Level 1		Level 1		Level 2	
	T-Statistic	Probability	T-Statistic	Probability	T-Statistic	Probability
CR4	-1.962114	0.2985	-9.030148	0.0000	-5.984888	0.0004
E	-5.065054	0.0013	-4.759076	0.0027	-4.084762	0.0096
RCA	-1.474396	0.5231	-3.610380	0.0165	-6.263977	0.0001
RSPO	-1.337712	0.5897	-4.242641	0.0046	-6.708204	0.0000
PCPO	-2.741903	0.0856	-4.776703	0.0017	-3.954856	0.0109
PCO	-0.795949	0.7960	-6.899735	0.0000	-3.954856	0.0109
XCPO	-3.863403	0.0094	-4.172907	0.0053	-3.344359	0.0342

Source: Eviews (2022)

Table 3: Unit root test.

			t-Statistic	Prob.*
Augmented Dickey-Fuller test statistics			-3.771598	0.0142
Test critical values:	1% level		-3.659148	
	5% level		-3.081002	
	10% level		-2.68133	

Source: Eviews (2022)

Table 4: Cointegration test.

From the Augmented Dickey-Fuller test statistic produces t-statistics -3.771598 > from test critical values and probability 0.0142 < 0.05). The Error Correction Term (ECT) value is stationary at the level level, the data has been cointegrated. That is, the data has a relationship both short and long term.

- Long-term and short-term estimation results

Model estimation results: (Table 5)

$$CR4 = 129.1103 - 128.4751E_t + 0.004622\ \beta_2 RCA_t - 0.015654\ \beta_3 RSPO_t + 0.218569\ \beta_4 PCPO_t + 0.029569 PCO_t - 0.107458 XCPO_t + e_t$$

Model estimation results: (Table 6)

$$\Delta CR4 = 0.015782 - 154.7064\Delta\_E_t - 0.002083\Delta\_RCA_t - 0.099217\Delta\_RSPO_t + 0.140016\ \Delta\_PCPO_t - 0.025026\Delta\_PCO_t - 0.068964\Delta\_XCPO_t - 0.015782ECT + e_t$$

Discussion

The declining technical efficiency in the Indonesian CPO industry both in the short and long term has led to an increase in industry concentration. Lower technical efficiency can weaken the dominance of large companies in the industry because they have a competitive advantage in producing CPO at a lower cost (Foxon, 2013). When the technical efficiency of the CPO industry declines, inefficient companies have difficulty in competing in a competitive market (Kumbhakar et al., 2014). As a result, they go out of business or are acquired by more efficient companies. In the process, efficient companies become more dominant and gain a larger market share (Autor et al., 2017). Decreased technical efficiency can create higher barriers to entry for start-ups looking to break into the CPO industry. Established and efficient companies have a competitive advantage in terms of price, quality,

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	129.1103	66.41519	1.943988	0.0739
E	-128.4751	66.23107	-1.939800	0.0744*
RCA	0.004622	0.002099	2.202289	0.0463**
RSPO	-0.015654	0.041571	-0.376557	0.7126
PCPO	0.218569	0.048158	4.538564	0.0006***
PCO	0.029569	0.039909	0.740914	0.4719
XCPO	-0.107458	0.035124	-3.059376	0.0091***
R-squared		0.788757		
Adjusted R-squared		0.691260		
F-statistic		8.090084		
Prob(F-statistic)		0.000870		

Note: Description: * = significant at 10 percent; ** = significant at 5 percent; *** = significant at 1 percent
Source: Data processed, Output Eviews (2023)

Table 5: Long-term model estimation results.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(E)	-154.7064	30.80550	-5.022037	0.0004***
D(RCA)	-0.002083	0.002121	-0.982331	0.3470
D(RSPO)	-0.099217	0.033889	-2.927694	0.0137**
D(PCPO)	0.140016	0.031289	4.474845	0.0009***
D(PCO)	-0.025026	0.036586	-0.684041	0.5081
D(XCPO)	-0.068964	0.033121	-2.082185	0.0615*
ECT (-1)	-1.742474	0.248655	-7.007591	0.0000***
C	0.015782	0.007473	2.111918	0.0584*
R-squared		0.940944		
Adjusted R-squared		0.903363		
F-statistic		25.03767		
Prob(F-statistic)		0.000006		

Note: Description: * = significant at 10 percent; ** = significant at 5 percent; *** = significant at 1 percent
Source: Data processed, Output Eviews (2023)

Table 6. Short-term model estimation results.

and distribution. This can make it difficult for new competitors to compete effectively. Thus, existing companies can maintain their dominant position and increase CR4 concentrations. In addition, industries with low efficiency, those companies that remain viable and efficient can have a greater influence in determining market dynamics (Tortorella and Fettermann, 2018). They have the power to set prices, set industry standards, or influence sector policy. In the process, they can strengthen their dominant position and increase CR4 concentrations.

Competitiveness (RCA) in the long term has a positive and significant relationship, while in the short term it is negative but not significant to the Indonesian CPO industry. Competitiveness (RCA) measures how much the export value of a product is compared to the global market share of that product (Mizik, 2021). A high RCA indicates that the country has a comparative advantage in producing such products and can compete in the global market (Rossato et al., 2018). In the long run, competitiveness (RCA) has a positive and significant relationship with the Indonesian CPO industry because increasing competitiveness can strengthen the market position of Indonesian CPO products in the global market and increase export demand (Pacheco et al., 2020). This can boost industry growth and help reduce the concentration of Indonesia's CPO industry by introducing more competitors in the global market. However, in the short term, the relationship between competitiveness (RCA) and the concentration of Indonesia's CPO industry is insignificant or may even be negative. In the short term, other factors such as market price fluctuations, global demand, and government policies can affect industry concentration (Dechezleprêtre and Sato, 2017). Moreover, in the short term, large companies that are dominant in the industry can still maintain their market share, even if the competitiveness of Indonesian products increases.

In the long run, the relationship between RSPO and Indonesia's CPO industry concentration tends to be negative but not significant. This is due to the fact that efforts to encourage sustainable palm oil production can increase production costs, which in turn can reduce corporate profits and reduce the tendency of new companies to enter the market (Tey et al., 2021). However, RSPO's efforts can also improve the image of Indonesia's CPO industry and open access to a wider global market, which in turn can help reduce the concentration of Indonesia's CPO industry by introducing more competitors in the global market (Lim et al., 2021; Sakai et al., 2022; Nagiah and Azmi, 2012). Meanwhile, in the short term, the relationship between RSPO and Indonesia's CPO industry concentration tends to be negative and significant. This is due to the fact that RSPO requirements for sustainable palm oil production could cause such large unqualified companies to lose their market share, and in turn could introduce more competitors into the industry. In addition, RSPO's efforts can also improve the image of Indonesia's CPO industry in the short term, which can open access to a wider global market in a faster time than in the long term.

World CPO Price (PCPO) both long and short term provides a positive and significant correlation to the concentration of the Indonesian CPO Industry. High world CPO prices (PCPO) can provide huge profits for CPO producers in Indonesia, because Indonesia is one of the largest CPO producers in the world. In the short term, the positive and significant correlation between PCPO and the concentration of Indonesia's CPO industry is due to the fact that companies that produce CPO will generate greater profits when CPO prices are high, and thus they will command a larger market share (Tey et al., 2020). In the long run, a positive and significant correlation between CPO prices (PCPO) and the concentration of the Indonesian CPO industry occurs because companies that produce CPO can gain substantial economic benefits when CPO prices are stable and high for a long period of time (Friedman, 2014). This can increase the company's profits, strengthen their position in the market, and reduce the likelihood of new companies entering the market. Thus, Indonesian CPO producers with low production costs and good technical efficiency can obtain large profits and control a larger market share.

The price of cooking oil (PCO) in the long run has a positive and insignificant effect, while in the short term it has a negative and insignificant effect. The price of cooking oil (PCO) is a factor that affects production costs for CPO producers in Indonesia (Nurcahyani et al., 2018). In the long run, high cooking oil prices can increase production costs, and thus can reduce the profits of CPO producers in Indonesia (Johari et al., 2015). Therefore, the positive correlation between PCO and the concentration of Indonesia's CPO industry is less significant in the long run. However, in the short term, the negative correlation between PCO and the concentration of Indonesia's CPO industry occurs because falling cooking oil prices can trigger an increase in demand for cooking oil products, thereby increasing demand for CPO as a raw material (Kaltschmitt and Neuling, 2017). In this situation, CPO companies may be able to increase their production and sales, and thus expand their market share. However, this correlation may not be significant because the decline in cooking oil prices may only be temporary and does not have a significant impact on CPO companies' long-term profits and production.

Indonesia's CPO exports in the long and short term have a negative and significant effect on the concentration of the Indonesian CPO industry. This is because the increase in demand from abroad for Indonesian CPO can make Indonesian CPO producers focus more on exports and less focus on strengthening the domestic industry. In the long run, if Indonesia continues to rely on CPO exports, there will be dependence on foreign markets (Nambiappan et al., 2018). If there is a fluctuation in global CPO prices, it will have a direct impact on the Indonesian economy. In addition, if the domestic industry is not strengthened, then Indonesia will not be able to compete with other countries that produce CPO. In the short term, an increase in Indonesia's CPO exports can make domestic CPO prices increase (Yanita et al., 2020). This can make domestic CPO producers prefer to export CPO rather than sell it domestically. As a result, the concentration of Indonesia's CPO industry may decrease due to declining domestic demand.

Conclusion

From the results of the research conducted, it was found that the concentration of the Indonesian CPO industry has a decreasing concentration value, which means that competition conditions increasingly lead to perfect competition criteria towards weak oligopolies with an average market share value of four companies of 12.9 percent. A decrease in technical efficiency in the CPO industry can also have negative economic consequences, such as decreased productivity, increased production costs, and decreased industrial competitiveness. In addition, negative impacts on the environment can also affect the image of the industry and have an impact on global market demand that increasingly demands sustainability and responsible production practices. To overcome these negative impacts, it is important to drive improved technical efficiency in the CPO industry through the adoption of modern technology, sustainable agricultural practices, and adequate workforce training. In addition, strong regulations and policies, both from governments and industrial organizations, can promote efficient, sustainable production-practices that take into account human rights and labor welfare.

Based on the results of econometric analysis, it was found that technical efficiency has a significant negative relationship with the concentration of the CPO industry, both in the short and long term. The competitiveness of Indonesia's CPO industry, in the long run, has a positive significant relationship, but in the short term it has a negative significant relationship. In the long run, the relationship between RSPO and Indonesia's CPO industry concentration tends to be negative, but not proven significant, while in the short term, the relationship shows a significant influence. In addition, world CPO prices in the long and short term have a significant positive correlation with the concentration of the Indonesian CPO industry. Meanwhile, Indonesia's CPO exports in the long and short term have proven to have a significant and negative effect on the concentration of the Indonesian CPO industry.

To mitigate the negative impact of the increasingly deconcentrated CPO industry, Indonesia has implemented policies and standards to promote sustainability and responsible practices in the CPO industry. Two important policies are the Indonesia Sustainable Palm Oil (ISPO) policy and the Roundtable on Sustainable Palm Oil (RSPO). CPO industry players need to ensure that they understand and implement ISPO and RSPO policies comprehensively. It involves a good understanding of the requirements, audit procedures, and standards to be met. Companies must conduct a thorough evaluation of their operations to ensure compliance with the policy. In addition to policy implementation, it is also important to ensure effective monitoring and enforcement of compliance with established sustainability standards. Collaboration between governments, producers, civil society, and international institutions is also an important factor in achieving the success of such policies and certifications. The implementation of ISPO and RSPO requires changes in technology and production-practices. Industry players need to allocate resources to investments in employee training, more efficient equipment procurement, and technologies that support sustainable production-practices. This helps improve the company's ability to meet sustainability standards.

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The Use of Products with a Monitoring System for Remote Bee Detection in Beekeeping in Czechia

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Abstract

The use of modern technology is becoming part of both industry and agriculture. These technologies can also be used in beekeeping, where they can help to monitor the operation of the hive remotely. Beekeepers can remotely monitor the weight of their hives, their temperature, humidity, and other parameters. The aim of this paper is to map the beekeepers in the use of products with monitoring system for remote bee detection in beekeeping in Czechia. To map the issue, qualitative research using semi-structured interviews was conducted with beekeepers, manufacturers/providers of smart devices in beekeeping, and other entities involved in beekeeping. The findings showed that the interest of manufacturers and sellers to offer these smart devices is significant, but the interest of beekeepers is rather less, due to e.g., the purchase price, weaker IT knowledge, traditional beekeeping practices, higher age of beekeepers and the joy of being personally with bees. The novelty of the paper is not to look at the provision of ICT in beekeeping from a technical perspective, but from the perspective of users (beekeepers) and manufacturers of these technologies. Through interviews with beekeepers as well as others in the apiculture sphere, a comprehensive view of the issue is developed. Moreover, this is the first piece of research on this area in Czechia. .

Keywords

Precision beekeeping, precision apiculture, ICT in beekeeping, monitoring systems for remote bee detection, hive scales, Czechia.

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Introduction

Beekeeping is one of the oldest human activities on Earth and has many benefits for us. The importance of bees lies not only in the fact that they produce biologically valuable and beneficial substances for human health - honey, pollen, propolis, royal jelly, bee venom and wax, but mainly due to the fact they monitor the quality of the environment and ensure pollination of most crops and wild vegetation. Both family income levels and food security may be enhanced via beekeeping (Gratzer et al., 2019).

As in many fields, in beekeeping today we can also encounter advanced technologies that can monitor the hive remotely. Although many beekeepers still do things traditionally, namely manually, there is still more significant scope for the application of information and communication technologies (further as ICT). ICT can help beekeepers with implementation of automatic or semi-automatic solutions for bee colony remote monitoring, apiary record making and other actions (Zacepins et al., 2021). Apiaries are frequently situated some distance apart, this entailing a high cost to reach them, so such technologies can alleviate travel costs when used alongside more traditional, physical checks made periodically in person (Alleri et al., 2023). In scientific papers, among beekeepers or other and other bee specialists, we can encounter various labels for IT tools and solutions that can be used in beekeeping, including monitoring systems for remote bee detection. There are many different designations for the potential use of ICT in beekeeping including Precision Beekeeping, Smart Beekeeping, Precision Apiculture, Apiculture System, Honey Bee Monitoring, Smart Hive or Connected Hive. In this paper the designation precision beekeeping (further as PB) is used. PB is defined as "an apiary management strategy based on the remote monitoring of individual bee colonies to minimise resource consumption and maximise the productivity of bees" (Zacepins et al., 2015).

The issue of precision agriculture has been the subject of much research, which includes the area of PB. The use of sensor technology has changed a lot and its use in bee research and general beekeeping is becoming more widespread (Meikle and Holst, 2015). Beekeeping is an important part of agriculture with scattered locations that require monitoring of animals on a continuous basis (Catania and Vallone, 2020). Most of the studies and papers focus on the evaluation and creation of remote bee monitoring systems from a technical point of view, which is, of course, very beneficial for beekeepers, but there is also a lack of beekeepers' perspectives and their experiences, i.e., what they prefer and why, what benefits they see and, on the contrary, what are the problems when using these products.

There are very few papers that focus on beekeepers in their research part. Those that do include, for example, the papers by Zapacins et al. (2021) or Wakjira et al. (2021). The research by Zacepins et al. (2021) surveyed beekeepers in collaboration with the Latvian Beekeepers Association and investigated the status of PB in Latvia, namely in importance in use of precision tools and types of tools in beekeeping practice. Only the beekeepers' perspective is presented here, the perspectives of other apiculture entities are missing. Also, in the research reported in Wakjira et al. (2023), the perspective of beekeepers was important for the next steps in smart apiculture management services. They identified and described user requirements and started "a collaborative design thinking process to produce conceptual design solutions and low-level prototypes for essential products around the decision support system and the advisory support service for beekeepers". The third paper, which partly touches on the problem examined in this paper, is research by Alerri et al. (2023). This paper aimed to prepare a systematic review of the current state of PB and to draw implications for future studies. They prepared the research in January 2023, where the Scopus database was used taking into consideration title, abstract and keywords connected to PB. They found 201 papers, which they reviewed. Firstly, internal parameters of the hive were taken into consideration, in turn divided by weight of the hive, internal temperature, relative humidity, flight activity, sounds and vibrations, and secondly, external parameters in turn divided by wind speed, rainfall and ambient temperature. Alerri et al. (2023) also mapped other areas, such as possible undesirable effects of the use of sensors on bees, economic aspects, and applications of Geographic Information System (GIS) technologies in beekeeping. The country of origin of the first authors found in the Scopus database was also utilised by Alerri et al. (2023), considering the geographical location of the publication. Most publications originated from Latvia - 28 papers, followed by the USA with 26 papers, Germany with 20 papers, Italy and the UK with 11 papers. No first author of the publications found in Scopus was from Czechia or the Slovak Republic.

To investigate the issue of monitoring systems for remote detection of bees, we used Products for Remote Monitoring (or PRM for short), a combination of surveys with beekeepers, manufacturers/suppliers of ICT for beekeeping and other beekeeping experts and apiculture entities within Czechia were prepared so that the issue was processed from a comprehensive perspective. Therefore, the aim of the paper was set as follows: The aim of this paper is to map the interest of beekeepers in the use of products with a monitoring system for remote bee detection in beekeeping in the Czechia. The mapping of beekeepers' interests is divided into finding out who the beekeepers using PRM are, what benefits they perceive from PRM and what areas are slowing down the implementation of PRM.

The novelty of the paper is not to look at the provision of ICT in beekeeping from a technical perspective, but from the perspective of users (beekeepers) and providers of these technologies. Through interviews with beekeepers as well as other parties/entities involved in bees, a comprehensive view of the issue is developed. Moreover, this is the first research on this area organised in Czechia.

Literature review

Czechia and beekeeping

The first mention of beekeeping in the Czech lands can be found in chronicles dating back to 993. Various groups of beekeepers and processors of bee products were also established here. One of the most important achievements was the issuing of a patent on the keeping and protection of bees by Maria Theresa in 1775. The first major beekeeping association was founded in 1872, initially comprising 10 beekeeping associations. This association was named the Czech Beekeepers' Association in 1970 (Bee Shop, 2023). The Czech Beekeepers' Association has more than 54,000 members and 203 youth beekeeping clubs. This number represents 98 percent of all beekeepers in our country. Thus, Czechia is one of the countries with the highest organisation of beekeepers in the world. Czech-organised beekeepers keep 573,676 bee colonies (including separations). This is 97% of the total number of bee colonies registered in the Czechia (Český svaz včelařů, 2023).

According to Václav Krištůfek from the Biological Centre of the Academy of Sciences of the Czech Republic, Czechia is the fourth most bee-dominated country in the world, with over 700,000 bee colonies and over 62,000 beekeepers (Český rozhlas, 2020). Czech beekeepers produce between seven and eight thousand tonnes of honey annually, with about a fifth of the honey going for export. However, Czech honey is also imported, mainly from Ukraine (the question to be asked is to what extent this situation remains the same in 2023), China, Uruguay and Germany (BussinesINFO, 2018).

The use of ICT in beekeeping

Increasingly, honeybee colonies are facing various challenges such as climate change, pesticides, and land use that affect their growth, reproduction, and sustainability (LeBuhn and Vargas Luna, 2021). The decline of honeybee colonies is a serious problem that leads not only to a reduction in honey production and quality, but also to a reduction in the pollination service that bees provide to ecosystems, and consequently to greater difficulties in maintaining native plants (Robustillo et al., 2022). Therefore, there are increasing efforts to help beekeepers also through ICT. In the first instance, the digitalization of beekeeping entails incorporating Internet of Things (IoT) technologies, e.g. sensors, to obtain and transmit data concerning bees. Subsequently, data analysis becomes vital as it enables the creation of models that create correlations between the collected data and the biological conditions of beehives, frequently employing artificial intelligence (AI) algorithms (Hadjur et al., 2022).

The interest in continuous monitoring of honey bee colonies, defined here as collecting data from the colony every hour or more frequently for more than two days, is not new (Meikle and Holst, 2015). Gates (1914) reported in 1907 hourly temperature data collected from the colony over several days. The use of ICT is also possible in beekeeping, where beekeeping solutions are increasingly offered. Smaller, cheaper and more accurate sensors, together with easier access to computers and the internet (Faludi, 2010), have enabled bee researchers and beekeepers to monitor many physical aspects of bee colonies around the clock, remotely and with little human labour (Meikle and Holst, 2015). Similarly, monitoring systems offer a reliable means of accessing, visualising, sharing, and managing data collected from agricultural and livestock activities, benefiting stakeholders in these respective fields. (Eitzinger et al., 2019, Popović et al., 2017).

The honey production cycle takes place in hives where it depends on many factors such as temperature, relative humidity, and wind (Catania et al., 2011), where it can benefit from advanced smart technology (Zgank, 2020). Real-time remote monitoring of bee colonies using ICT can help beekeepers detect abnormalities and identify colony conditions. This data can be made available to beekeepers in a real-time web-based system (Zacepins et al., 2020). The data obtained from bee monitoring, e.g., weight and temperature, can also be used for comprehensive colony monitoring over a longer period. Subsequently, a wide range of information can help to predict future bee behaviour. In summary, according to Robustillo et al. (2022) PB was created in response to the need for optimal management of beekeeping, using technology and statistical methods to help beekeepers understand what is happening inside hives without having to open them and thus disturbing the colonies.

Monitoring systems for remote bee detection and its benefits

A well-designed monitoring system comprising modern software architecture, such as microservices, is invaluable for managing honey bee activities and ensuring their overall health within beehives (Aydin and Aydin, 2022). Additionally, the beekeeping system incorporates a remote hive monitoring software, facilitating beekeepers to conveniently check on their hives from the convenience of their own homes (Ammar et al., 2019).

To help beekeepers and facilitate the process of implementing PB solutions, local start-ups and entrepreneurs have begun to develop products and tools for remote colony monitoring and management (Zacepins et al., 2021). PB utilises advanced technology in the form of smart hives fitted with sensors to monitor the health of bee colonies. These sensors detect various parameters that indicate the state of the colonies and transmit this information to the beekeeper through web-based networks that can be accessed via smartphones. This allows the beekeeper to focus their attention on the hives that require urgent inspection. The sensors are connected to a microprocessor, which is powered by a battery and connected to a network to remotely transmit the collected data to a server. Currently, the two main types of microprocessors used for this purpose are Arduino and Raspberry Pi. The data harvested is then sent to the cloud for storage, analysis, and alarm generation. Some systems even provide beekeepers with an application that organises the data by hive, allowing for easy monitoring and management.

Most commonly, in addition to weight, the temperature and humidity in the hive are also measured, with data captured hourly and displayed in a web-based application (Zacepins et al., 2021). Utilising sensors enables hive observation without provoking disturbance. Conducting frequent and invasive hive inspections to collect field data on colony growth and phenology for assessing treatment effects can induce defensive behaviour from bees, potential robbing by other colonies, and jeopardising the queen's well-being, in addition to disrupting the hive environment. In contrast, the use of small, autonomous sensors, especially when connected to wireless networks, can supply real-time information without causing any disturbances (Meikle and Holst, 2015).

Several solutions are available for remote monitoring of bee colonies. According to Wakjira et al. (2021), the adoption of PB is growing in Europe, but its implementation in Africa and Asia is occuring at a slower rate. In recent studies, there is a trend towards utilising more electronics with increased sampling frequency to measure a variety of hive parameters (Meikle and Holst, 2015). Commercial or handcrafted solutions primarily monitor weight and temperature (Meikle et al., 2017). Technology can help beekeepers better understand colony behaviour without having to look inside the hive (Zacepins et al., 2021). According to Pejić et al. (2022), in the traditional approach, hives are typically inspected roughly 15 times per year. However, this method lacks the ability to provide beekeepers with real-time information about the condition of their colonies, preventing them from taking timely action. Remote monitoring of colonies minimises the number of visual inspections required; therefore, it helps reduce colony stress (Stalidzans et al., 2017). The use of PB allows beekeepers to monitor colonies for many possible reasons, such as research, information on the daily management of bees by beekeepers, and learning how to reduce resources and time allocated to tasks without reducing production (Gil-Lebrero et al., 2017). The beekeeping system monitors the beehive by exploiting images of in and out activities of bees in combination with measurable parameters, such as temperature, humidity, light, noise, beehive weight, and weather conditions (Ammar et al., 2019). Advanced ICT and remote sensing technologies enhance PB and assist in the increase of the role of bees in pollination services as well as the production of hive products while maintaining a healthy environment (Wakjira et al., 2021).

For the feeding activity of the colonies, the best solution is to use hive scales for continuous weight monitoring, where monitoring the weight of bees can help determine the start of an intense nectar flow and signal the beekeeper when additional stores need to be placed in the hive (Zacepins et al., 2021).

In recent years, several studies have underlined the potential of integrating digital technologies to monitor honey bees. A great deal of research has been carried out on IoT-based beekeeping monitoring systems (Aydin and Aydin, 2022). Meikle and Holst (2015) describe an overview of the parameters examined and methods used, including location, number of replicate colonies and duration of hourly datasets. When in the early days, weight and temperature were investigated using mechanical balance (Gates, 2014). In recent years, e.g., temperature (Stalidzans and Berzonis, 2013), vibration (Bencsik et al., 2011), acoustics, temperature, relative humidity (Ferrari et al., 2008) were measured using in-hive sensors. Forager traffic was measured using hive entrance sensors e.g., by Mezquida and Martínez (2009) and through RFID tags and entrance sensors (Schneider et al., 2012). Furthermore, relevant studies and its comparison according to nine different criteria were presented in the paper of Aydin and Ayding (2022), where monitoring system were categorized as WSN-based Audio Events Monitoring, WSN-based Beehive Monitoring; IoT-Gateway Design for Beehive Monitoring, Cloud-based Data Storage Architecture for Monitoring Bee's Behaviors, IoT-based Intelligent Beehive and Intelligent Factory; IoT-based Bee Colony Monitoring, AI-based Assistance System; IoT-based Bee Colony Monitoring and Bee Colony Real-Time Monitoring. Monitored metrics in the above-mentioned paper of Aydin and Aydin (2022) were temperature, humidity, sound, relative humidity, acceleration, rainfall, dust, light intensity, air contaminants, image, iight, smoke gas, weight, video, various gases concentration, entrance counts, pressure, altitude, carbon monoxide, nitrogen dioxide, hydrogen concentration, alcohol concentration, propane concentration, oxygen, carbon dioxide, ultraviolet, infrared light, liquefied petroleum gas and acoustic parameters.

Meikle and Holst (2015) report that the behaviour and condition of bee colonies can be monitored using temperature, humidity, acoustic, video, weight, and other sensors. There have been many studies on monitoring of colony parameters, and it is concluded that weight and temperature are the main ones because the cost compared to the information on the results is sufficient (Zacepins et al., 2020). Monitoring of colony weight provides one of the most important types of data a beekeeper can have on the colonies (Fitzgerald et al., 2015). Automated weight tracking systems can provide the beekeeper with important information about several important colony events (Meikle et al., 2008). The second important parameter of the colony is temperature, because bees can regulate the temperature inside the hive (Southwick, 1992). Measuring the temperature of honeybee colonies has the longest history and currently measuring the temperature of honeybee colonies appears to be the simplest and cheapest way to monitor honeybee colonies (Zacepins and Karasha, 2013). In fact, a temperature sensor is usually added to virtually every honeybee colony monitoring device (Zacepins et al., 2020). Long-term monitoring of bee colonies can lead to long-term data for better analysis and understanding of colony behaviour (Kviesis et al., 2020). As was mentioned above, Alerri et al. (2023) found that from 201 selected papers in Scopus database was 98 focused on internal temperature, 69 for relative humidity, 66 for mass in the sense of weight of the hive, 68 for sound, 27 concerning flight activity, specifically entry and exit of the hive (bee inflow/outflow). For the external parameters, 14 for wind speed and 12 for rainfall.

Incorporating sensors into the hives and processing the data, provides the beekeeper with real-time information on the status of the hives without having to travel to them, making decision-making easier and minimising resource consumption and stress in the hive (Robustillo et al., 2022). As the cost of end systems decreases and their precision and valuable outcomes increase, continuous and real-time monitoring of colony parameters is becoming more feasible even for smaller beekeepers. The implementation of PB systems is estimated to bring economic benefits to beekeepers (Zacepins et al., 2020). Another benefit includes a reduction in the number of manual spot checks, thereby reducing the impact of disturbance to bees (Zacepins et al., 2020). Frequent physical inspections of colonies disrupt the normal life of bees and can cause additional stress that negatively affects the productivity of the entire colony (Komasilovs et al., 2019). Similarly, scattered colony locations are often encountered and therefore suggest the need to facilitate 24/7 monitoring of animals, which can be facilitated by advanced smart environment technologies (Zgank, 2019).

Based on the research made by Zacepins et al. (2021) by 234 Latvian beekeepers showed that the most important areas for the beekeepers are: "Preserving bee colonies and ensuring the well-being of bees" (48% respondents), "Honey harvest" (41% respondents) and "Reduction of inspections" (36% respondents), which also dominates in all groups of beekeepers. Two less important areas for beekeepers in terms of use of digital tools are "Traceability of honey products" (44% respondents) and "Anti-theft and avoiding animal attacks" (57% respondents), which are not so evenly distributed among all groups of beekeepers and are slightly more preferred by professional beekeepers (Zacepins et al., 2021). For Latvian beekeepers is important to prevent theft and wildlife attacks from remotely located colonies, so video monitoring of colonies and GPS systems of colonies are important (Zacepins et al., 2021). Researchers in recent times began exploring the (IoT) potential as it relates to beekeeping (Tashakkori et al., 2021) and using AI. These fields are not covered in this paper.

Considering the growing interest of the researchers towards smart technologies in beekeeping, the research focused on this area was to map the interest in products for remote monitoring systems for bee detection in Czechia. The research does not look at the provision of ICT in beekeeping from a technical perspective, but from the perspective of users (beekeepers) and providers of these technologies. As confirmed by Zacepins et al. (2021) current beekeepers are more educated and technologically advanced and start to use and apply ICT solutions and tools more actively (Zacepins et al., 2023). To fulfil this aim, three research questions RQ1-RQ3 have been prepared:

RQ1: Who are the customers of PRM?

RQ2: What are the advantages of the PRM?

RQ3: What areas are slowing down implementation of PRM?

To answer these research questions, qualitative research was conducted with beekeepers, manufacturers/vendors of ICT in beekeeping and other beekeeping experts and entities within the country, so that the issue was processed from complex perspectives. This comprehensive view on the use of monitoring systems for remote bee detection in beekeeping is a clear contribution of this paper.

Materials and methods

The field of PB in the context of beekeepers and others within the apiculture sphere is not sufficiently explored. Therefore, the research was prepared to get new insights. Through interviews a comprehensive view of the issue is developed. Respondents were beekeepers, producers/sellers of product for remote monitoring (PRM) and other professionals and institutions related to beekeeping, see Figure 1. Beekeepers were divided into two groups, namely small beekeepers (called hobby beekeepers) with up to 60 colonies and large beekeepers (usually beekeeping is their main source of livelihood) with more than 60 colonies. This is the first qualitative research on this area in Czechia.

Figure 1 and Figure 2 show all respondents from all researched fields. Figure 1 shows three main groups of respondents, such as beekeepers, non-beekeepers and other apiculture entities. Figure 2 shows the respondents from the group of bee institutions. The number in the brackets shows the number of interviews. The total number of interviews was 67. All participants in the research were deeply connected with beekeeping and are professionals in this field.

To propose a broader understanding concerning the usage of PRM in Czechia, the research was conducted among many groups of respondents (see Figure 1 a Figure 2).

Some family members and many of the author's friends are beekeepers, so respondents for qualitative research were selected firstly on the basis of the knowledge and web search of the author of this paper. Secondly, snowball sampling (Coleman, 1958) was used, when the process began with suggestions from some possible respondents, who have some experience with PRM or are involved in beekeeping. Interviews lasted 20-90 minutes and were held from September 2022 to November 2023. The interviews were done personally or via online calls through Google Meet. One interview with a producer was done by company chat, where the questions were directly answered. The total number of interviews is 67 including 42 with beekeepers, 11 with bee institutions, 14 with no-beekeepers and companies cooperating with beekeepers.

The qualitative research undertaken via interviews consisted mostly of open-ended questions, which were partially based on the literature review, mostly

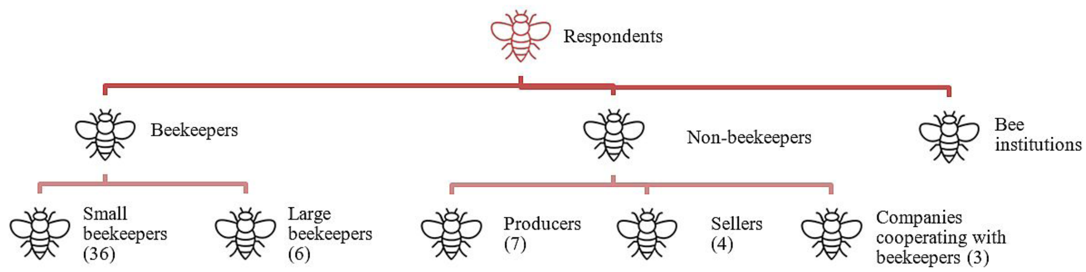

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Figure 1: Overview of three main groups of respondents.

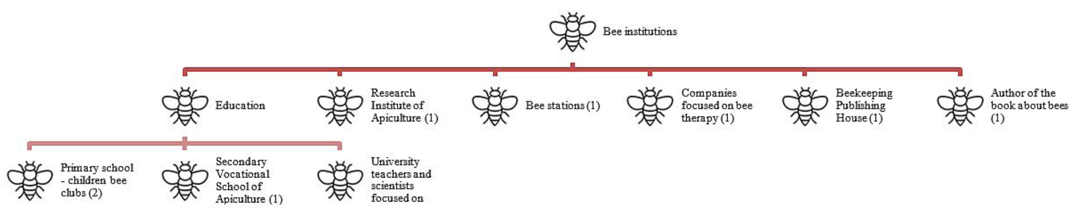

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Figure 2: Respondents from apiculture entities.

Zacipens et al. (2021). The rest of the questions were prepared in order to fulfil the aim of the research. The areas of research that are presented in this paper included the following aspects: Current situation in beekeeping with the focus on PRM; Main customers of PRM; Advantage of PRM; and Areas of slowing down implementation of PRM. The questions were almost identical for all respondents involved. The aim of the comprehensive and complex research was to learn about PRM issues from multiple perspectives.

The interviews were mostly recorded and transcribed. Open coding was used to organise the data from open-ended questions and convert them into discrete thematic blocks. Based on the initial research focused on RQ2, a total of 28 first-order categories for advantages of PRM were identified. These categories were further analysed to identify similarities and differences. During this process, the number of codes was reduced, resulting in the identification of four aggregate themes: Information, Control, Activity/ Reaction and Savings. The final coding structure, showcasing these themes, is presented in Table 1. Similarly, from the research focused on RQ3, a total of 42 first-order categories for area slow down implementation of PRM were identified. These categories were further analysed to identify similarities and differences. During this process, the number of codes was reduced, resulting in the identification of six aggregate themes: Unawareness, Disinterest, Tradition, Beekeeper, PRM operation and Price of PRM. Even after some consultations with bee professionals, there is still a degree of subjectivity in the categorisation. Direct interview quotations were added to increase the transparency and credibility of the findings.

As qualitative case research is sensitive to researchers' subjective explanations, some peer consultation was needed to avoid researcher bias and to ensure greater objectivity in the study. A rich set of direct interview quotations to demonstrate interpretations was added to support the transparency and conformability of the findings.

Results and discussion

Specifics of the Czech market in relation to PRM in beekeeping

Bee monitoring is not something new. Bees have been monitored in the Czech environment for a long-time using devices that were usually made by amateurs and technically proficient beekeepers. Most often, the weight of the hive or the temperature was monitored, even with a simple thermometer. Professional devices were often born in the minds of beekeepers who lacked these more advanced devices in their beekeeping.

The current situation in the Czech environment is such that many manufacturers and sellers unfortunately perceive certain shortcomings in the sale of remote monitoring of beehive weight. For most beekeepers, a better-quality solution is too expensive and not worthwhile. One PRM measures the activity of only one hive, and usually beekeepers have multiple hives, so this also increases the cost of acquisition. With cheaper solutions there is some risk in the quality of the equipment, the monitoring itself and the data transmission. There are smaller garage companies on the market where their products have different designs, features, variable quality and are not very reliable. Also, the data display and the way the platform would need to be improved, often they just send a file or put something on the web.

Beekeeping is still associated with a certain conservatism, traditional beekeeping methods, older age of beekeepers, rural areas and the penetration of modern technology is slower among beekeepers. Of course, all this is gradually changing and improving. However, the younger generation is becoming more involved in beekeeping, their relationship with modern technology is much better and constant monitoring of data (bees) is much more natural for them. Also, it is these devices that can help young and novice beekeepers to navigate the bee care environment better and more quickly.

To sum up, more interest in these products, such as PRM, can be expected in the future, when overall IT literacy will increase, the benefits of these devices will be actively used by beekeepers and promotion about the benefits of these products will expand.

Interviews focused on mapping the interest of the use of PRM in beekeeping showed many interesting findings related to RQ1-RQ3. The findings to RQ1 – RQ3 are presented below along with a set of direct interview quotations, which support the transparency and conformability of the findings. Qualitative research is sensitive to researchers' subjective explanations, so some consultations with bee professionals were needed to eliminate researcher bias.

RQ1: Who are the customers of PRM?

The findings from the interviews showed that the interest of manufacturers and sellers to offer these smart devices is significant, but the interest of beekeepers is rather less, due to the purchase price, weaker IT knowledge, traditional beekeeping practices, higher age of beekeepers and the joy of being personally with bees. All areas slowing down the implementation of PRM are mentioned below, see findings for RQ3.

Interviews with all stakeholders revealed that the typical PRM customer is a beekeeper who is between 30 and 50 years old and has a positive attitude towards PC/mobile and ICT (see Figure 3). Of course, there are also customers of PRM at older ages, even in their 80s, but they tended to be in the minority. Customers, or users, of PRM included, for example, beekeeping institutions, beekeeping institutes and companies on whose land the bees are located were also included in the research (see Figure 1 and Figure 2).

Also, Figure 3 shows the groups of beekeepers who use PRM, such as beekeepers who are beginners, young or experienced. Each group may see slightly different benefits of PRM, see RQ2, but the primary objective is the same - to be able to monitor the activities of their colony remotely.

Opinions on the "typical" beekeeper with a PRM were not entirely clear, but from the information from the interviews a more detailed characterization was prepared and is presented in Figure 3 and mainly in Figure 4.

As seen in Figure 4 the characteristics of beekeepers with PRM are varied and of course do not apply to all beekeepers. However, usually a large part of the characteristics is typical for customers/users. The characteristics could be further categorised into those related to the beekeeper themselves, such as lower fineness on tradition, (characteristics are marked in Figure 4 in italics), and those related to external environmental factors, such as higher income.

Some respondents' quotes focused on the characteristics of the customers are mentioned below:

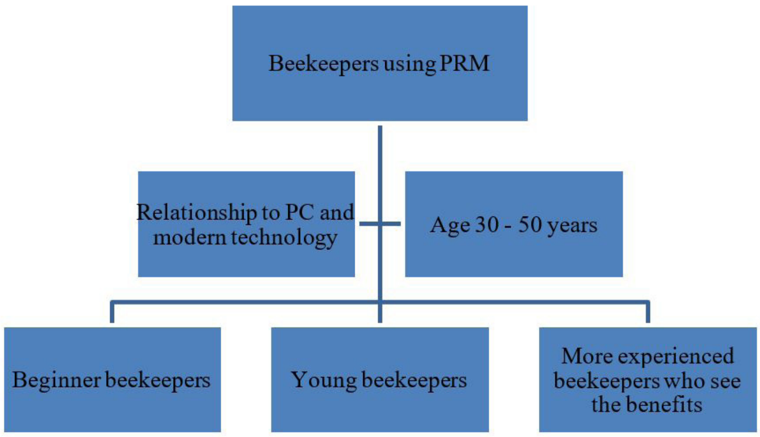

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Figure 3: Main characteristics of beekeepers with PRM.

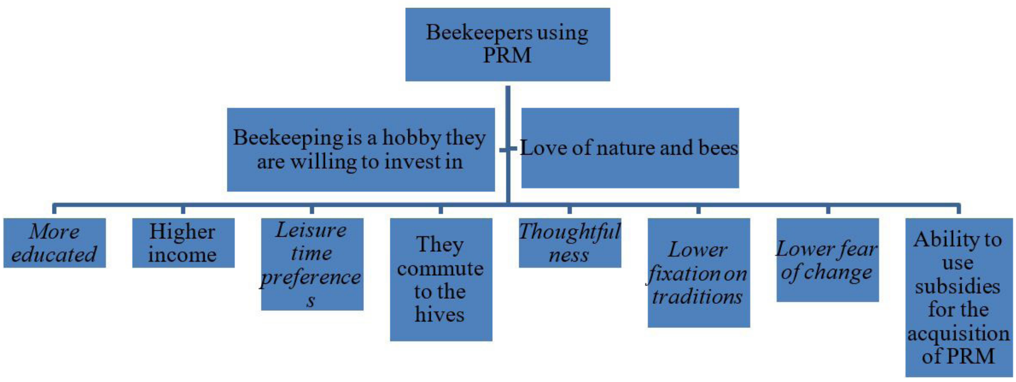

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Figure 4: Other characteristics of beekeepers with PRM.

"We have two main customer segments. The first is beekeepers aged 40-50 with a financial background, who usually do not use subsidies (they do not want to fill in forms), where PRM has the advantage of access to hive control information, where it is not necessary to be physically at the bees so often. The second segment is seniors who have bees at their cottage, which is far away, so they can monitor the bees remotely. They also work with beekeeping clubs, where the PRM kids really like it and are open to it, but the buyer is then the parent…" (Manufacturer 1)

"Our customers are mostly beekeepers who have bees located farther away and they are from so-called 4 groups: a) Toy beekeepers - want to know more about bees, b) don't have time, c) too careful - don't want to have any losses - swarming, theft, tree fall, and d) non-beekeepers -rent equipment or their bees to schools (they give schools the outputs from sensors and cameras, which is beneficial for teaching, e.g., work with graphs - use in mathematics, physics)." (Manufacturer 2)

"The younger generation who are more open to PC/technology, they have little time, so it's useful to them." (Teacher from children bee club).

"They definitely have to have a relationship with modern technology, and then they are also customers who get subsidies to buy PMR, so they try to buy, and some people move on, some people don't." (Manufacturer 3)

"For the young beekeepers, where PMR helps for better orientation and to absorb information, because they don't know much about bees yet and they want to help themselves a little bit with this, which helps them to accelerate their know-how on how to take care of bees." (Seller 1)

"This cannot be answered unequivocally. We have customers who are young, but also long-time beekeepers who are over 80 years old." (Manufacturer 4)

"Young and old, it's not about age, and it's not mass, but there is still interest... how to characterise them? They are definitely thoughtful people who are not fixed in traditions and are not afraid of change." (Manufacturer 5)

The results are probably not surprising, as it was expected that since PRM is linked to ICT, it would be closer to younger beekeepers who have no problems with ICT and moreover ICT is part of their work and personal life. Since many beekeepers are of a higher age, it could be expected that ICTs would be more distant for them and that they would also emphasise beekeeping according to their traditions and practices. It can be expected that in the coming years, as younger beekeepers become more and more aware of ICT, interest in PRM and other PB tools will also increase. Therefore, many PRM manufacturers/sellers are actively targeting younger and novice beekeepers. As Zacepins et al. (2023) state there is an enormous potential for an increase in Latvia, such as to shift the traditional method of apiary record making to the digital environment.

RQ2: What are the advantages of the PRM?

Based on the qualitative research, the respondents perceive the main advantage of PRM to be: Information, Control, Activity/Reaction and Savings. The final coding structure is shown in Table 1.

First-order categories		**Aggregate themes**
Hive weight information	→	Information
Hive temperature information	→	
Information about the swarm, swarm mood, motherlessness, mortality, etc.	→	
Information on stock levels, winter consumption, starvation	→	
Information about the beginning of bee brood and its end (healing)	→	
Information when the colony has a problem	→	
Instant overview of the whole bee.	→	
Change of hive location (wind, theft)	→	
Departure of bees (swarming)	→	
Tracking backwards even after years	→	
Information clearly in graphs	→	
Track the relationship between flowering/ weather and swarming	→	
Information without opening hives	→	
Better understanding of the colony	→	
Check the status of the colonies	→	Control
Check weights	→	
Temperature control	→	
Stock level check	→	
Observing and learning how the colony works	→	
Being able to react quickly as a beekeeper	→	Activity/ Reaction
Reducing the number of unnecessary checks	→	
Readiness for visiting bees	→	
Optimising work	→	
Helping with feeding	→	
Assistance with treatment	→	
Saving time on commuting	→	Savings
Saving commuting costs (e.g., petrol)	→	
Economic effect	→	

Source: Author

Table 1: Advantages of PRM.

Some respondents' quotes focused on the advantages are mentioned below:

"I go to the beehive and I'm ready - the day before I go to the computer and check what's going on and then it goes ready (like a car - use the dipstick to see how much gas, ...)." (Beekeeper 1)

"It's useful and I wonder who doesn't have it." (Manufacturer 1)

"Beekeeping is expensive, so the weight is lost then...it's a long shot." (Beekeeper 2)

"The battery lasts for 10 years, it's only replaceable, otherwise no work." (Beekeeper 3)

"It is definitely a benefit if the beekeeper wants to follow it." (Research Institute of Apiculture)

"Primary is weight, it is the most important and shows a lot of information, then temperature and humidity." (Beekeeper 4)

"I only use it on one hive. And more just out of interest, curiosity, and deepening experience. The biggest benefit is monitoring the weight." (Beekeeper 5)

"It is easy to find out the return from PMR, e.g., by the price of petrol and the number of visits to the bees required." (Manufacturer 1)

As shown in Table 1, the aggregate themes Information and Control are given separately, but they are certainly very closely related, rather the two areas are also intertwined. Similarly, the other themes are also very interlinked. Using the information that the beekeeper gets from the PMR, they can then control and react to what is happening in their colony. These Reactions/Actions to what is going on in the hive can then have the impact of saving time and saving cost in transport and dealing with the problem. Thus, it can be said that the benefits from PMR are overall comprehensive and build on each other as shown in Figure 5.

The benefits mapped in the Czech environment are consistent with the findings of Zacepins et al. (2021) for Latvian beekeepers, which are reported in theory, such as preserving bee colonies and ensuring the well-being of bees, reduction of inspections or antitheft. As was mentioned by Meikle and Holst (2015) the use of autonomous sensors enables observation of hives in real time without disturbance of bees.

The interviews revealed that the primary concern for beekeepers is to obtain information about hive activity. The most monitored parameters include weight and temperature monitoring, which correspond with Zacepins et al. (2020), where it is concluded based on many studies on monitoring of colony parameters that weight, and temperature are the main parameters because the cost compared to the information on the results is sufficient. It exactly shows the Savings benefit (see Table 1) that is associated with monitoring hive activity.

RQ3: What areas are slowing down implementation of PRM?

Based on the qualitative research, the respondents' areas which slow down implementation of PRM, are as follows: Unawareness, Disinterest, Tradition, Beekeeper, PRM operation and Price of PRM. The final coding structure is shown in Table 2.

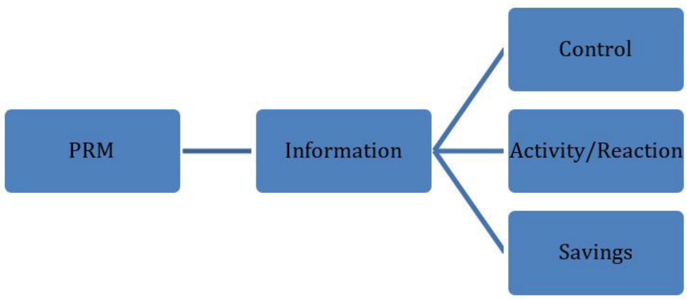

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Figure 5: Linking the advantages of PRM.

First-order categories		Aggregate themes
Unawareness of PMR	→	Ignorance
Little awareness of the benefits of PMR	→	
Lack of technical knowledge	→	
Insufficient knowledge of modern technologies	→	
Poorer understanding of PMR outputs (e.g., graphs)	→	
Little interest in technology, including PMR	→	Disinterest
PMR is not needed	→	
No interest in innovation	→	
No interest in PMR data/outputs	→	
PMR is not a necessity for beekeepers	→	
Distance to the hive	→	
Humidity and temperature in conventional beekeeping without research are useless	→	
Use does not mean better results	→	
It does not bring joy	→	
Traditional approach to beekeeping	→	Tradition
Reluctance to make changes	→	
Monitoring is no substitute for physical inspections (e.g., during the laying season)	→	
Visiting hives is not guided by monitoring at all	→	
Technology does not belong in hobby beekeeping	→	
Mechanical recording of weight data	→	
Distrust of PMR (and of Interest)	→	
The power of nature	→	
Higher age of beekeepers	→	Beekeeper
Unawareness or lack of interest in PC/IT technologies	→	
Joy of being with bees	→	
Reluctance to learn something new	→	
Reluctance to change their established practices	→	
Working with bees for a long time (great experience)	→	
Need to calibrate over a period of time	→	PRM operation
Poor mobile signal at the site	→	
Use of el. energy - disruption of bee biofield	→	
PMR unreliability (especially hive scales)	→	
Low PMR efficiency	→	
PMR complexity	→	
Complexity of PMR installation	→	
Ignorance of working with PMR	→	
1 hive = 1 hive scale	→	
Fear of PMR theft	→	
Higher purchase price of PMR	→	Price of PRM
Purchasing a PMR is an additional cost	→	
Priority to purchase other necessary equipment	→	
Reluctance or inexperience to apply for subsidies	→	

Source: Author

Table 2. Areas slowing down implementation of PRM.

For some information from respondents, as with Table 1, it was not entirely clear where to place them, such as distance to the hive. Certain areas of ambiguity were discussed with experts, but even so it was not always clear. Therefore, some respondents' quotes were added.

"Technology doesn't belong to hobby beekeeping because beekeeping is about observing bees, nature, about joy, about feelings. Being with bees is relaxation." (Beekeeper 1)

"Nature is wise, it can cope without our interference and waves." (Beekeeper 2)

"Now the priority was to get other necessary equipment, but we are going to take this step (buying a PMR) as well." (Beekeeper 3)

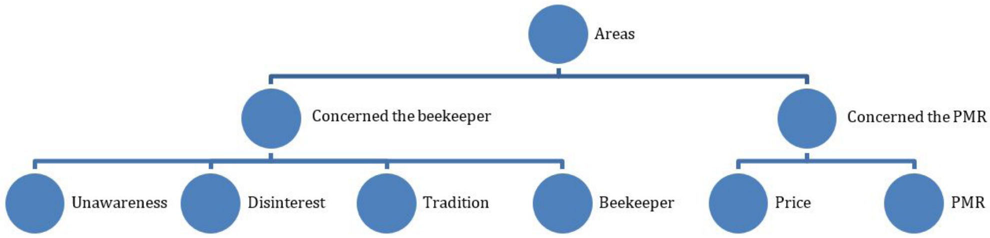
"I have bees in my garden near my house, so it (PRM) is not worth it." (Beekeeper 4)

"I have several locations with several hives, so it would not be worthwhile to get scales (PRMs) under all of them." (Beekeeper 5)

Based on the information from the interviews and their arrangement in Table 2, these six aggregate themes can then be divided into two areas. The first area concerned the beekeeper himself, where four aggregate themes (Unawareness, Disinterest, Tradition and Beekeeper) were given. The second area concerned the PRM where two themes (Price and PMR) were given. This division is shown in Figure 6.

As seen in Table 2 and Figure 6 the price of PRM is one area that reduces the expansion of PRM. Zacepins et al. (2020) mention that beekeepers are not usually keen on investing in digital solutions; therefore, the cost of smart hives becomes a crucial aspect, and should be reduced to the minimum possible (Zacepins et al., 2020), which could maybe help for faster expansion of PB. However, even though there are sufficient hardware and technical means for the practical application of PB, the market uptake of sensor-based decision support systems is still very low (Alleri et al., 2023). The main reason for this is the uncertainty about the economic benefits that the use of such systems could bring (Robustillo et al., 2022).

Another problem is that a PRM is only for one hive, and usually beekeepers have several hives in several locations. As Hadjur et al. (2022) state to decrease costs, only some of the hives per apiary could be equipped with sensors, supposing that different colonies in the same environment are in similar conditions.



Source: Author

Figure 6: The areas of slowing down implementation of the PRM.

Theoretical implications

Among the theoretical implications of the qualitative research, we can certainly mention the summarisation of the findings in the description of the specificities of PRM users (see Figure 3 and Figure 4), which are based on the research of both beekeepers, non-beekeepers and other apiculture entities (see Figure 1). Other implications include a sorting and categorization of interview outputs on two areas, namely a) advantages of PRM (Table 1) and b) areas slowing down the implementation of PRM (Table 2). The significance of these findings is certainly in the uniqueness of the topic under study, including the treatment of complex perspectives by many respondents from different groups, which increases the possibility of generalisation.

Managerial implications

Given the fact that most beekeepers are aware of modern practices, it would be good to focus on better education and promotion of PB, namely PRM. It would be beneficial to make beekeepers aware of the benefits of PRM through concrete examples and to show how the equipment works in real situations, what data it provides and what the data can be used for. It would also be good to emphasise awareness when installing the PRM, changing the battery and possibly other activities related to the PRM. As stated by Zapiens el al. (2021), to select a PRM, it is important to know a) the data transmission method and possible additional costs of data transmission (e.g., paying for the mobile network and SIM card), b) the size of the system to infer the possible location of the system (inside or outside the hive), and c) the battery life of the system (frequent battery replacement can lead to additional workload and frustration).

Practical demonstration and sharing of experiences with beekeepers who demonstrate PRMs seems to be key. Producers/vendors should prepare themselves for this form of education and aim for real contact with beekeepers at their beekeeping institutions, beekeeping events such as beekeeping seminars, fairs, balls, clubs, etc. Similarly, as Zacepins et al. (2021) mentioned to accelerate the uptake of precision beekeeping, more educational activities and information seminars for beekeepers are needed to explain the potential benefits that these technologies can bring. It would also be advisable to complement these offline activities with online activities, e.g., prepare educational videos, online seminars. Planned activities should be based on customer insights (see RQ1), and take findings from RQ2 and RQ3.

The results of the above research were presented by the author of the article to beekeepers and the professional beekeeping community at COLOSS: Olomouc Beekeeping Seminar 2023, in November 2023, where they were discussed.

Limitations of the paper

The following two areas can be considered as limitations of qualitative research. The first area is the lack of validation of the findings from the interviews with a larger sample of respondents. This could also be an opportunity for further research, where it would be interesting to find relationships between their approach to PB or PMR and the personality of the beekeeper. The second area of limitations relates to not including the use of AI in PB in the research. This area of further ICT development could also be considered in future research.

Conclusion

Today, it is almost impossible to imagine life without the use of ICT because they have also become part of modern agriculture, including beekeeping. In beekeeping, these technologies can be used for remote monitoring of bee colonies and for efficient colony management. Several solutions are available in the context of remote monitoring of bee colonies, mainly monitoring the weight and temperature of hives.

This paper contributes to the mapping of beekeepers' interest in the use of products with monitoring systems for remote bee detection in beekeeping in Czechia. Specifically, the paper focused on mapping the current state of the specifics of the Czech market in relation to PRM in beekeeping, description of PRM customers, benefits of PRM and areas of slowdown in PRM implementation.

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The Impact of Information and Communication Technology (ICT) on Pesticides Use of Potato Farmers in Indonesia

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Abstract

Reducing pesticides is an important driver in preserving a healthy and sustainable environment and protecting human health. In the digital era, understanding the role of information and communication technology (ICT) on pesticide use in crucial. Therefore, This study aim to estimate the impact of ICT on farmers' pesticide used. This study uses a cross-sectional data from a survey to 150 farmers in Indonesia. Furthermore, the data is analyzed by ordinary least square (OLS) and instrumental variable quantile regression (IVQR). The main results indicate that ICT has an essential impact on pesticide used reduction. Farmers who has access on the ICT tend to use lower pesticide that the farmers who did not use the ICT. The IVQR results, make the claim more robust, which is show a negative and significant impact of ICT on farmers pesticide use in all quartile groups. Therefore, this finding implies that there is a need to develop agriculture related ICT continuously among smallholder farmers to reduce the pesticide use.

Keywords

ICT, pesticide, instrumental variable quantile regression, multiple linear regression, Indonesia.

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Introduction

The intensity of pesticide use has played an important role in increasing agricultural yields and global food security in the past few decades. Ma and Zheng (2021)state that excessive use of chemical pesticides can cause various diseases in humans, such as respiratory disorders, cancer, reproductive disorders, neurological dysfunction, and diabetes. In addition, the intensity of pesticide use will pollute the environment through air, soil, or water. Beketov, Kefford, Schäfer, and Liess (2013) reported that pesticide use can reduce 42% of biodiversity worldwide. Reducing pesticides is an important driver in preserving a healthy and sustainable environment and protecting human health. Various strategies in the form of policy instruments and new technologies are being implemented as a way to reduce the use of agrochemicals. Such strategies include setting maximum limits on pesticide use, increasing farmers' knowledge of the dangers of pesticides, and promoting organic farming practices. Furthermore, the Thai government implemented policies in 2015 such as integrated pest management, pesticide taxes based on the level of agrochemical risk (toxicity), and subsidies for biopesticides as an alternative to reduce the use of chemical pesticides (Grovermann, Schreinemachers, Riwthong, and Berger, 2017). This strategy is seen to be able to reduce almost 35% of the use of chemical pesticides without reducing the average income of farmers. On the other hand, crop insurance programs also have an impact on reducing pesticide use in the agricultural sector. This is in line with the statement of Feng, Han, and Qiu (2021), where crop insurance programs not only stabilize agricultural income but also can significantly reduce the intensity of pesticide use. On the other hand, along with technological advancements, the use of information and communication technology (ICT) also influences farmers' decisions in using pesticides (Ma and Zheng, 2021; Zhao, Pan and Xia, 2021).

Various technologies have been introduced to reduce pesticide use as technology develops.

One of them is information and communications technology (ICT) (Chandio et al., 2023; Manjula et al.; Mwenda et al., 2023; Tambo et al., 2023; Zhu et al.). The advancement of information in agriculture plays a crucial role in effective decision making. The rapid technological advancements and changes in the agricultural system require sophisticated and real-time information and knowledge transfer to farmers through existing media (Rahman, Toiba, Nugroho, Sugiono, and Saeri, 2023). The limited knowledge of farmers in making decisions to adopt new agricultural technology, where the information obtained by farmers about new agricultural technology and practices can only be obtained through agricultural extension services organized by the public, resulting in asymmetry of information. Ali (2012) states that ICT has great potential to transform the agricultural system, including small-scale agriculture, into a profitable farming business. Farmers who consider agriculture as a business will practice diversified cropping systems using ICT-based information to facilitate obtaining the desired information.

The rapid progress of ICT makes information about reforestation and the dangers of excessive use of chemicals easily accessible through reliable applications and websites. In Indonesia, examples of such applications and websites are Simbah, Tanihub, and Pak Tani Digital. According to Zhao et al. (2021), the use of ICT has a significant impact on farmers' ability to obtain information. However, in developing countries, many farmers still rely on traditional information sources (such as information passed down from other farmers), which limits small farmers' ability to obtain market information about agricultural inputs or outputs, leading to low productivity in farming businesses (Hennessy and Wolf, 2018). For example, in the purchase of pesticides, farmers may not know the required dosage, so they fail to make decisions on how much to buy due to inadequate information, resulting in information asymmetry and imperfect competition in the market.

Several studies have investigated the relationship between ICT and pesticide use. Like the study conducted by Zhao et al. (2021), they showed that internet use has a significant direct impact on pesticide reduction. The ability of farmers to obtain information about green (environmentally friendly) production and sales through the internet significantly reduces pesticide use and improves agricultural sustainability. Using data from farmers in China, Hou, Huo, and Yin (2019) state that information technologies such as mobile phones, computers, televisions, and radios have the ability to deliver relevant and timely information. The information facilitates making the right decisions to use resources in the most productive and profitable way. Thus, it affects farmers' decisions in purchasing inputs, including pesticides. The next research by Ma and Zheng (2021)states that the use of smartphones significantly increases pesticide expenditure by 33%. They also added that the use of smartphones affects the expenditure on pesticides and fertilizers heterogeneously, and as a result, the use of smartphones has an impact on pesticide expenditure.

Although research on the relationship between ICT and pesticide use has been extensively studied by several researchers before. However, the findings generated are still inconsistent across the characteristics of farmers. This is because of the differences in socio-demographic conditions of the research locations, such as knowledge, experience, and age. This highlights the importance of examining the impact of ICT on pesticide use in Indonesia, which has not yet been studied. As we know, Indonesia is an agrarian country that certainly has a relatively large use of pesticides. According to data from the Ministry of Agriculture, the number of registered pesticide brands from 2015-2020 has increased to almost 1800 brands, including fungicides, herbicides, and insecticides. Therefore, it is important to understand the role of ICT in pesticide use in Indonesia. The main objective of this research is to determine the impact of ICT on pesticide use in the agricultural sector in Indonesia.

Materials and methods

Research data

The research was conducted in Probolinggo Regency and carried out in October-November 2021. The selection of the location was intentionally done or "purposive" based on specific characteristics considered. The research location will be selected in two villages based on the consideration that most of the population work as potato farmers, namely Wonokerso Village and Ledokombo Village. This research uses a data collection technique conducted by Ma and Abdulai (2017), Rahman et al. (2022) and Rahman, Huang, et al. (2023), which employs multistage sampling. The sampling was conducted in East Java Province by purposively selecting two villages in one district of Probolinggo Regency, namely Wonokerso

Village and Ledokombo Village, based on the consideration that these two villages are potato production centers in Probolinggo Regency. The sample selection was done randomly, with a total of 150 potato farmers selected, 75 respondents from each village. Data collection was conducted using a questionnaire administered through direct interviews with the respondents. The interview gathered information about the use of pesticides, age, education, number of family members, farming experience, asset ownership, land size, farmer group membership, off-farm jobs, ICT, and social networks.

Data analysis

Linear regression analysis aims to analyze the value of the dependent variable if the value of the independent variable is increased or decreased. This analysis is based on the relationship between one dependent variable and one or more independent variables. In this study, multiple linear regression is used because it involves one dependent variable, which is pesticide use (Y), and nine independent variables, which consist of ICT adoption (X_1), Age (X_2), Education (X_3), Number of family members (X_4), Farming experience (X_5), Land area (X_6), Asset ownership (X_7), Farmer group (X_8), and Side job (X_9). The multiple linear regression equation used in this study can be formulated as follows:

$$Y = b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_6X_6 + + b_7X_7 + b_8X_8 + b_9X_9 + e_u \quad (1)$$

Multiple linear regression analysis aims to determine the impact of ICT adoption on pesticide use. However, this Multiple Linear Regression analysis has some limitations. Firstly, the multiple linear regression analysis can only measure the impact of ICT adoption on pesticide use homogeneously, while the impact of ICT adoption on different groups of farmers with different pesticide use may differ. The second limitation of multiple linear regression analysis is that it can only observe observable variables such as age, experience, and others. However, variables that are unobservable cannot be analyzed by multiple linear regression analysis, so to overcome this limitation, further analysis is required (such as IVQR).

To measure the impact of ICT adoption on pesticide use, this study uses Instrumental Variable Quantile Regression (IVQR) analysis. With this analysis, we can estimate and measure the impact of ICT adoption on pesticide use heterogeneously by grouping farmers based on the quantile of pesticide use. According to Ma and Zheng (2021), IVQR can be formulated as follows:

$$y_i = q(\mathbf{g}, \mathbf{x'}, \mathbf{u}) = a_t g + \beta_\tau x' + e \quad (2)$$

where y_i represents the pesticide use of farmers, g is the variable of interest which is the use of ICT measured by a dummy variable (1 if farmers use ICT, and 0 otherwise), x' is the vector of exogenous or control variables (i.e. age, education, number of family members, farming experience, asset ownership, land area, farmer group, and side job), and e is the error term. Furthermore, $q(.)$ is a function of the τ-quantile conditional. a_t and β_τ are the parameters to be estimated at the quantile of Pesticide Use. In addition, in estimating IVQR, at least one instrumental variable is required which is expected to have a significant correlation with the variable of interest (i.e. ICT usage), but does not have a significant effect on the outcome variable (pesticide usage). The instrumental variable in this study will use social network (1 if neighbouring households use smartphones, 0 otherwise).

Results and discussion

Descriptive statistics

The results of the descriptive analysis are presented in Table 1. The variables in this study are divided into three groups, including independent variables, dependent variables, and instrumental variables. Table 1 shows the results of the descriptive analysis.

The first independent variable is ICT (smartphone) using a dummy variable with an average value of 0.58 or 58%, indicating that respondents in this study on average have adopted ICT (smartphone). However, the instrumental variable of neighbour's adoption of ICT (smartphone) is relatively low with an average value of 0.35, indicating that 35% of respondents reported that their neighbours did not adopt ICT (smartphone). The average value of the variable of farmer group is 0.57, indicating that 57% of respondents participated in farmer groups and 43% of farmers did not participate in farmer groups. The average age of respondents is around 48 years old with an average education level of 6 years. This indicates that the respondents only completed elementary school, and the minimum education level of respondents is 0 years, indicating that some respondents did not attend school.

Concept of Variables	Indicator Variable	Scale of Measurement	Mean	Std. Dev
Dependent variable	Pesticide use	Liter	17.47	13.24
	ICT (Smartphone)	Dummy	0.58	0.50
	Age	Year	48.18	12.82
	Education	Year	6.47	3.43
	Number of household members	People	3.89	1.41
Independent Variable	Farming experience	Year	31.39	13.72
	land area	Ha	1.71	1.29
	Asset	Dummy	0.73	0.44
	Farmer group	Dummy	0.57	0.50
	Side jobs	Dummy	0.33	0.47
Instrumental variable	IV	Dummy	0.35	0.48

Source: Primary data processed, 2022

Table 1: Descriptive statistic.

However, some respondents have an education level of around 16 years, indicating that they have completed their education up to a bachelor's degree. The average value of farming experience is 31 years with a minimum average value of 1.43% of the maximum value of 70 years, and a minority (33%) of respondents have a side job outside of farming. In agricultural activities, respondents produce an average of 73% of assets such as diesel, storage facilities, and tractors. The average number of household members for the respondents was 1-4 people per household, with an average land area of around 1.71 hectares. The average pesticide usage was 17.47 litters, with a maximum usage of 50 litters and a minimum of 0.93 litters.

Empirical results

The coefficient of determination is used to see the ability of independent variables to contribute to the dependent variable in a certain percentage. The coefficient of determination analysis is used to determine the overall influence of independent variables on the dependent variable. Chicco, Warrens, and Jurman (2021) explained that Adjusted R squared is the coefficient of determination that has been adjusted for the number of variables and sample size. The results of the R-squared test are presented in the Table 2 below.

Based on Table 2, the Adjusted R-square value is 0.452, which means that the independent variables, namely ICT adoption, age, education, number of family members, farming experience, land area, asset ownership, and farmer groups, collectively explain 45.2% of the variation in pesticide use. This influences the dependent variable by 45.2%, while the remaining 65.8% is influenced by other variables that were not used in this study. The constant value obtained is 19.578, which means that when the independent variables used in this study are not present, the value of farmers' pesticide use is 19.578 L.

The F-test aims to determine whether the independent variables, consisting of ICT adoption, age, education, number of family members, farming experience, land area, asset ownership, and farmer group membership, have a significant influence on the dependent variable, which is pesticide use. This study obtained a probability value of F equal to 0.000, which indicates that the independent variables have a significant effect on the dependent variable, which is the use of pesticides.

Next, analysis regression testing is used to determine whether each independent variable in the regression model has a significant effect on the dependent variable individually. The analysis results indicate that the variables of ICT adoption, age, land area, farming experience, side jobs, and assets have a significant effect on pesticide use. However, the number of family members, education, and farmer groups do not have a significant effect on pesticide use.

ICT has a negative and significant effect on pesticide use with a significance level of 1% and a coefficient value of -10.880. This means that farmers who use ICT tend to use 10.880 liters less pesticide compared to farmers who do not use ICT. This is because ICT provides various information related to agricultural activities such as the use of inputs, efficient use of pesticides, and the negative impact of pesticide use on the environment and health.This finding is consistent

Variables	Coefficient	Standard Error	Probability
ICT	-10.880	(2.254)	0.000***
Age	0.470	(0.112)	0.000***
Number of household members	0.388	(0.593)	0.514
Education	-0.203	(0.278)	0.468
Total land area	-2.304	(0.725)	0.002***
Farming experience	-0.595	(0.105)	0.000***
Farmer group	1.311	(1.759)	0.457
Side job	-4.920	(2.172)	0.025**
Asset	6.603	(2.302)	0.005***
_cons	19.578	(4.417)	0.000
F count	14.680		
Prob > F	0.000		
Adj R-squared	0.452		

Note: *** Significant 0,01; ** Significant 0,05
Source: Primary data processed, 2022.

Table 2: The impact of ICT adoption on pesticides use: Multiple Linear Regression Analysis.

with the study conducted by Ma and Zheng (2021), which also found that the use of ICT can significantly reduce pesticide use.

Age has a positive and significant effect on pesticide use with a significance level of 1% and a coefficient value of 0.470. This indicates that when a farmer's age increases by one year, pesticide use will increase by 0.470 L. The age factor affects respondents' understanding in accepting new innovations in the use of pesticides. This finding is in line with Jannah and Sunarko (2018), which also found that age significantly affects the use of pesticides. The age factor affects respondents' understanding in accepting new innovations in the use of pesticides. This finding is in line with Jannah and Sunarko (2018), which also found that age significantly affects the use of pesticides.

Experience in farming also has a significant negative effect on pesticide use with a significance level of 1% and a coefficient value of -0.595. This indicates that for each additional year of farming experience, pesticide use is reduced by 0.595 L. Farmers who have more experience in farming provide knowledge about agricultural inputs and pesticide use. This finding is in line with Adesuyi, Longinus, Olatunde, and Chinedu (2018) study which also found that farming experience significantly affects pesticide use. Total land area has a negative and significant effect on pesticide usage with a significance level of 1% and a coefficient value of -2.304, meaning that when a farmer's land area increases by one hectare, pesticide usage will decrease by 2.304 L. The larger the land area owned by farmers; the less pesticide use per hectare tends to be.

The side job has a negative and significant influence on pesticide use with a significance level of 5% and a coefficient value of -4.920. This indicates that farmers who have side jobs tend to use pesticides 4.920 L less than farmers who do not have side jobs. This is because a side job can reduce the intensity of agricultural activities, including the use of pesticides. However, this finding differs from the previous study by Ma, Abdulai, and Ma (2018), which used pesticide expenditures to measure the pesticide variable. Meanwhile, this study used the amount of pesticide used. Assets have a positive and significant effect on pesticide use with a significance level of 1% and a coefficient value of 6.603. It shows that farmers who have assets tend to use 6.603 more pesticides compared to those who do not have assets. This is because farmers who have assets tend to apply higher intensity of agricultural activities, and this can be seen from the use of pesticides.

The measurement of the impact of ICT usage on pesticide use through IVQR analysis is presented in Table 3. The analysis results show that the use of ICT has a negative and significant impact on all quantiles, including the 20th, 40th, 60th, and 80th quantiles. However, the reduction in pesticide use is lower at the lowest quantile (quantile 20 ICT) at 29.795 liters. This is because ICT provides accurate and efficient information on the use of pesticides. Therefore, farmers who adopt ICT tend to use less pesticides compared to those

Variable	Quintile 20		Quantile 40		Quantile 60		Quantile 80	
	Coef.	Standard Error	Coef.	Standard Error	Coef.	Standard Error	Coef.	Standard Error
ICT	-29.796***	(5.882)	-32.692**	(15.253)	-50.086**	(23.471)	-48.584*	(28.797)
Age	0.355**	(0.160)	0.438	(0.327)	0.812***	(0.277)	0.762**	(0.304)
Number of household members	0.634	(0.516)	0.741	(0.526)	0.612	(0.908)	0.599	(0.944)
Education	-0.206	(0.286)	-0.276	(0.382)	-0.637	(0.520)	-0.585	(0.620)
Total land area	-0.423	(1.085)	0.120	(1.241)	1.142	(2.018)	0.998	(2.183)
Farming experience	-0.357**	(0.175)	-0.477	(0.341)	-0.895***	(0.289)	-0.827***	(0.298)
Farmer group	0.948	(1.625)	1.843	(2.332)	-0.996	(4.124)	-0.836	(4.199)
Side job	0.157	(3.762)	-1.234	(4.065)	0.429	(6.046)	2.104	(6.682)
Aset	20.581***	(2.865)	22.122**	(8.956)	32.154**	(15.956)	30.103*	(18.111)
_Cons	4.641	(6.022)	7.933	(8.268)	17.924	(7.322)	49.308	(18.377)

Note: *** Significant <0.01 ** Significant <0.05 * Significant <0.10
Source: Primary data processed, 2022

Table 3: The impact of ICT adoption on Pesticides Use: IVQR.

who do not adopt it. The finding is consistent with a study conducted by Ma and Zheng (2021) on the impact of ICT adoption on pesticide use. They found that the use of ICT can significantly reduce pesticide use.

The study conducted by Zhao et al. (2021) on ICT's ability to help reduce pesticide use found that the use of ICT has a significant impact on reducing pesticide use by farmers. At the 40th quantile, a significant negative result of 32,692 liters was obtained at a significance level of 0.05%. Quantile 60 also obtained a negative and significant result of 23,471 liters with a significance level of 0.05%, while the highest quantile (Quantile 40) obtained a negative and significant result of 48,584 liters with a significance level of 0.10%. This is because the use of ICT provides farmers with quick information on the proper use of pesticides and improves the efficiency of reducing pesticide use, so ICT can contribute to reducing pesticide use. The negative relationship between ICT use and pesticide reduction is also consistent with the findings of (Zhao et al., 2021).

The influence of independent variables such as age, number of household members, education, total land area, farming experience, farmer groups, side jobs, and assets. The research results showed that farming experience has a positive and significant influence on pesticide use in quartile 20, 60, and 80 with a high significance in quantile 60 (farming experience). This indicates that farmers with more experience tend to have more knowledge about inputs and the use of pesticides in agriculture.

Age has a positive and significant influence on pesticide use in quantiles 20, 60, and 80. The highest significance value was at the 60th quantile (age) of 0.812 liters because young age affects farmers' understanding of pesticide use steps. The asset also has a positive and significant effect on pesticide use in all quantiles, namely in quantiles 20, 40, 60, and 80, with the highest significance value in the lowest quantile, namely quantile 20.This concludes that farmers who have assets tend to use higher amounts of pesticides compared to farmers who do not have assets. Here is the table 3 of IVQR analysis results:

Conclusions

This study aims to investigate the impact of ICT usage on pesticide use. The study was conducted in Probolinggo regency, East Java province, using data from 150 respondents from farmer households. This study used instrumental quantile regression (IVQR). The results of the IVQR analysis found that farming experience has a negative and significant impact on pesticide use. However, asset and age have a positive and significant impact. Asset has a significant impact on the 20th quantile, while age has a significant impact on the 60th quantile, meaning that farming experience, asset, and age have an influence on reducing the use of pesticides. The multiple linear regression analysis results obtained show that farming experience, total land area, and side jobs have a negative and significant impact on pesticide use. Meanwhile, age and assets have a positive and significant impact on pesticide use.

The results of IVQR analysis showed that the use of ICT has a negative and significant impact on the 20th, 40th, 60th, and 80th quantiles. However, the highest reduction in pesticide use is in the lowest quantile or the 20th quantile, which amounts to 29.796 liters with a significance of 0.000. The Multiple Linear Regression Test also shows that the use of ICT has a negative and significant impact on pesticide use. This means that the use of ICT has an impact on reducing pesticide use.

Based on the results of the research and data analysis, the study provides several recommendations as follows: For farmers, this study recommends increasing the use of ICT because it can provide information on more efficient use of pesticides. For the government, it is necessary to increase awareness and capability of farmers in using ICT by providing counseling and training through agricultural institutions and cooperatives. Then, the government needs to improve ICT facilities and infrastructure in rural areas by collaborating with internet providers that can provide better internet access.

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Multivariate Analysis of Food Security and Its Driving Factors

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Abstract

The main objective of the presented paper was the analysis of the current state of food security in the world, segmentation of 100 selected countries and determination of its main driving factors. The analysis used 27 indicators covering 5 basic areas: agricultural production, poverty, demography, economic development, and environmental indicators. The analysis was based on data from the FAO and World Bank for the most recent available period, which was year 2020. The data dimension was reduced with the application of factor analysis, and the main driving factors of food sufficiency were determined. The result was 6 factors: technological development, economic development, agricultural production, environmental factor, and physical quality of life and environment. To group similar countries in terms of selected indicators, a cluster analysis was performed, whereby countries were grouped by similarity into three clusters. The 1st cluster consisted of the most economically developed countries, where only 2.54% of the population suffers from malnutrition. The countries in this cluster were characterized by high levels of economic development, high caloric intake of the population, and high, life expectancy. On the other hand, they recorded negative development in demographic indicators such as fertility and birth rates. The 2nd cluster included the poorest areas of the African continent, which were most endangered by direct food insufficiency (23.74% of the population). In contrast to the first cluster, these countries were characterized by low levels of economic development, high prices, and low-calorie intakes of the population, as well as low life expectancy, while on the other hand, these countries had high fertility and birth rates. The third largest cluster consisted of countries with a medium threat of food insufficiency, where 6.37% of the population suffers from malnutrition. The countries in the third cluster excelled in terms of crop and livestock production volumes, but in contrast to this, they achieved lower levels of fat, protein, and calorie intake of population.

Keywords

Food security issues, driving factors of food security, multidimensional analysis.

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Introduction

Population pressure is significantly concentrated mainly in larger urbanized units, which offer their inhabitants quality education, the opportunity to find a job in the labour market, health care, and concentration of all-important institutions. Yet, because of their boom, large, developed cities must contend with poverty, lack of adequate jobs, and environmental problems. Under such pressure, farmers are forced to change their approach to the land stock in a way that will have as little impact on its erosion as possible. Excessive deforestation is caused by land destruction due to violent urbanism. It is also important to consider production capacity of the soil. Factors adversely affecting the reduction of this capacity are negatively correlated with population pressure. It is therefore important for agricultural production to be diversified to ensure sufficient safe and nutritious food for the future (Putri et al., 2019).

There is a significant correlation between food availability and the occurrence of armed conflicts. Thus, it is obvious that the likelihood of conflict will mainly concern those areas where people suffer from long-term food deprivations. These attacks will focus especially on areas with a good agricultural base (Koren and Baggozzi, 2016).

The pressure caused by military conflicts creates enormous uncertainty. In recent years, we can talk about an intensification of the conflict on the African continent. The most significant escalation is observed especially in the Central African Republic, the Democratic Republic of Congo, and the NW Mozambique (FSIN and Global Network Against Food Crises, 2022). We saw similar adverse developments in the countries of West Africa. This is particularly the case for the states of Mali, Burkina Faso, and Niger, which make up the Sahel region (Raleigh et al., 2021). One of the main causes of conflict in this area is political decisions and constant power struggles. Drought and, in some areas, long rainy seasons are also contributing negatively to the negative development of the situation (Seter et al., 2016).

The countries of East Africa, in particular Ethiopia, South Sudan, Somalia, Burundi, Uganda, Rwanda, and the relevant regions have forced their inhabitants to flee their homes because of ongoing military conflicts. Limited supplies of resources, shutdowns of production, and widespread market restrictions have prevented access to food and necessities of life for thousands of people (FSIN and Global Network Against Food Crises, 2022). Food security may be threatened because of the deepening crisis, especially in the countries of the Middle East and North Africa that are dependent on food imports. The war has greatly disturbed global food security, which has already been affected in the past by rising prices of raw materials. The severely limited export possibilities of cereals and fertilizers in the Black Sea ports resulted mainly in an increase in the prices of wheat and related goods (Hassen and Bilali, 2022).

In Europe and Asia, we have seen also several significant conflicts that have affected the food insufficiency of the population, especially in countries such as Afghanistan, Iraq, Palestine, Syria, and Yemen. The conflict, which has significantly affected the European Union and global food security is war in Ukraine (FSIN and Global Network Against Food Crises, 2022). It has brought various socio-economic problems which have international impact. Russia and Ukraine have a significant share of corn and wheat exports, the prices of which have increased substantially due to the military conflict and sanctions against Russia. High prices of inputs to production and the production process itself will push commodity prices even higher, especially for energy-intensive goods. Oil and gas outages from Russia have significantly threatened individual countries, and therefore the primary goal should be to reduce dependence on energy imports and increase self-sufficiency (Mayr, 2022).

Climate change is also factor with a significant impact on crop cultivation. In the future, it will change substantially the cultivation of agricultural commodities in some regions. It is therefore important that crop production systems adapt more quickly to expanded urbanization, and the high rate of population growth, to ensure food sufficiency in the affected regions (Kogo, 2020).

Several predictions for the upcoming decades warn that population growth and changing consumer preferences caused by scarcity of land resources and drinking water will seriously threaten world food allocations. To avert these predictions, several measures have been proposed to regulate future food supplies to all parts of the world. These measures concern:

- changes in the eating habits of individuals,
- reducing food waste (Kummu et al., 2017),
- productivity growth, reduction inefficiencies and management costs, and overall improvement of cross-sectoral cooperation within the food sector through information technology (Bilali and Allahyari, 2018),
- reducing phosphorus, nitrogen, and carbon dioxide production to sustainable levels (Willet et al., 2019),
- optimization of distribution channels of agricultural production (Davis et al., 2017).

Nowadays, new forms and approaches to farming and processing of agricultural production are coming to the front. It is assumed that the use of genetically modified crops will play a key role in ensuring sufficient, safe, and sustainable food in the future. Through genetic modification, farmers can transform plants in a way that improves their resistance to drought, various diseases, and pests or enriches their nutritional value, which is an essential part of sustainable production in the context of population expansion and food shortages (Vij and Tyagi, 2007).

The consequences of climate change will also affect access to safe water. With current population growth and changing dietary habits, is predicted increase of current water demand by 22% by 2090 because of changing climatic conditions (Mekonnen and Gerbens-Leenes, 2020).

It is necessary to accurately predict the development and changes in population size which helps to detect problems related to the deficiency of resources in the future, such as a shortage of drinking water, fuel, electricity, and food. We should also focus on the environmental burden on the planet associated with overpopulation (Mazzuco and Keilman, 2020). Currently, about 8 billion people live in the world.

The main objective of the presented paper is to find an optimal segmentation of countries on food security and nutritional status that are similar in a cluster but are different from observations in other clusters with the application of cluster analysis. The partial objective was to identify the main driving factors of food security. This was achieved with the application of factor analysis, which allowed us to reduce the dimension of the data and determine facts that were used as input variables in cluster analysis.

Cluster analysis was used previously in several food and nutrition studies. Most of them applied this kind of analysis at the micro-level to create a typology of households based on their food security characteristics as Mariovet et al. (2019). Smith et al. (2000) analysed a sample of developing countries in the period of the 1990s and found poverty as the main constraint for food security improvement. According to his results, many countries also faced problems with national food availability, and cluster analysis in this case was used primarily for poverty mapping.

According to Babu and Gajanan (2022), there are three reasons to use cluster analysis for the investigation of food security:

- Poverty maps are an important tool for targeting resources and interventions more effectively.
- Maps allow visual comparison and help to investigate spatial trends, clusters, or other patterns in the data.
- As one maps the geographic data, it allows one to show variability in data, especially geographic variation in poverty, which is related to different conditions in resources and living conditions.

Several research has analysed dietary patterns by application of cluster analysis based on the data coming from the food frequency questionnaires (see, for example, Wirfalt and Jeffery 1997, Greenwood et al. 2000, Millen et al. 2001). It is important to note that these studies have been undertaken mainly for developed countries such as the United States and European countries. The findings of these studies, in general, indicate the existence of distinct dietary patterns in the analysed population.

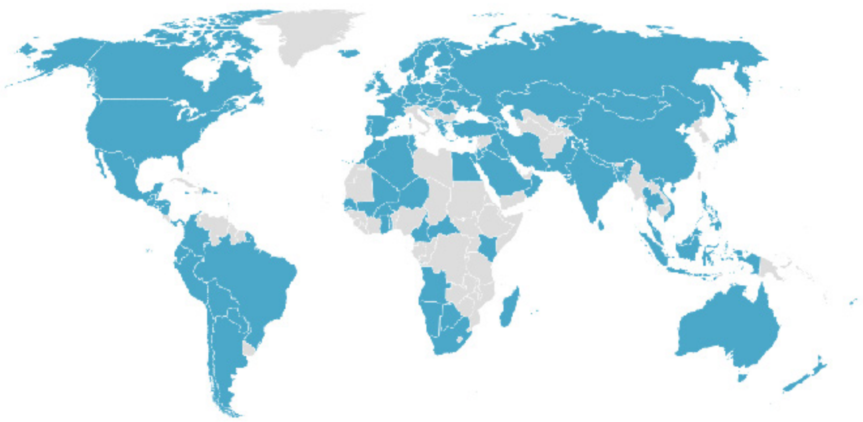
In addition, cluster analysis is usually applied to factor analysis when studying food security. Babu and Gajanan (2022) state two main advantages of this procedure:

- Factor analysis achieves data reduction and helps to summarize data when investigating food security. Analysed variables are usually linearly related to the Kaisere-Meyere-Olkin (KMO) measure which indicates that a factor analysis is appropriate method.
- Food security is determined by a set of complex variables, such as food accessibility, food availability, technology, economic development, and market access variables, it is important to condense the information contained in many variables into a smaller number of factors.

Materials and methods

Practical part of paper is devoted to the analysis of selected countries and their mutual characteristics. The choice of countries, analysed indicators, and the investigated period was influenced by the availability of data retrieved from the databases FAOstat and World Bank.

The following countries were included in the analysis: Albania, Algeria, Angola, Argentina, Armenia, Australia, Austria, Azerbaijan, Bangladesh, Belarus, Belize, Belgium, Bolivia, Botswana, Brazil, Burkina Faso, Canada, Cameroon, Chile, China, Central African Republic, Colombia, Croatia, Cyprus, Czech Republic, Dominican Republic, Denmark, Ecuador, Egypt, El Salvador, Estonia, Fiji, Finland, France, Germany, The Gambia, Georgia, Ghana, Greece, Guatemala, Honduras, Hungary, Iceland, India, Indonesia, Iraq, Iran, Ireland, Israel, Jamaica, Japan, Jordan, Kazakhstan, Kenya, Kuwait, Kyrgyzstan, Latvia, Lithuania, Madagascar, Malaysia, Mali, Malta, Mauritius, Mexico, Mongolia, Morocco, Namibia, Nepal, Netherlands, New Zealand, Nicaragua, Niger, North Macedonia, Norway, Oman, Pakistan, Panama, Paraguay, Peru, Poland, Philippines, Portugal, Russia, Romania, Saudi Arabia, Senegal, Slovak Republic, South Africa, Sri Lanka, Spain, Switzerland, Sweden, Thailand, Togolese Republic, Tunisia, Turkey, Ukraine, England, United States and Vietnam. In total, analysis covers 110 world countries shown in Figure 1.



Source: Author´s work

Figure 1: Countries included in the presented study.

Countries were assessed based on 27 indicators in period of year 2020, which can generally be classified into the following 5 categories:

1. Agricultural output indicators
   - Agricultural land per. capita (ha/km^2) – Agri_land,
   - Agriculture, forestry, and fishing (in USD p. capita) - Forest,
   - Cereal production per capita (in tonnes) – Cereal_p,
   - Index of plant production (2014 – 2016 = 100) – Crop,
   - Livestock production index (2014 – 2016 = 100) – Livestock,
2. Poverty indicators
   - Access to clean fuels and cooking technologies (% of the population) – Tech_cook,
   - Access to electricity (% of the population) – Electr,
   - Fertility rate of adolescents aged 15-19 years (per 1000 women) – Adol_fert,
   - Total population with access to safe drinking water (% of the population) – Water,
   - Health care expenditure per capita (in USD) – Health_exp,
   - Infant mortality (per 1000 live births) – Mort_rat,
   - Prevalence of malnutrition (% of the population) – Undnrsh,
   - Calorie intake per day (per capita) – Kcal,
   - Protein intake per day (per capita) – Protein,
   - Fat intake per day (per capita) – Fat,
3. Demographic indicators
   - Birth rate, gross rate (per 1000 inhabitants) – Birth_r,
   - Mortality, crude rate (per 1000 inhabitants) – Death_r,
   - Total fertility (births per woman) – Fert_r,
   - Life expectancy (years) – Life_exp,
4. Economic indicators
   - Consumer price index (2010 = 100) – CPI,
   - GDP per capita (2015 = 100, in USD) – GDP_pc,
   - Household final consumption expenditure (% of GDP) – House_exp,
5. Environmental indicators
   - Methane emissions from agricultural production (in tonnes p. capita) – Meth_em,
   - Nitrous oxide emissions from agricultural production (in tones p. capita) – Nitro_em,
   - Fertiliser consumption (kg per ha) – Fertiliz_con,
   - Pesticide consumption in agriculture (in tonnes p. capita) – Pesticid_agr,
   - Temperature changes (in ℃) – Temp.

The relationship between input variables was analysed using Pearson´s correlation coefficients, which can be calculated using the following Equation 1:

$$r_{xy} = \frac{cov(X,Y)}{s_X s_Y} \quad (1)$$

Where *cov(x,y)* is the covariance between *X* and *Y*,

s_X is the standard deviation of *X*,

s_Y is the standard deviation of *Y*.

A value close to 1 means a strong positive relationship – if the first variable increase, then increase also the second variable. Correlation coefficient values close to 0 mean weak or no relationship between variables. Value close to -1 means a strong negative relationship – if the first variable increase, the second one decrease. The significance of correlation coefficient can be verified using test statistics in the form of Equation 2:

$$t = r\sqrt{\frac{n-2}{1-r^2}} \quad (2)$$

Where *t* denotes test statistics value,

r value of correlation coefficient and

n number of observations

Statistics follow t distribution with *n*-2 degrees of freedom.

If the test statistics exceed the critical value, it means the rejection of the null hypothesis about the zero value of the correlation coefficient and the relationship between variables is significant. On the other side, if the test statistics are smaller than the critical value, the correlation between variables is not significant.

Factor analysis was applied to reduce the data dimension and to determine driving factors of food security.

In general, factor analysis can be described as a multidimensional statistical method whose main goal is to reduce data dimension from a wide range of variables and summarize it into smaller number of factors. It assumes multicollinearity in data, which is eliminated by its application. Furthermore, the Kaiser-Mayer-Olkin measure characteristic was used (Equation 3):

$$KMO = \frac{\sum_{i\neq j}^{m}\sum_{j\neq i}^{m} r_{ij}^2}{\sum_{i\neq j}^{m}\sum_{j\neq i}^{m} r_{ij}^2 + \sum_{i\neq j}^{m}\sum_{j\neq i}^{m} a_{ij}^2} \quad (3)$$

Where r_{ij}^2 – Pearson´s correlation coefficient between two variables

a_{ij}^2 - partial correlation coefficient

Countries were divided into clusters according to their level of food security indicators using cluster analysis. Driving factors of food security obtained by factor analysis were used as input to cluster analysis.

The main idea behind grouping objects into clusters is their similarity to each other. It is therefore desirable that objects included in the same cluster should be as similar as possible and, conversely, that they should differ as much as possible from objects classified in other clusters (Stankovičová and Vojtková,2007). In the presented paper was used Ward´s minimum variance method of clustering with Euclidean distance between points.

The selection of number of significant clusters is first step in this analysis. This can be determined from a heuristic point of view, where decisions are made based on an assessment of the graphical results of the dendrogram or by using aggregation quality indicators, which include standard deviation, coefficient of determination, semi-partial coefficient of determination and cluster distance. Analysis was performed in SAS Enterprise Guide 7.1.

Results and discussion

The analysis included 100 countries from around the world in the period of year 2020. Based on indicators of agricultural production, poverty, demography, economic development, and environmental indicators, it can be concluded, that on average 92.26% of the population of analysed countries has access to electricity (Electr), while there are countries where only about 15% of the population has access to electricity (Table 1). On average, 92.8% of the population has access to safe drinking water, but minimum value is only 49% of the population. The cereal production per capita in tonnes (Cereal_p) also varies across regions. There are countries where production per capita is 2.34 tonnes, but also countries where cereals are not grown at all. The incidence of malnutrition (Undnrsh) also shows large regional differences. Average value in the sample was 7.52% of the population, which suffers from malnutrition, yet there are countries with value up to 52.2%. Health care (Health_exp) spending in countries ranges from $19.85 to $10921.01 per capita. This is also reflected in the Life Expectancy (Life_exp) indicator, with smaller value than 55 years in developing countries, while in economically developed countries it is up to 84.62 years. Among economic indicators, the Consumer Price Index (CPI) is interesting, ranging from 98.82 in developed countries to 895.09 in less developed regions. Descriptive characteristics of analysed indicators shows significant differences between world regions.

	Mean	St Dev	Minimum	Maximum
Tech_cook	78.97	30.30	0.80	100.00
Electr	92.26	18.66	15.47	100.00
Adol_fert	39.23	36.37	2.41	177.46
Agri_land	0.02	0.04	0.00	0.34
Meth_em	0.0007	0.0009	0.0000	0.0054
Nitro_em	0.0005	0.0006	0.0000	0.0041
Forest	495.22	372.95	111.17	2711.55
Water	92.80	10.88	49.00	100.00
Birth_r	16.99	8.82	6.80	45.59
Cereal_p	0.42	0.49	0.00	2.34
CPI	162.11	113.86	98.82	895.09
Health_exp	1542.93	2256.10	19.85	10921.01
Death_r	8.47	2.95	2.91	15.90
Fert_r	2.29	1.15	1.13	6.89
Fertiliz_con	202.16	311.69	0.19	1952.09
GDP_pc	15779.33	19142.38	375.22	84434.78
House_exp	61.46	12.62	24.86	91.20
Life_exp	73.86	6.63	54.60	84.62
Mort_rat	14.60	14.88	1.50	77.50
Undnrsh	7.52	8.49	2.50	52.20
Kcal	2977.71	449.77	1846.70	3829.00
Protein	84.80	20.52	25.01	135.25
Fat	97.88	38.07	23.15	177.60
Pesticid_agr	0.0006	0.0008	0.0000	0.0053
Temp	1.71	0.72	0.08	3.69
Crop	108.45	20.76	55.87	205.88
Livestock	108.64	14.73	86.39	177.18

Source: Author´s work based on data from FAO and World Bank

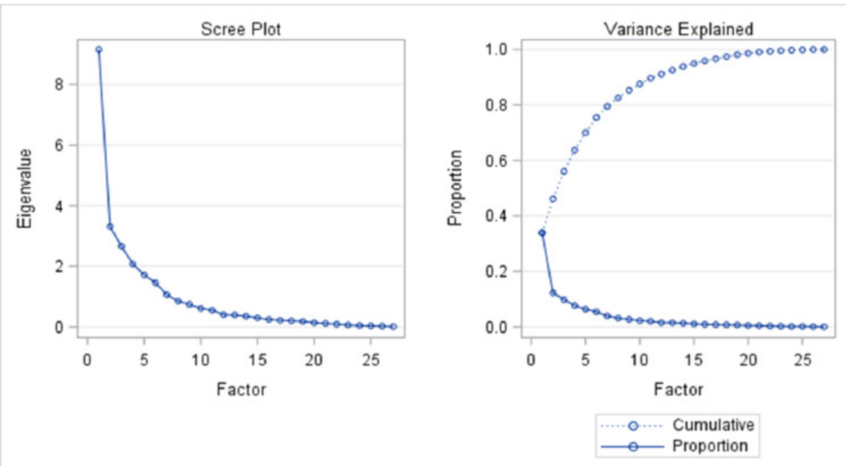
Table 1: Descriptive characteristics of analysed indicators.

To measure multicollinearity between indicators, was used the Pearson correlation coefficient, the results of which showed that there is a strong dependence between most indicators. KMO statistics reached 0.79, which means that data are suitable for factor analysis. The number of factors was determined according to eigenvalues and proportion of explained variability. The variability was explained at 79%, and the number of factors in which eigenvalues reached values greater than 1 was seven (Figure 2). The most of analysed variables are in first two factors, which explains approximately 50% of original indicators variability. In case of using just first two factors in further analysis, results would not consider agricultural production and environmental factors. This could cause smaller number of groups in results of cluster analysis.

Factor analysis was performed with orthogonal equamax rotation. Not all indicators had a clear classification, as the factor weights of some indicators exceeded value 0.5 within the two groups. Interpretation of these variables in relation to factors was based on logical reasons and a higher factor weight. The results and the actual classification of indicators into factors are presented in Table 2. The appropriate number of factors was 6 that can be seen in Table 2.

Based on results of factor analysis can be driving factors of food security interpreted as follows:

- Factor 1 – has the highest weights in variables electricity, access to water, life expectancy, and percentage of population with access to clean fuels and cooking technologies (Tech_cook variable), which



Source: Author´s work

Figure 2: Scree plot – determination of number of factors.

Rotated Factor Pattern						
	Factor1	**Factor2**	**Factor3**	**Factor4**	**Factor5**	**Factor6**
Electr	**0.77**	0.13	0.25	-0.11	-0.36	-0.33
Water	**0.65**	0.24	0.42	-0.09	-0.32	-0.26
Life_exp	**0.64**	0.37	0.30	-0.11	-0.29	-0.42
Tech_cook	**0.62**	0.34	0.28	-0.05	-0.38	-0.21
Cereal_p	**0.52**	0.49	0.04	0.25	0.09	0.32
Undnrsh	**-0.63**	-0.36	-0.39	0.12	0.21	0.16
Adol_fert	**-0.63**	-0.16	-0.30	0.00	0.56	0.19
Mort_rat	**-0.68**	-0.26	-0.42	0.04	0.32	0.33
Birth_r	**-0.77**	-0.15	-0.37	-0.01	0.40	0.04
Fert_r	**-0.79**	-0.08	-0.36	-0.02	0.35	0.10
Health_exp	0.10	**0.83**	0.25	0.06	-0.26	-0.04
GDP_pc	0.12	**0.80**	0.26	0.12	-0.37	-0.11
Fat	0.40	**0.69**	0.39	0.09	-0.27	-0.04
Protein	0.50	**0.60**	0.32	0.09	-0.29	-0.04
Forest	0.07	**0.59**	0.20	0.26	-0.16	-0.33
Kcal	0.55	**0.59**	0.33	-0.06	-0.27	-0.09
CPI	-0.01	**0.58**	0.28	-0.12	-0.08	-0.12
Crop	-0.02	0.14	**0.86**	-0.14	-0.07	-0.20
Livestock	0.14	0.11	**0.75**	0.16	-0.17	0.40
Nitro_em	-0.05	0.13	0.03	**0.96**	-0.01	0.01
Meth_em	-0.04	0.12	0.01	**0.92**	0.05	-0.10
Agri_land	0.02	-0.16	-0.09	**0.82**	-0.07	0.08
House_exp	-0.07	-0.18	-0.15	-0.08	**0.63**	0.16
Pesticid_agr	0.33	0.30	0.27	0.10	**0.58**	-0.34
Death_r	-0.29	0.09	0.10	0.12	0.03	**0.81**
Temp	0.34	0.21	0.14	-0.18	-0.45	**0.60**
Fertiliz_con	-0.06	0.24	0.17	0.08	-0.27	**-0.56**

Source: Author´s work based on data from FAO and World Bank

Table 2: Factor weights after rotation.

can be concluded as development factor in technological sense.

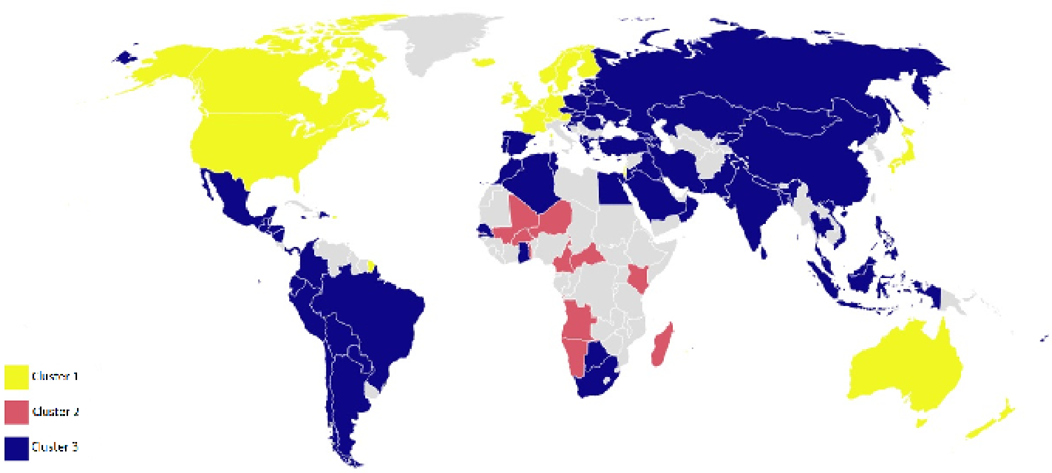
- Factor 2 – the highest weights have this factor for variables health expenditures, GDP per capita, and caloric, fat, and protein supply. This could be concluded as economic development because high values of these variables are characteristic for developed countries.
- Factor 3 – the highest weights have factor 3 for variables crop and livestock production, which could be concluded as a food production factor.
- Factor 4 – highest weights can be found in variables Nitro emissions, Methane emissions, and agricultural land. These variables could be concluded as environmental factors.
- Factor 5 – the highest weight has a factor in variables household expenditures and pesticides in agriculture.
- Factor 6 – highest weights have variables Death rate and temperature change. The last two factors are related to the physical quality of life and environment.

Subsequently, based on 6 factors described above was performed a cluster analysis The number of clusters was determined based on semi-partial coefficient of determination. The optimal number of clusters is 3 clusters. Based on the distribution function, which was used to verify the correct classification of countries in clusters with the cross-verification method, it could be considered to relocate Canada from cluster 1 to cluster 3 and Namibia from cluster 2 to cluster 3. Distribution of countries across clusters is shown on Figure 3.

The first cluster contained the most developed countries which are least affected by food insufficiency. Cluster included Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Iceland, Ireland, Japan, Malta, the Netherlands, New Zealand, Norway, Sweden, Switzerland, England, and the United States. 100% of the population in all these countries had access to the electricity. The same result was recorded also in case of the availability of green fuels and cooking technologies. In terms of the prevalence of malnutrition, all countries performed equally, with only 2.5% of the population. The average daily caloric consumption of an adult was 3051 kcal, with proteins making up 88 g and fat 106.5 g. 99.8% of the population had access to clean and safe water. The average gross domestic product was $49,523 per person. In terms of healthcare spending, the highest cost was about $10921 per person for residents of the United States, where life expectancy reached 77.3 years. Japanese residents lived the longest, dying on average at the age of 84.6 years. The largest area of agricultural land of 13.87 hectares per person was in Australia, where was recorded the highest use of pesticide with 2.5 kg per ha. of land. The largest grain producers included Canada, Denmark, and the United States of America, where the average grain production was 1540 kg per person. From a climatic point of view, this cluster experienced the highest temperature increase, with average value equal to 1.93 ℃.

The second cluster consisted of the poorest regions of the African continent, which were most at risk of direct food insufficiency. 11 countries were included in the cluster: Angola, Burkina Faso, Cameroon, Central African Republic, Gambia, Kenya, Madagascar, Mali, Namibia, Niger, and Togo. 52.2% of the Central African Republic population was at risk of malnutrition prevalence, followed by Madagascar with 48.5%. The average daily caloric consumption of an adult was 3031.34 kcal per day, while the daily intake of protein and fat was 86.7 g and 98.7 g, respectively. On average, 70% of the population had access to drinking water. Life expectancy does not vary significantly between countries in the second cluster, with an average value of 61 years. Demographically, there were an average of 35.8 births per 1,000 inhabitants. However, mortality in new-borns was high, with 46 dying out of 1,000 babies born. The highest recorded GDP per capita in second cluster was in Namibia equal about $4155.13. By contrast, the lowest GDP per capita in the Central African Republic was $375.22.

The third and most numerous cluster consisted of Albania, Algeria, Argentina, Armenia, Azerbaijan, Bangladesh, Belarus, Belize, Bolivia, Botswana, Brazil, Chile, China, Colombia, Croatia, Czech Republic, Dominican Republic, Ecuador, Egypt, El Salvador, Estonia, Fiji, Georgia, Ghana, Greece, Honduras, Hungary, India, Indonesia, Iraq, Iran, Jamaica, Jordan, Kyrgyzstan, Lithuania, Latvia, Malaysia, Mauritius, Mexico, Mongolia, Morocco, Nepal, Nicaragua, North Macedonia, Oman, Pakistan, Panama, Paraguay, Peru, Poland, Philippines, Portugal, Russia, Romania, Saudi Arabia, Senegal, Slovak Republic, South Africa, Sri Lanka, Spain, Thailand, Tunisia, Turkey, Ukraine, and Vietnam. These countries could be



Source: Author´s work based on data from FAO and World Bank

Figure 3: Segmentation of countries into clusters.

characterized by medium risk of food insufficiency. The prevalence of food insufficiency was most obvious among the population of Botswana, where 21.9% of the population was directly at risk of food insufficiency. Daily caloric intake ranged from 1872 kcal to 3574 kcal per person, with Malaysian residents at the lower end of the range and Ghana residents at the upper limit. The average number of inhabitants with access to clean drinking water was 94.4%. Limited access to fuels and meal preparation technologies was most pronounced in Bangladesh, Fiji, Ghana, Guatemala, Honduras, Nepal, Pakistan, the Philippines, Sri Lanka, and Senegal, where the average population with access to these technologies was 38.6%. The country with the largest area of agricultural land was Mongolia, with a land area of 34.2 hectares per person. Lithuania became the largest grain producer per capita in 2020, accounting for 2340 kg of grain per person. Other important producers include Argentina with a production of 1910 kg of grain and Ukraine with 1460 kg of grain per capita. Life expectancy in third-cluster countries was 73.5 years. The lowest spending on health care was for Pakistani residents, with a share of $39.5 per person. By contrast, the highest $2711.19 value in cluster 3 was recorded in Spain.

It should be noted that year 2020 was influenced by spread of Covid 19 in the world. Variables such as health care expenditures, life expectancy and mortality rate could be influenced by pandemic situation, which should be considered when interpreting results. One of possible effect could be impact on reliability of collected data. The largest relative increase in mortality rate in pandemic year between analysed countries was recorded in Albania, Armenia, Chile, Ecuador, El Salvador, Japan, Mexico, Lithuania, and North Macedonia. Almost all countries belong to cluster 3, only Japan is from cluster 1. The largest decrease in life expectancy in pandemic year was recorded in Mexico, Bolivia, Azerbaijan, and Ecuador which are also countries from cluster 3. This result suggests, that Covid 19 pandemic has the worst impact on countries in cluster 3 and mostly on South American countries. Health care expenditures in 2020 in many countries increased, and the highest percentage increase due to pandemic situation was recorded in Armenia, Azerbaijan, Bangladesh, Ecuador, and China.

The overall comparison of clusters in terms of input indicators' mean values is shown in Table 3. The cluster with the highest value for every variable is highlighted in bold. The worst situation is in cluster 2. Countries in this cluster have the highest average fertility, and mortality rate with the smallest average life expectancy. There is also a slightly higher value of agricultural area, but on the other hand also the highest prices and expenditures in comparison with other clusters. Countries in this cluster have also the smallest agricultural production, problems with population access to water, and a significant prevalence of undernourishment in the population. An interesting fact is, that despite of significant prevalence of undernourishment in the population is average caloric supply in these countries higher than in cluster 3 countries.

Variable	Cluster 1	Cluster 2	Cluster 3
Tech_cook	**100**	15.08	83.05
Electr	**100**	44.87	97.57
Adol_fert	7.3	**108.55**	37.43
Agri_land	0.01	**0.02**	0.01
Meth_em	0	0.001	0.001
Nitro_em	0	0.001	0.001
Forest	**845.42**	224.58	436.86
Water	**99.85**	69.96	94.39
Birth_r	10.5	**35.8**	15.87
Cereal_p	**0.53**	0.16	0.43
CPI	114.72	**174.93**	173.8
Health_exp	**5562.09**	80.18	611.15
Death_r	**8.83**	8.4	8.38
Fert_r	1.6	**4.86**	2.08
Fertiliz_con	313.58	14.56	199.77
GDP_pc	49523.57	1235.84	8316.92
House_exp	49.94	**73.04**	62.95
Life_exp	**81.97**	61.08	73.55
Mort_rat	3.19	**46.18**	12.87
Undnrsh	2.54	**23.74**	6.37
Kcal	**3051.92**	3031.34	2947.65
Protein	**88.24**	86.72	83.5
Fat	**106.51**	98.68	95.25
Pesticid_agr	0	0.0001	0.001
Temp	**1.93**	1.27	1.71
Crop	93.74	111.78	**112.18**
Livestock	103.19	107.52	**110.39**

Source: Author´s work based on data from FAO and World Bank

Table 3: Comparison of mean values in clusters.

Cluster 1 is in sharp contrast with cluster 2. This cluster includes the most developed countries, with a high technological level of development. Countries have the highest agricultural production, the smallest average price index and household expenditures, and a very small prevalence of undernourishment. In contrast with cluster 2, it also has much higher life expectancy and smaller mortality rates, on the other side, with the lowest average birth and fertility rates.

It seems that cluster 3 is not interesting, because it does not look the best or the worst. But it is noteworthy, that this cluster recorded the highest average crop and livestock production compared to other clusters. Despite this fact was recorded the smallest average caloric, protein, and fat supply in this cluster.

Discussion

Results of presented paper divide countries into segments according to their food security performance. This helped to analyse spatial trends as it was stated by Babu and Gajanan (2022) and to analyse geographic variation in selected variables. Each segment should be treated differently to ensure sustainable food security. The worst situation is in countries in cluster 2. All countries within this cluster are from African region which is influenced by uncertainty caused by military conflicts, as it was stated by FSIN and Global Network Against Food Crises (2022) and Raleight et al. Results also confirmed conclusion by Seter et al. (2016) that negative development in this area is supported also by drought and water shortages. Significant problem could be possible also fast population growth which also confirmed Kogo (2020), Mazzuco and Keilman (2020).

On the other side, best food security level was recorded in cluster 1 which consists of the most developed countries. Food security issues in these countries have different nature. In these countries is enough food. Questionable can be its nutritional value. In contrast with prevalence of undernourishment in cluster 2 is large caloric intake per day in cluster 1. Results support suggestions by Kummu et al. (2017), that developed countries should focus more on changes in the eating habits of their inhabitants. These countries currently also use the highest number of fertilizers and are significantly influenced by climate change. Challenging for developed countries can be optimization of agricultural production in sustainable way and reducing emissions as it was suggested also by Willet et al. (2019) and Davis et al. (2017).

On the most numerous cluster 3 could be applied some characteristics from both previous clusters. This cluster does not seem to be interesting, because it is not the best nor the worst. To climate change and sustainability challenge could be added also fight with poverty in weak social groups, which remains the main constraint for food security improvement in many countries, especially in South American, African, and Asian countries within cluster 3. Social help could be addressed by created characteristics of food insecure households based on microdata similarly to study conducted by Mariovet et al. (2019) and Smith et al. (2000). Presented study created typology of countries, which could help to address appropriate food security help for analysed countries at global level.

Conclusion

Food security is a multidimensional issue related to many sociological, environmental, and economic aspects. The comparison of the examined countries was based on set of 27 indicators which covered 5 areas: agriculture, economy, poverty, demography, and environment. Results helped to identify similarities and differences among analysed countries. There has been significant contrast among the most advanced countries and food sufficiency of the least developed countries.

Variables in the selected 5 dimensions were used as the input to factor analysis to determine the main driving factors of food security. Based on its results were identified following factors: technological development, economic development, food production, environmental factor, and physical quality of life. These factors were used as inputs to cluster analysis to divide world countries into segments based on their food security situation. This procedure considered the multidimensional nature of the food security topic.

Based on the cluster analysis, countries were divided into three clusters, between which there are significant differences in most indicators. The first cluster consisted of economically developed countries with minimal levels of food insufficiency, the second cluster consisted of the least developed countries, and the third consisted of the largest group of countries with moderate levels of food security risk. Population of all countries in the first cluster have access to electricity. Third-cluster countries with moderate food insufficiency rates have access to electricity in an average of 97.6% of population. By contrast, only 44.9% of the population in the second cluster countries have access to electricity. In terms of growing cereals, which has a crucial role in food energy intake, China (3rd cluster) and the United States (1st cluster) were world leaders.

The results obtained in case of malnutrition incidence reflected significant differences between the studied countries. The conclusion was that countries in Africa, but also Central and South America and Asia, were most at risk. On average, people are malnourished in 23.74% of population of Cluster 2 countries, and in 6.37% of population in Cluster 2 countries. The relationship between malnutrition and the daily energy intake of adults has made it possible to analyse in-depth countries whose inhabitants should enrich their diets with energy-rich foods.

In case of limited resources of fresh drinking water, was analysis focused on countries where access to safe water was limited. It should be noted that the most vulnerable countries included Angola, Senegal, Namibia, Madagascar, Niger, Kenya, and the Central African Republic (1st cluster access to safe drinking water in 99.85% of population, second cluster 69.96% of population and third cluster 94.39%). Even though developed countries are not in risk in terms of drinking water access, it is assumed that by 2050 these countries will also record a water shortage. Another environmental problem which should be emphasized is the production of carbon dioxide, which, together with other greenhouse gases, has the largest influence on climate change. A major problem is also the dramatic deforestation that was recorded, both in the Amazon rainforest and in other parts of the world.

Comparison of clusters in terms of healthcare expenditure and related life expectancy also revealed significant differences. While Cluster 1 countries spend an average of $5562 per capita on health care and life expectancy is therefore the highest (81.97 years), in Cluster 2 countries health care expenditure is the lowest, averaging $80.18 per capita, which also affects the lowest life expectancy of 61.08 years.

The results of our analysis showed the contrast between the developed world and poor countries. Developed countries evaluated as food secure must solve issues with population aging and unhealthy diet. On the other side, African countries evaluated in our results as the most food insecure, have problems with the large prevalence of undernourishment, poor health care, and fast growth of population.

Acknowledgments

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The Relationship Between Agricultural Holdings and Municipalities

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Abstract

The aim of the paper is to assess the differences in opinions on relation of agricultural holdings (agri-holdings) and the municipalities. Whether the relationship rating depended on the intensity of cooperation in particular area (social life, public benefit activities, ecological activities and strategic planning) was tested.

The relationship was rated positively in majority of cases which helped to create social capital in the locality. Strong influence on it had sponsorship of the fire brigade (from point of view of agri-holdings). From the standpoint of municipalities, almost all activities were important. Better promotion of agri-holdings' activities in all areas can be suggested as not all actions of agri-holdings were known to the representants of the municipality. Negative relationship was mainly due to the agri-holding damaging the environment. Hence, responsible behaviour is an important for the agri-holding reputation.

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Keywords

Agricultural holding, social responsibility, municipality, relationship, social capital, stakeholder.

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Introduction

Stakeholder is a person or group that can influence the firm and is influenced by the firm such as suppliers, customers, employees and management of the firm, state, municipality's representatives etc. Agricultural firms have special position as their activities influence large groups of stakeholders, because agricultural activities take place in certain cadaster of the municipality / municipalities. Also, agriculture can be considered an important activity in rural areas and the interaction between local government and the agricultural entity is part of rural life (Boukalová and Pechrová, 2013).

Therefore, their relations toward the environment and stakeholders are essential. Corporate social responsibility (CSR) in agriculture has been assessed recently by many scholars, especially in the context of the environmental protection and rural development. "It is widely acknowledged nowadays that agricultural production has to comply not only with the economic and legal requirements, but also with the ethical responsibilities" (de Olde and Valentinov, 2019). "CSR is considered the response to the increasing social demand aiming to create the win-win situation for all actors of supply chain and society." (Levkivska and Levkovych, 2017).

CSR represents a broad concept where the firms is voluntarily involved in a series of commitments towards the society and the environment beyond legal and regulatory requirements. These commitments involve considering the expectations and interests of all the agents that affect or are affected by the company's activity. In this regard, the stakeholder theory (Freeman, 1984), which is one of the most widely used in the literature on CSR, claims that an organization is made up of a series of agents (stakeholders) that affect its activity or are affected by business decisions. From this point of view, "CSR can be observed as a multidimensional concept in the agri-food domain, which captures CSR orientation towards shareholders, employees, customers, farmers, community, and competition, as main firms' stakeholders" (Coppola et al. 2020).

The stakeholder theory believes that the exchange and division of various resources between a corporation and its stakeholders is a necessary condition for its success (Yuan and Cao, 2022). "Organizations are dependent on stakeholders for many reasons, from survival, the fulfilment of goals, success and value creation, to providing resources or a license to operate." (Miles, 2017). The activities have several layers. Carroll (1991) created a pyramid of CSR where the base are economic responsibilities, then there are legal, ethical and philanthropic responsibilities. However, Luhmann and Theuvsen (2017) who focused on consumers' perception of CSR by agricultural holdings in Germany found that "consumers distinguish between different responsibility levels, that is, they separate economic commitment from other internal and external aspects of a firm's CSR commitment but do not actually distinguish between legal, ethical and philanthropic responsibilities." (Luhmann and Theuvsen, 2017).

CSR activities shall contribute to the competitiveness of the firm and enhance their reputation. The link of company's CSR practices to firm's financial performance is through the reputational mechanisms (Yang and Stohl, 2020). All businesses, in addition to the objective of profit maximization shall observe their effect to the environment, consumers, employees and community. (Matei and Done, 2011) As stated by Mazur-Wierzbicka (2015) socially responsible farmers should pay attention to sustainable agricultural production, which is environmentally friendly, the welfare of farmed animals, food security as well as job creation, and the development of the employees.

Our article focuses on the relation of agricultural holdings (agri-holdings) and municipalities. We examine large firms, because we expect that there is a higher pressure on socially responsible behavior towards the stakeholders. See e.g., Udayasankar (2008) who found out that "smaller firms may face fewer pressures compared to large ones and receive little recognition for their CSR because of their lower visibility." The relationship between municipalities and rural areas was studied by Rosas and Noriega (2014). They found only weak involvement in CSR actions in the municipality of Guasave, Sinaloa, Mexico except for one farm whose business objective covers both economic, social and environmental issues.

We can perceive the agri-holding as a corporate firm and the municipality as one of the most important stakeholders that affects the decision-making of a firm. The cooperation between them can lead to enhancement of the social capital in rural areas. The aim of the voluntary CSR commitments is to strengthen the relation with the stakeholders. Therefore, it can be expected that activities that are done in favor for the inhabitants of the municipalities bring better relation. In this sense, the cooperation can help to the creation of the social capital in the locality. We refer to the Putnam's definition of social capital that is treated as a public good – the amount of participatory potential, civic orientation, and trust in others available to cities, states, or nations. For Putnam (1993) social capital are the "features of social organizations, such as networks, norms and trust that facilitate action and cooperation for mutual benefit".

Materials and methods

The aim of the paper is to assess the opinions of representatives of agricultural holdings on relation of agricultural holdings towards their main stakeholders that are the municipalities where their agricultural activity takes place and vice versa. The differences between answers are examined. The paper follows Internal Research Project number 1117 from year 2018 (IAEI, 2018) when the survey took place. The questionnaires were dedicated for the representatives of agri-holdings and of municipalities. Sample contained 133 agri-holdings farming in the municipality with a maximum of 2000 inhabitants (rural municipality) and with more than 50% share of agricultural land in the cadaster and 120 municipalities. Around 61% of interviews were realized directly with the director, chairman of the agri-holding. There were men in 82.0% of cases, average age was 50.8 years and the highest education was university degree in 66.2% cases (the rest graduated from high school with a degree). The investigation focused on larger corporations – one farm employed 48 employees on average and average acreage of agricultural land was 1565 ha. The legal forms were joint-stock companies (42.9%), cooperatives (37.6%) or limited liability companies. Type of farming was found out only for 1/3 of the sample. Prevailing farming type was mixed production (24.1%), then there was livestock (6.8%) and crop production (5.3%). The rest were undetected.

According to the Eurostat (2020), large agricultural enterprises "are more likely to have a legal form of cooperatives" and have over 100 ha of utilized agricultural land. In comparison with agri-holdings in other member states, the Czech farms are the largest in terms of average UAA in the EU.

In most cases (85.8%), the interview was conducted directly with the mayor of the municipality. The respondents were mostly men (in 69.2% cases).

Their average age was 52.8 years and their highest education high school degree in 64.2% cases. Statistical description of the sample is provided in the Table 1A in Appendix.

The questions and answers were similar for agri-holdings (A) and for municipalities (M). First, the relationship was ranked on a scale from very positive, rather positive, rather negative to very negative (and I do not know). Whether the answers between the representatives of the agricultural holdings and the municipalities differ was tested by χ^2 test of goodness of fit. Null hypothesis H_0 of the test is that the relative frequencies of the answers are equal for both subjects. Test criterion G follows χ^2, so it is compared with its critical value (1).

$$G \approx \chi^2_{1-\alpha}\left[k-1\right], \qquad (1)$$

where k is the number of variants of the answers and α is a level of significance set on 0.05.

The rating of the relation can be influenced by the extent to which is agri-holding involved in activities from (1) social area (in the life of the municipality), (2) in public benefit activities, (3) in ecological area and (4) in strategic area.

It was tested in contingency tables by $\chi 2$ test whether the quality of relationship rating depended on the intensity of cooperation area. H_0 states that the variables are independent. Test criterion G follows χ^2 distribution, so it is compared with its critical value (2).

$$G \approx \chi^2_{1-\alpha}\left[(r-1)(c-1)\right], \qquad (2)$$

where r is number of rows and c is number of columns in the contingency table. When the value of the test criterion G exceeds the critical value of the χ^2 distribution at the appropriate significance level α = 0.05, the H_0 is rejected and the variables are dependent. The strength of the dependence was measured by Cramer's contingency coefficient V (3), which takes values from 0 to 1 (0% to 100%). The closer is the value to 1, the stronger the dependence is.

$$V = \sqrt{\frac{G}{n(q-1)}}, \qquad (3)$$

where n is the number of observations and q is the minimum from rows or columns.

Results and discussion

Perhaps due to a less formal form of contact between representatives of agricultural firms and representatives of municipalities, they saw the relationship between the enterprise and the municipality generally as positive. Over 70% of joint-stock companies and limited liability firms rated the relationship as rather positive and around 20% as very positive. Cooperatives had better relations, as 32% of representatives rated it as very positive and 60% as rather positive. Only few enterprises had negative relations. 3 joint-stock companies and 2 cooperatives had rather negative relation and 1 limited liability company and 1 cooperative had very negative relation. However, the differences among various legal forms were not significant (p = 0.406). Hence, all types of firms have similarly good or bad relationship with the municipalities.

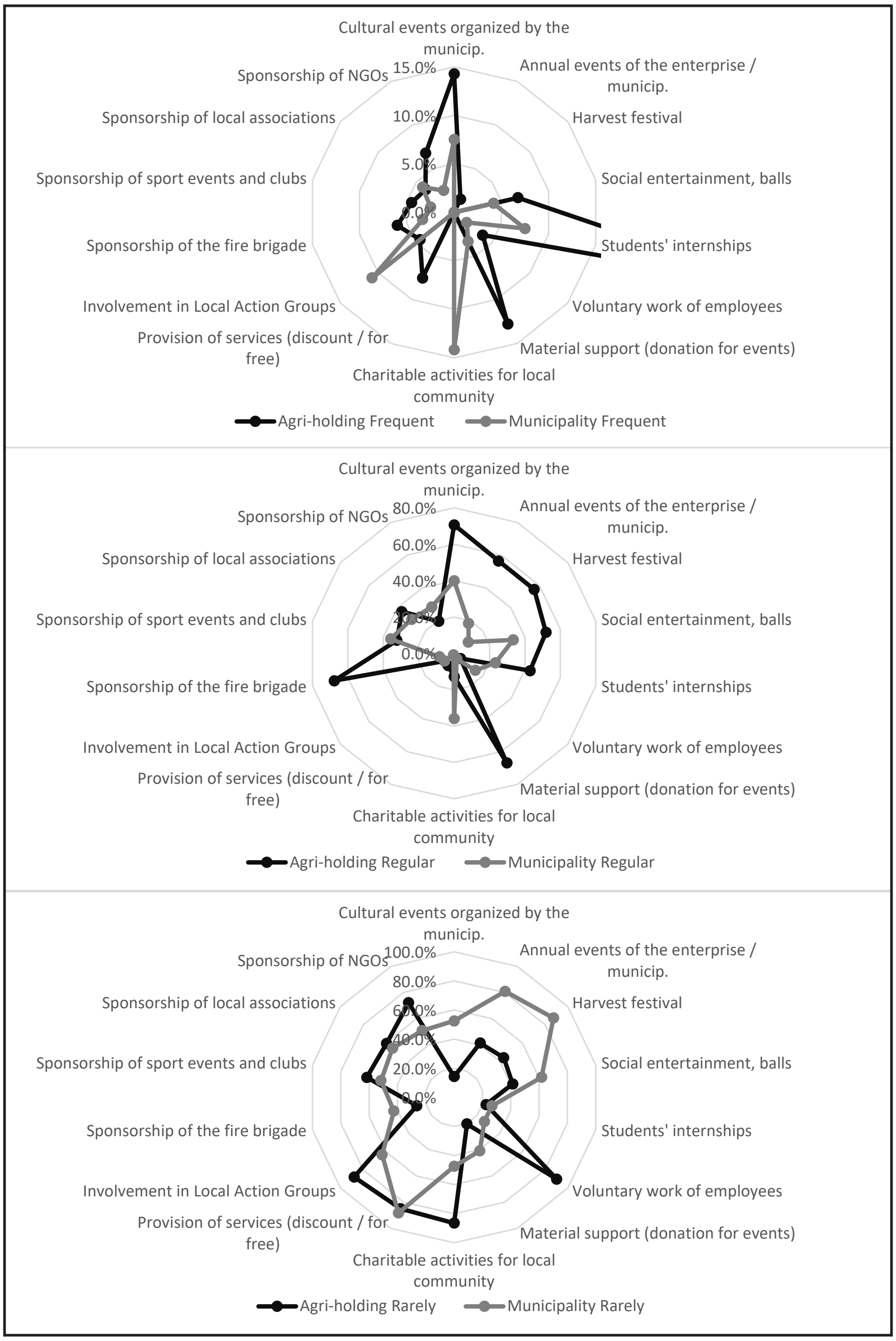
Representatives of the municipalities evaluated the relationship between the municipality and the company positively too. Again, the negative rating was in minority. The answers statistically significantly differed between those two subjects. (Because the p-value of χ^2 test was 0.000, we rejected H_0 that the frequency of the answers is the same.) There were few “rather” and “very negative” evaluations, so it was necessary to merge them.

Social area

Each agri-holding participated in some way in the life of the municipality. Firms differ in the frequency (rate) of their activities, only one company stated that it does not participate at all. Mostly the firms took part in cultural events in the village once or twice a year – mainly because of their nature. For example, 70.7% of agri-holdings participated in events organized by municipalities, 56.4% in annual events of the municipality, 51.9% in social entertainments and balls. Student were accepted on internships in 42.9% of firms. The support of the fire department was the most often represented in the area of sponsorship, which was also perceived by representatives of municipalities (albeit with a lower frequency).

The representatives of the municipalities are more often unable to say whether and how the company participates in life in the village. From the standpoint of the municipality management, agri-holdings participate in cultural events mostly 1–2 times a year. Municipalities perceive more donation of products for events and providing services with a discount or free of charge. Also, sponsorship that mostly takes the form of donating products to events is recognized by municipalities. The highest support is provided to voluntary fire brigade. The frequency of charity activities and volunteering is low which is reported by firms and municipalities alike. Only few agricultural holdings were involved in the activities of Local Action Groups.

The differences in the answers are quite contrasting as it can be seen from Figure 1. Especially students' internships are done more often than representative of the municipalities know. Only in case of charitable activities for local community, the representants of the municipalities thought more often that they are done by agri-holdings. Hence, visible actions bring to the company higher visibility and better reputation.



Source: own elaboration

Figure 1: Participation of the agri-holding on the social life in the municipality.

It was further tested whether the frequency of social activities influence the relationship. The answers "I cannot assess" were omitted from the analysis. "Rather negative" and "Strongly negative" categories were merged as there was only few persons from agri-holdings or municipalities who rated the relation negatively. Category of "frequent" and "regular" were merged several times in order to meet the requirement of the χ^2 test.

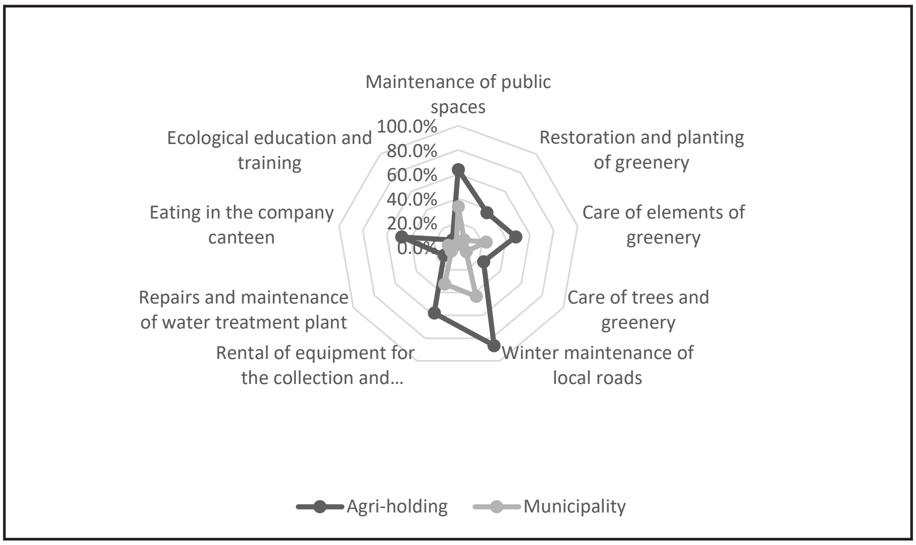
From the point of view of the agricultural holding, most social activities did not influence the relationship (the p-values of the tests were higher than 0.05). Only exception was the support of fire brigade, where the relation between an agricultural holding and a municipality depended on the frequency of sponsorship (p-value 0.048). The dependence was very weak (V = 19.3%).

The situation was different from the point of view of the representants of the municipalities. The relationship with agricultural holding relatively strongly depended on how often the agricultural holdings support cultural events organized by the municipality (p-value = 0.000, V = 43.2%). It also depended on whether it supports annual events of the firm / municipality (p-value = 0.005), but the dependence was weaker (V = 26.4%). Similarly organizing of harvest festival and balls was significant (both p-values = 0.002 and V = 23,7% and V = 27,9%, resp.). The relation depended on if the agricultural holding is accepting the students on internship too (p-value = 0.004), this time relatively strongly in comparison with others (V = 34.5%). Material support (donation on events) was significant too (p-value = 0.008, V = 25.4%). Similarly, as from the point of view of the representatives of agricultural holdings, the relationship also depended on the sponsorship of fire brigade (p-value = 0.013, V = 25.3%). In the same pattern also sponsoring of sport events and clubs and of other local associations was significant (p-values = 0.024, V = 23.9% and 0.004, V = 29.2%, resp.). Charity activities could not have been tested because of low frequencies.

Also, when the economic ties were investigated, we also asked about regular financial contribution or sponsorship to the municipality for public expenditure and found out that only 11 agri-holdings (8.2%) sponsored the municipalities regularly with amount varying from 5 000 to 150 000 CZK. Average contribution was 50 000 CZK, but median only 20 000 CZK. Mostly, the amount was 5000, 10000 and 20000 CZK.

Public benefit activities

Support of public benefit activities was various. Figure 2 shows that winter maintenance of the roads is the most frequently activity performed from the point of view firms (86.5%) and municipalities (43.3%). 47.4% of company representatives and 33.3% of municipalities mentioned the possibility of catering in the canteen and delivery of meals as an activity carried out by holding. From the point of view of the company, however, the improvement of public spaces was more significant (63.9% companies, 23.3% municipalities). 57.9% of agricultural holdings provided equipment to ensure the collection and removal of scrap iron in the municipality, but only 32.5%



Source: own elaboration

Figure 2: Participation of the agri-holding on public benefit activities.

of the municipalities noticed this. While 48.1% of businesses stated that they take care of greenery, only 7.5% of municipal representatives knew this.

No dependency was found from the point of view of agri-holdings between relationship and whether the company participate on public benefit activities.

On the other hand, there was dependence in almost all activities from the standpoint of the municipalities. Only exception was in case of repair and maintenance of water treatment plant and local water supply. Care of elements of greenery and possibility to eat in company´s canteen was both significant at 0.1 level as the p-values were 0.075 and 0.062, respectively. The strongest dependence (V = 37.5 %) was in case of winter maintenance of local roads. Hence, the public benefit activities are more important from the point of view of the municipalities than of agri- holdings for good relationship between those two subjects.

Ecological area

From Figure 3 can be seen that agricultural enterprises contribute to the improvement of the landscape and cultivated land the most. Technical assistance provided by means of mechanization and transport (maintenance of field roads, local roads, etc.) and employment of the inhabitants of the municipality (including the social aspect, e.g., employment of socially disadvantaged groups) were less beneficial for the municipality. The involvement of agricultural enterprises in the development of rural tourism and agri-tourism had only very limited importance. There was no dependence between activities of agri-holding in ecological area and the quality of the relationship with the municipality from the point of view of the representatives of the agri-holding. On the other hand, the activities were important from the point of view of the municipalities. The relation

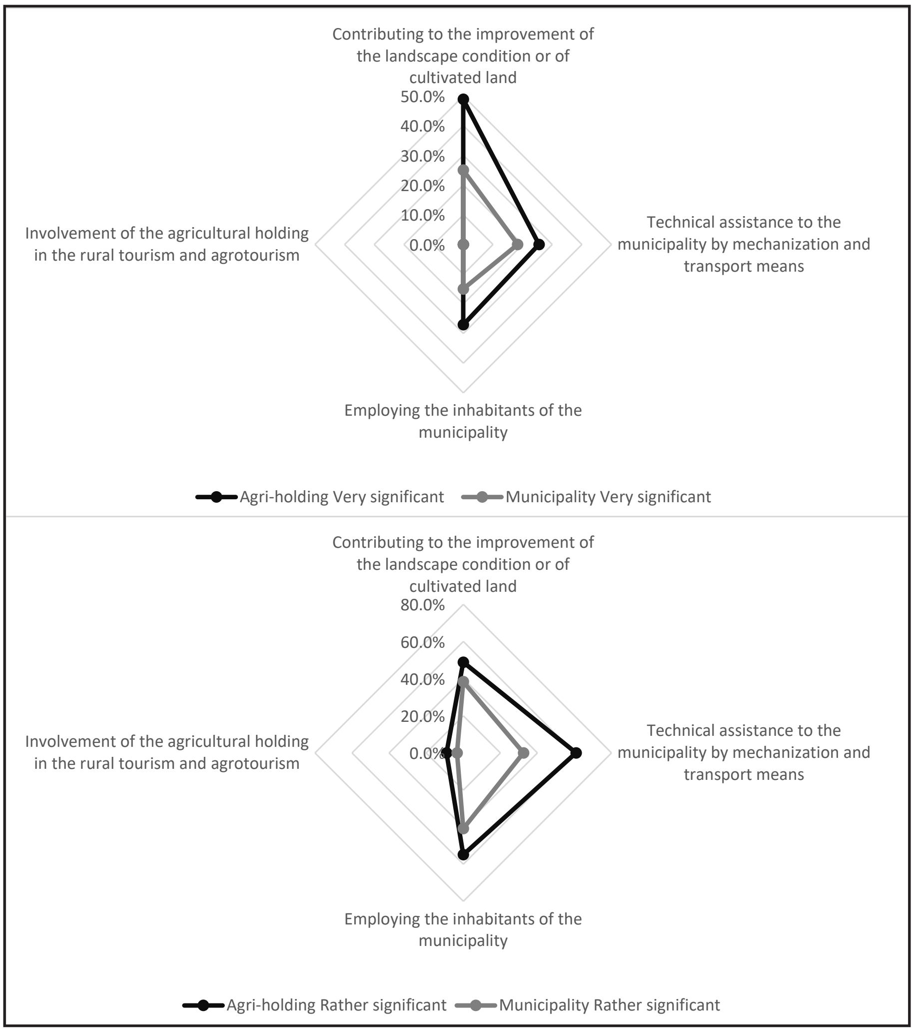


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Figure 3: Cooperation of the agri-holding in ecological area (To be continued).

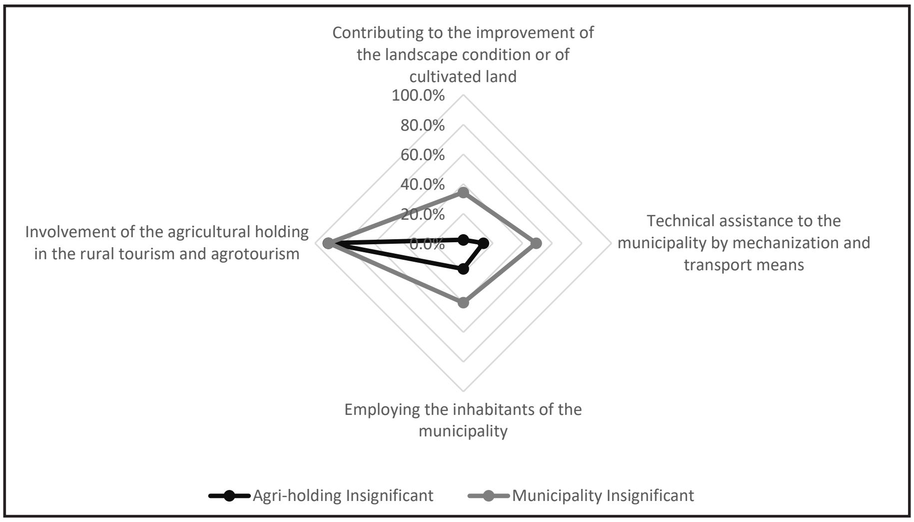

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Figure 3: Cooperation of the agri-holding in ecological area (Continuation).

between the two subjects depended on whether the agri-holding contributed to the improvement of the landscape condition or of cultivated land (p-value = 0.000, V = 32.8 %). Also, the technical assistance to the municipality by mechanization and transport means was significant (p-value 0.000, V = 34.9). The strongest statistically significant dependence was between the relation of the municipality and agri-holding and the employing the inhabitants of the municipality (p-value = 0.000, V = 37.1%).

Strategic area

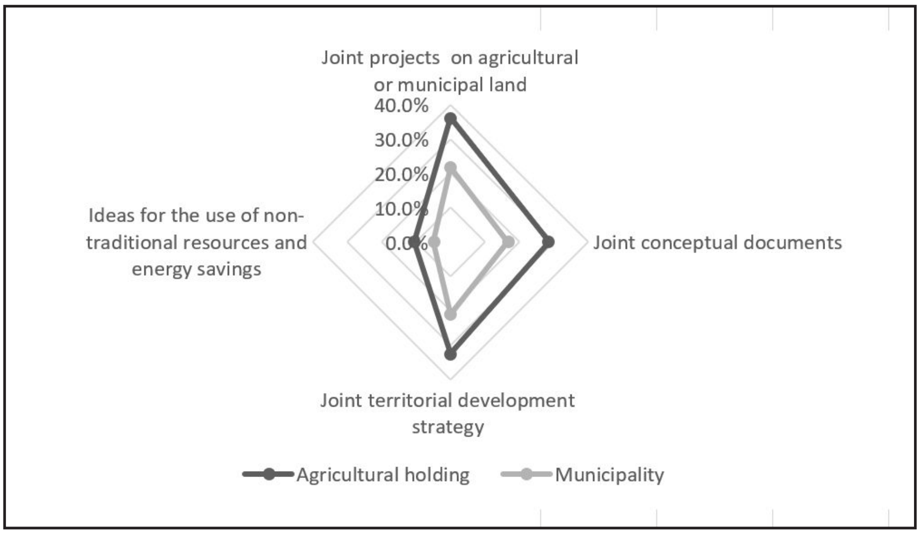
Over half of agri-holdings (52.6%) cooperated with the municipality in at least one area. It was the most often on preparation and implementation of joint projects on agricultural or municipal land. One third of agri-holdings helped to form the joint territorial development strategy for the territory of the municipality and over one fourth of agricultural land representatives said that they helped the municipality to draw up common conceptual documents.

The scope of cooperation was lower from the point of view of the municipalities. Less than one third of municipalities cooperated with agri-holdings in at least one strategic area. It was the most often on joint projects on agricultural or municipal land and forming joint territorial development strategy for the municipality's territory. The assessment is displayed at Figure 4.

There was no dependence found between the relationship and cooperation in strategic area from the point of view of the representatives of agri-holdings, but only from the standpoint of the municipalities. The dependence was significant in the case of preparation and implementation of joint projects (p-value = 0.000, V = 39.7%), then in case of cooperation on joint conceptual documents (p-value = 0.000, V = 41.2%) and cooperation on joint territorial development strategy for the municipality's territory (p-value = 0.000, V = 37.7%).

The positive perception of the relation between agricultural holdings and the municipalities prevails on both sides, despite that the assessment differs. From the point of view of agricultural holdings, the relation is seen as very positive in less cases than from the point of view of the municipalities. Positive relation and cooperation between those two subjects can contribute to the creation of the social capital in the municipalities as one of the components of the Putnam's (1993) social capital are social networks. The central thesis is that if a region has a well-functioning economic system and a high level of political integration, these are the result of the region's successful accumulation of social capital. „The quality of the civil society "predestined" to a large extent the future economic and political development of the region." (Siisiäinen, 2000). Hence, when there are voluntary activities done by the agri-holding and appreciated by the municipalities in the rural areas, this can enhance social capital creation.

Regarding the motivation of agricultural holdings for maintaining good relations with the municipalities, there can be some intangible factors that support which support this endeavor. Almost 60% of the respondents from agri-holdings lived in the municipalities where the agricultural



Source: own elaboration

Figure 4: Cooperation of the agri-holding in strategic area.

activity took place. When the representatives of the firms are local, they motivation to maintain good relations with inhabitants and representatives of the municipalities is higher. Besides, the management of the agri-holdings also intensively (65.4% cases) or at least occasionally (34.6%) observes the activities in the municipality. They mostly meet informally or formally with the mayors at face-to-face discussions but also over half of them read local newspapers. Those intensive and current contact also support the good relations.

According to the expectations mostly the representative of the municipalities knew about the activities of the agricultural holdings less than the representatives of agricultural holdings. The representatives of the municipalities must observe more stakeholders in their area. Nevertheless, better promotion of their activities shall be recommended to agri-holdings. The necessity of promotion was highlighted also by Gagalyuk et al. (2021) when one interview farmer stated a case when they improved street lighting, but the effort was attributed to the mayor by the inhabitants. He stated that “We have to inform and reach out to local people to make them understand who is doing all of these good things for them.” (Gagalyuk et al., 2021).

Regarding the participation of the agricultural holdings on social life in the municipality (with exception of sponsoring of the fire brigade that was frequently or regularly done by 73.7% of agri-holdings) the activities do not influence the relation with the municipality.

The perception of the agricultural holdings by the municipality depended of whether the company participates on cultural events, annual events, harvest festivals and balls. Those events enable the agricultural holding to promote their name and “brand” to large audience. Organization of those events sometimes require close cooperation with the municipalities (or other stakeholders in the locality), which could enhance the relationship. Also, material donations of the products on the events helps the company to become more visible.

Besides, the relation also depended on whether the agricultural holdings accepted students on internships. Another important determinant was the sponsorship of fire brigade, sport clubs and events and other local clubs. This type of activities promotes the company to certain circle of people but is still large enough to bring the benefit of visibility to agri-holding and important to help to create the relation with the municipality.

Surprisingly according to the agri-holdings’ representatives’ answers, the relation with the municipality did not depend on any public-benefit activities that were realized by the company. On the other hand, the relation between municipality and agricultural holding depended on whether it maintain the public spaces, restore and plant the greenery in the village and its surroundings, and take care of trees and greenery. Besides, winter maintenance of local roads and rental of equipment to ensure the collection and subsequent removal of iron were also important determinants of the relation with the municipality. Finally, the relation depended on if the agricultural holding provided ecological education and training of children and youth.

In case of benefit of the agricultural holding for the municipality, there was no statistical dependence from the point of view of the agricultural holdings. On the other hand, the relation with agricultural holding depended on whether it contributed to the improvement of the landscape condition or of cultivated land, it provided technical assistance to the municipality by mechanization and transport means or it employed the inhabitants of the municipality.

The relation of the agri-holding did not depend on the cooperation with the municipality in the strategic area, but the situation was opposite from the point of view of municipalities. The low level of cooperation between agri-holdings and municipalities should be improved in the future as there is an important impact of spatial planning decision on agriculture which was confirmed by the study of Wachter and Wytrzens (2022) because “spatial planning plays a substantial role in securing agricultural production requirements”.

Because the relations were good, we looked closely on the negative cases as they can pointed out on certain problems. Seven agri-holdings did not have good relations with the representatives of the municipalities. Two mentioned the reason that the municipality does not invest into the local roads and that locals did not like the company because of the smell, so the relations were not good. Six municipalities had problems with the agricultural holding especially because they did not comply with agrotechnical principles and deadlines. One municipality stated that the soil flooding occurred. Hence, the relation towards environment is important and predetermines the relation towards municipality’s inhabitants in some cases.

Conclusion

Corporate social responsibility represents a broad concept where the firms is voluntarily involved in a series of commitments towards the society and the environment beyond legal and regulatory requirements. The aim of those commitments is to strengthen the relation with the stakeholders. Therefore, it could have been expected that activities that were done in favor for the inhabitants of the municipalities would have brought better relation between representatives of the agri-holdings and the municipalities. We found out that the positive perception of the relation prevailed on both sides despite that the point of view of the representatives of agri-holdings and municipalities on their relation was statistically significantly different. This good cooperation can help to the creation of social capital in the sense of the Putnam’s definition and hence to the development of the locality.

The agri-holdings participated on many events and were active in many areas of the social life in the municipality, but the visibility of those activities was insufficient. The representatives of the municipalities answered less often that agricultural holdings are realizing certain activities than the representatives of the firm themselves. Promotion could help the agricultural holdings to enhance their good name in and lead to the prosperity of the firm because the CSR activities should pay off.

The quality of the relation was statistically significantly dependent on the whether the agricultural holdings cooperated with the municipality mainly from the point of view of the public sector representatives. Almost all activities done by the agri-holdings were statistically significant determinant. From the standpoint of the representatives of agri-holdings, the number of supported activities was not statistically significant determinant of the quality of relation. The only exception was the support of local fire brigade.

From the negative examples can be deducted that bad land management practices and insufficient care of the environment caused negative relations between municipalities and agri-holdings. Environmental responsibility is hence necessary to enhance the relationship towards the municipalities and its inhabitants.

To maintain good relationship with the municipalities, agricultural holdings have to comply with the legal framework on environmental protection as the basic step. Then there is the superstructure in the form of support for social life and the practical running of the village. It can be recommended to maintain those activities and enhance their visibility, because social responsibility of agri-holdings is an important feature for the reputation of the holdings. From the point of view of the municipalities, participation of agricultural firms on public life can help to enhance the quality of life in rural areas. Therefore, it can be recommended to maintain good relationship with the representatives of agri-holdings, to monitor and observe their activities and also publicly appreciate their effort.

Exemplary cooperation between municipality and agricultural holding shall be also appreciated publicly by the authorities to highlight the good practices. In this area, the existence of the Orange ribbon award for cooperation between agricultural firm and the municipality managed by the Ministry of Agriculture of the Czech Republic is especially important.

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Appendix

Characteristics of agricultural holdings		
Number of employees	Minimum	4
	Median	40
	Average	47.9
	Maximum	350
Agricultural land	Minimum	261.4 ha
	Median	1338.6 ha
	Average	1565.0 ha
	Maximum	7864.9 ha
Legal form	Joint-stock company	42.90%
	Limited liability company	19.50%
	Cooperative	37.60%
Characteristics of the representatives of agricultural holdings		
Respondent's sex	Male	82.00%
	Female	18.00%
Respondent's age	Average	50.8 years
	21-40	21.10%
	41-60	63.90%
	61-80	15.00%
Respondent's education	High school, graduated	33.80%
	University	66.20%
Respondent's position	Director / Chairman / Chairman of the Board	60.90%
	Managing director	6.80%
	Deputy chairman	3.80%
	Economist	19.50%
	Agronomist	3.00%
	Others	6.00%
Characteristics of the representatives of municipalities		
Respondent's sex	Male	69.20%
	Female	30.80%
Respondent's age	Average	52.80%
	21-40	6.70%
	41-60	75.00%
	61-80	18.30%
Respondent's education	High school, non-graduated	2.50%
	High school, graduated	64.20%
	University	33.30%
Respondent's position	Mayor	85.80%
	Deputy mayor	6.70%
	Others	7.50%

Source: own elaboration

Table 1A: Statistical description of the sample.

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Optimizing IoT Data Aggregation: Hybrid Firefly-Artificial Bee Colony Algorithm for Enhanced Efficiency in Agriculture

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Abstract

The data aggregation process in this study has been enhanced by the hybrid firefly-artificial bee colony algorithm (HFABC) by increasing the average packet delivery ratio, end-to-end delay, and lifespan computation. In this study, HFABC and Multi Hop LEACH are two algorithms that are used to aggregate IoT data. Their performance is compared using evaluation criteria including average End-to-End Delay, PDR, and network lifetime. The HFABC method reduces average End-to-End Delay more effectively than Multi Hop LEACH, with gains of 2.20 to 8.66 %. This demonstrates how well it works to reduce the lag times for data transfer in IoT networks. With improvements ranging from 3.45% to 45.39%, HFABC has a greater success rate than Multi Hop LEACH in effectively delivering packets. HFABC increases network lifetime by 0.047 to 2.286 percent, indicating that it helps keep IoT networks operating for longer. For effective data aggregation in IoT networks, HFABC is a superior solution that decreases delays, improves packet delivery, and lengthens network lifetime.

Keywords

AHFABC, IoT, performance, Average End-To-End Delay, Average Packet Delivery Ratio, lifetime computation.

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Introduction

Agriculture is crucial for human sustenance, and IoT sensors enable farmers to monitor, manage, and optimize activities. Data-driven decisions and improved irrigation and fertilizer application improve crop yield and resource management. Traditional data aggregation methods in agriculture are time-consuming, labour-intensive, and inefficient. IoT technology offers automated data collection, real-time monitoring, and remote access, enabling continuous data collection from sensors and drones for precision agriculture practices (Patel et al., 2012). The network is divided into clusters and each cluster has a cluster head or coordinator responsible for data aggregation. Sensors or nodes within a cluster transmit their data to the cluster head, who aggregates it and transmits it to the base station. These clusters include LEACH (Low-Energy Adaptive Clustering Hierarchy), HEED (Hybrid Energy-Efficient Distributed clustering), PEGASIS (Power-Efficient Gathering in Sensor Information Systems) (Sinha and Lobiyal, 2013). Clustering is crucial in IoT applications for efficient data acquisition, dissemination, and network longevity, minimizing communication overhead and optimizing access to devices (Kumar and Zaveri, 2018). IoT networks consist of IP-enabled devices and sensor devices. Clustering designates a node as the Cluster Head (CH), providing scalability, reduced routing overhead, efficient bandwidth utilization, and improved stability. CHs minimize packet exchange, simplify network topology, and aggregate sensor data, reducing packet exchange rates (Sholla et al., 2017). Cluster Head optimizes device battery life using advanced scheduling algorithms, enabling low-power mode operation when inactive, avoiding collisions, and prolonging device lifespan.

LEACH is a routing protocol that balances energy consumption by randomly selecting cluster heads (CHs) for data collection and merging. It operates in two stages: setup phase, based on probabilistic models, and steady phase, optimizing energy usage and network lifetime (Zheng et al., 2017). TL-LEACH is an improved LEACH algorithm with a two-level clustering hierarchy, primary and secondary Cluster Heads, and simple sensing nodes. It uses data fusion and TDMA-based scheduling for efficient communication, ensuring fairness in CH selection and distribution (Boyinbode et al., 2010). FLOC is a distributed technique that creates well-balanced clusters with minimal overlap in wireless networks. It classifies radio nodes based on their proximity to the inner Cluster Head and uses an i-band membership preference. This enhances intra-cluster communication robustness, efficiency, and reduces interference, improving network performance and reliability (Abbasi and Younis, 2007). HEED optimizes energy efficiency in WirelessSensor Networks (WSNs) by considering communication cost and energy factors. DEEC is a multilevel algorithm for heterogeneous WSNs, ensuring low probability of selecting the same CH, adapting to energy consumption, and allowing adjustable CH selection probabilities (Katiyar et al., 2010). EECS involves dynamic cluster sizing based on distance from the base station, ensuring equal energy distribution among nodes. This approach improves network lifetime, connectivity, and reliable sensing capabilities, enhancing energy efficiency and performance in wireless networks (Katiyar et al., 2011).

EEUC divides nodes into clusters, reducing energy consumption for data forwarding. SEP improves LEACH by considering node heterogeneity and assigning higher probability of CH to advanced nodes, resulting in more efficient and balanced clustering (Tewari and Vaisla, 2014). The Deterministic Energy Efficient Clustering Algorithm (DEC) is a deterministic clustering protocol that minimizes uncertainties in Cluster Head selection. SECA ensures uniform cluster formation and load distribution by selecting CH nodes based on distance, and a centralized controller sink updates nodes for cluster formation (Rajput and Kumaravelu, 2018). NCACM is a centralized protocol for clustering heterogeneous wireless sensor networks to improve energy efficiency. It enhances the selection process of Cluster Head Nodes (CHNs) and considers factors like distance and battery power. NCACM maximizes overall network energy efficiency and performance by considering multiple parameters.

LEACH is a crucial hierarchical routing protocol in Wireless Sensor Networks (WSNs) to extend network lifetime. It uses cluster heads to collect and aggregate data from non-CH nodes, ensuring fair energy distribution and prolonging the network's operational lifespan (Lee et al., 2017). The ODL-CNN system uses IoT cameras for surveillance, utilizing IEHO algorithm optimization. Deep learning analysis generates sketches, and effectiveness is evaluated through examination and simulation, ensuring reliability and accuracy in fire surveillance applications (Elhoseny et al., 2020). The proposed approach improves traditional IDS performance and adaptability by combining MOPSO and Lévy flight randomization, introducing evolutionary and intelligent elements for effective multi-objective handling and enhanced intrusion detection capabilities (Hussein et al., 2022).

The PL50 Optimization method uses dynamic pheromone adjustment in real-time data for logistics optimization. Combining mathematical modeling, fuzzy time windows, and an improved Ant Colony algorithm, it enhances production logistics efficiency and effectiveness. Numerical experiments validate its viability and performance (Huang et al., 2020). The competitive nature and superior performance of MOPSO over traditional machine learning methods, NSGA-II, and filter-based methods highlight its effectiveness as a powerful optimization algorithm for solving multi-objective problems (Habib et al., 2020). The Ant Colony Optimization (ACO) multi-objective service selection algorithm delivers quick, effective solutions, improving recall and precision while maintaining high efficiency. This approach has potential for enhancing service selection processes in various applications (Tian et al., 2019). The modified Genetic Algorithm for Resource Selection (MGA-RS) algorithm identifies optimal data using a modified genetic algorithm, showing superiority when combined with kNN-based fitness function. This improves resource selection and classification accuracy in various applications (Bharti et al., 2019). Improved GA and DBN enhance intrusion attack recognition rates, reduce neural network complexity, and optimize IoT network performance for effective data transmission (Zhang et al., 2019). the Grey Wolf Algorithm-based intelligent approach for routing in IoT networks demonstrated its superiority over AFSA and ABC in terms of energy consumption and network throughput. The findings emphasize the effectiveness of utilizing GWA for optimizing routing decisions and improving the overall performance of IoT networks (Mahdy et al., 2023). Bee-Inspired Routing Algorithm (BIRA) is an energy-aware routing algorithm inspired by bee communication, designed for D2D IoT communication. It offers better packet delivery ratio, reduced energy consumption, and lower end-to-end delay, enhancing efficiency and reliability in IoT networks (Almazmoomi and Monowar, 2019). The Firefly algorithm improves mobile sink path optimization for sensor networks by optimizing storage and computing resources, improving connectivity and communication efficiency. It also shows superior performance in cluster head energy balance and network reliability compared to alternative methods (Sun et al., 2022). QoPF uses the Backtracking Search Optimization Algorithm (BSOA) to optimize resource allocation and meet QoS requirements in service-oriented IoT environments. It outperforms other techniques and enhances user experience by addressing metrics like jitter, delay time, and throughput (Badawy et al., 2020).

A routing scheme developed using CSA Cuckoo Search Algorithm demonstrated effectiveness in network routing, with promising results compared to other contemporary algorithms (Nagavalli and Ramachandran, 2019). Adaptive Immune algorithm and Endocrine regulation offer innovative solution for dynamic service issues, with simulation-based evaluation proving effectiveness and superiority over existing optimization techniques (Yang et al., 2019). A novel routing algorithm based on ACO optimizes path selection in IoT systems, addressing challenges in intersected areas. NS-2 evaluation shows effectiveness in improving energy consumption, end-to-end delay, packet loss ratio, bandwidth consumption, throughput, and control bit overheads (Said, 2017).

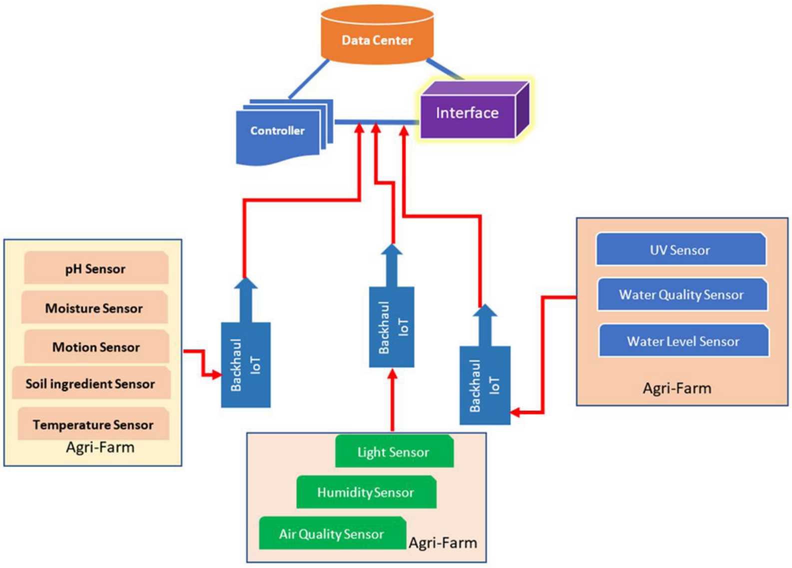
Thus, Advanced Clustering Algorithms are essential for IoT networks to address scalability, energy efficiency, and heterogeneity. Dynamic and adaptive algorithms adapt to network changes, while hybrid clustering and optimization techniques integrate. QoS-Aware Clustering optimizes energy efficiency and application-specific requirements, while Security and Privacy in Clustering addresses unique security challenges.

Materials and methods

In a low-power network topology designed for measuring and monitoring factors in a smart agricultural farm, the system includes (Figure 1):

- **IoT Sensor Nodes:** These nodes are responsible for collecting data from the farming environment, such as soil moisture, air humidity, temperature, nutrient ingredients of soil, pest images, and water quality. They transmit the collected data to the IoT backhaul devices.
- **Reduced-Function Devices (RFDs):** Some IoT sensor nodes are installed as RFDs, which have limited functionality and can only communicate with Full-Function Devices (FFDs). RFDs are designed to conserve energy and reduce investment costs. They cannot communicate with other RFDs.
- **IoT Backhaul Nodes:** IoT backhaul nodes not only function as IoT sensor nodes but also act as intermediate nodes in the network. They receive information from other IoT nodes and transmit it to the control center or central server. IoT backhaul nodes are typically installed as FFD devices, capable of connecting to both FFD and RFD devices.
- **Full-Function Devices (FFDs):** FFDs are devices that have complete functionality and can communicate with both FFD and RFD devices. They play a key role in relaying data between different nodes in the network, including IoT sensor nodes and IoT backhaul nodes.

The IoT sensor nodes, whether RFDs or FFDs, collect data from the farming environment and transmit it to the IoT backhaul nodes. The IoT backhaul nodes, particularly the FFDs, receive information from various nodes in the network and transmit it to the control center or central server for further processing and analysis



Source: Own processing

Figure 1: Low-power network topology: Smart agricultural farm.

(Cheng et al., 2022). This network topology enables efficient data collection, communication, and management in a smart farm environment.

The simulation parameters for the experiment include a total area of a sensor network deployment of 2000×2000 square meters, with the number of sensor nodes ranging from 100 to 1000, which determine the density and scale of the sensor network. The initial energy level (2 J) assigned to each sensor node in the network is used for sensing, communication, and other tasks.

The energy consumption rate (EC-energy per bit) for the electronic components of a sensor and electronic node during communication can be measured by a formula (Sharp et al., 2020).

$$E_C = E_{tx} + E_{rx} = (Eelec_{tx} + Eelec_{rx}) \times Tb = (Eelec_{tx} + Eelec_{rx}) \times L/R \quad (1)$$

where L is the packet length in bits, R is the data rate in bits per second, $Eelec$ - total energy consumption rate (energy per bit), E_{tx} - energy consumption rate for transmitting one bit of data, E_{rx} - energy consumption rate for receiving one bit of data, Tb -transmission time

The energy consumption rate (energy per bit per square meter) for free space transmission between sensor nodes can be calculated by the Equation 2.

$$E_{FC} = Eelec_{fs} * d^2 \quad (2)$$

where $Eelec_{fs}$ - energy consumption rate per bit for free space transmission, d is the distance between the transmitting and receiving nodes in meters.

The energy consumption rate (E_{mp}) for multi-path fading transmission calculated by the Equation 3. It can be measured by energy dissipation per bit of data ($Eelec_{mp}$) with respect to distance between the transmitting and receiving nodes (d) in meters.

$$E_{MC} = Eelec_{mp} \times d^4 \quad (3)$$

The reference distance (d_f) at which the E_{fs} energy model is calibrated is measured in meters and is used to determine the energy consumption for free space transmission. The maximum communication range between sensor nodes (d_{max})in the network can be measured in meters. Packet length measures the data packet transmitted between sensor nodes, indicating the maximum distance for direct communication.

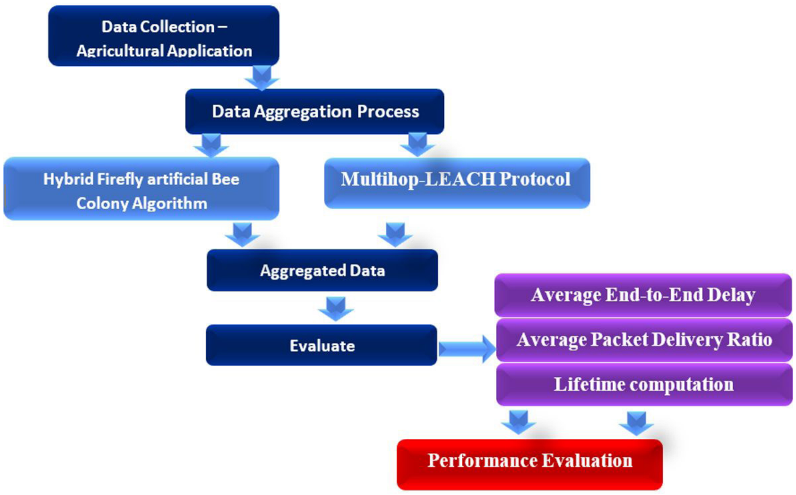
Table 1 displays IoT device parameters in agriculture, including coverage, sensor node count, initial energy consumption, communication distances, and packet length. Figure 2 shows IoT data aggregation performance analysis using Multihop Leach Protocol and HFABC.

The average End-to-End Delay and average Packet Delivery Ratio (PDR) are commonly used metrics to evaluate the performance of network communication. Here are the formulas

S. No.	Parameter	Value
1	Area	2000 * 2000 m^2
2	Number of Sensor Nodes	100,200,300,400,500,600,700,800,900, 1000
3	Initial Energy of Nodes	2 Jules
4	$E_{consume}$	50 nJ/bit
5	E_{FC}	10 pJ/bit/m^2
6	E_{MC}	0.0013pJ/bit/m^4
7	d_f	87
8	d_{max}	25 m
9	Packet length	30 bit

Source: Own processing

Table 1: Smart agricultural farm IoT system energy parameters and their values.



Source: Own processing

Figure 2: Schematic arrangement for performance analysis for IoT data aggregation using Multihop Leach Protocol and HFABC.

for calculating these metrics (Khan et al., 2013):

Average End-to-End Delay: The average End-to-End Delay is the average time a packet takes to travel from source to destination in a network, calculated by summing individual packet delays and dividing by total packets using the Equation 4.

Average End-to-End Delay = (Sum of Delays for all packets) / (Total number of packets) (4)

Average Packet Delivery Ratio (PDR): It measures the efficiency and reliability of message delivery by comparing the number of successfully delivered packets to the total number sent within the network (Equation 5).

Average PDR = (Number of successfully delivered packets) / (Total number of packets sent) (5)

Lifetime computation: Estimate lifetime computation for IoT devices using the Equation 6.

Lifetime = (Initial Energy / Energy Consumption Rate) × (1 - (1 - *PDR*)^n) (6)

Where, *Initial Energy* - The initial energy level of the sensor nodes, *Energy Consumption Rate* - The rate at which the sensor nodes consume energy during their operations, *PDR* (Packet Delivery Ratio) - The ratio of successfully delivered packets to the total number of packets sent and *n* - The number of rounds or cycles.

Multihop-LEACH Protocol

The Multihop-LEACH Protocol is an extension of the LEACH protocol for multi-hop communication in Wireless Sensor Networks (WSNs). The Multihop-LEACH Protocol improves network scalability, energy efficiency, and connectivity by enabling data transmission through intermediate nodes. Clusters form, with a designated Cluster Head responsible for data aggregation and transmission. This approach extends coverage and enables efficient data routing over longer distances, enabling WSNs to monitor and collect data from a wider geographic area (Patil, 2012). Multi-hop LEACH improves network scalability, energy efficiency, and coverage area by optimizing data transmission over long distances (Biradar et al., 2011).

The implementation steps of the Multihop-LEACH Protocol are as follows:

- The network is initialized by deploying sensor nodes in the target area. Each node is equipped with energy and communication capabilities.
- Nodes organize themselves into clusters with a designated Cluster Head (CH). The CH selection process can be based on various factors such as energy level, distance to the base station, or a combination of these factors.
- Non-Cluster Head nodes collect data from their sensing environment and transmit it to the CH within their cluster.
- The CH collects the received data from its member nodes and performs data aggregation to reduce redundancy and minimize the amount of data to be transmitted further.
- Instead of directly transmitting data to the base station, the CHs utilize other CHs as relay nodes to establish multi-hop communication. The data is forwarded from one CH to another until it reaches the base station.
- To ensure balanced energy consumption, the role of CH is rotated among nodes in subsequent rounds. Nodes with higher energy levels are selected as CHs, distributing the energy load throughout the network.
- The exact formulas used in the Multihop-LEACH Protocol may vary depending on the specific implementation and variations of the protocol. However, some commonly used formulas in the protocol may include:
- The formula to determine the probability of a node becoming a Cluster Head, which can be based on parameters like residual energy, distance to the base station, or a combination of factors.
- A formula to calculate the optimal path for data transmission through intermediate CHs, considering factors such as distance, energy consumption, or link quality.

Hybrid firefly - artificial Bee colony algorithm (HFABC)

The hybrid firefly-artificial bee colony algorithm solves complex optimization problems by combining fireflies and artificial bees. Fireflies communicate using light signals, while artificial bees mimic honey bees' foraging behavior, using employed, onlooker, and scout bees to explore solutions and exploit promising regions. The hybrid firefly-artificial bee colony algorithm combines firefly's attractiveness with artificial bee colony's exploration and exploitation strategies, increasing diversity and efficiency. This adaptive optimization tool exploits local and global search spaces, making it popular in engineering, economics, and other fields (Mallala et al., 2022).

The algorithm randomly places fireflies in a search space and evaluates their objective function using artificial bees. Iteratively, iterates until a termination condition is met, encouraging exploration and exploitation. Onlooker bees select employed bees based on fitness, and employed bees generate new solutions using exploration and exploitation strategies. The algorithm evaluates and updates the best solution if a better one is found. An explanation of the different components and steps in the provided MATLAB code for the hybrid firefly-artificial bee colony algorithm (Mallala et al., 2022):

- **Initialization of parameters and variables:** Code initializes parameters like coverage area, sensor node number, energy consumption, communication distances, and packet length.
- **Main loop for different number of sensor nodes:** Loop iterates over sensor node values, executing and evaluating algorithm for specified numbers.
- **Firefly initialization:** Code generates random initial firefly positions in specified coverage area for each iteration.
- **Evaluation of firefly fitness:** The code evaluates firefly fitness using the evaluateFitness() function, solving a specific problem by calculating fitness based on provided parameters.
- **Artificial bee initialization:** The employed bees are initialized based on the positions of the fireflies.
- **Best solution initialization:** The code initializes the best solution and best fitness variables to track the best solution found during the algorithm execution.

- **Main algorithm loop:** The code enters a loop that iterates for a specified number of iterations. This loop represents the main algorithm execution.
- **Firefly movement:** The **moveFireflies()** function is called to update the positions of the fireflies based on their attractiveness and distance. The fireflies move towards brighter and closer fireflies, exploring and exploiting the search space.
- **Artificial bee movement:** The **moveBees()** function is called to update the positions of the employed and onlooker bees based on the positions of the fireflies. This movement allows the bees to explore and exploit the search space using the employed bees' generated solutions.
- **Evaluation of employed bees' fitness and updating best solution:** The fitness of the employed bees' positions is evaluated using the **evaluateFitness()** function. The code then updates the best solution and best fitness if a better fitness value is found among the employed bees' solutions.
- **Scout bees exploration:** The **scoutBeesExploration()** function is called to perform exploration for the employed bees. It updates their positions to explore new regions of the search space.
- **Output the best solution found:** After the main algorithm loop completes, the code outputs the best solution and its corresponding fitness for the current number of sensor nodes.

Hybrid firefly-artificial bee colony algorithm for IoT agriculture devices, enabling customization and adaptation (Table 2).

Parameter	Example Value
Population Size	50
Iterations/Generations	500
Attractiveness	0.7
Distance	Calculated using a distance metric (e.g., Euclidean or Manhattan)
Exploration Rate	0.6
Exploitation Rate	0.4
Fitness Function	Problem-specific
Initial Energy of Nodes	2 Jules
Energy Consumption Rate	50 nJ/bit
E_{FC}	10 pJ/bit/m²
E_{MC}	0.0013 pJ/bit/m⁴
Communication Range	25 meters

Source: Own processing

Table 2: Hybrid firefly and artificial bee colony algorithm.

Experiments with sensor nodes ranging from 100 to 1000 are conducted, with lifetime computation performed for 0 to 1000 rounds. Results include average End-to-End Delay, Packet Delivery Ratio, and Lifetime Computation. Network lifetime is evaluated based on alive edge sensor nodes, providing insights into performance changes as rounds progress. A MATLAB code program is provided to simulate average End-to-End Delay, Packet Delivery Ratio, and Lifetime computation for the hybrid firefly artificial bee colony algorithm (Yang and Slowik, 2020; Karaboga and Basturk, 2007; Karaboga and Basturk, 2008). MATLAB code simulates average end-to-end delay and average PDR for hybrid firefly-artificial bee colony algorithm using IoT device parameters in agriculture. The IoT device initializes parameters like area, sensor count, energy consumption, communication distances, and packet length. A hybrid firefly-artificial bee colony algorithm is implemented, considering population size, generation iteration, attractiveness, distance calculation, exploration, exploitation rates, and fitness function. The simulation loop iterates over 100-1000 sensor nodes and rounds for lifetime computation. The algorithm calculates average End-to-End Delay and Average PDR after each round, and displays results for each iteration.

- **Fitness Calculation (calculate Fitness function):** Fitness calculation function evaluates position fitness based on optimization goals and problems, determining position suitability.
- **Firefly Movement (firefly Movement function):** Firefly movement function adjusts position based on attractiveness and distance, aiding search space exploration.
- **Artificial Bee Movement (artificialBeeMovement function):** Artificial bee movement function simulates population movement based on exploration and exploitation rates.
- **Update Best Solution (updateBestSolution function):** Update best solution function compares fitness values for optimal performance in iterations.
- **Calculate End-to-End Delay and PDR (calculate EndToEndDelayAndPDR function):** Function calculates End-to-End Delay and Packet Delivery Ratio by determining optimal position, measuring packet travel time, and dividing successful packets.
- **Update Lifetime Computation (updateLifetime function):** Update lifetime computation function updates network lifetime based on PDR, node number,

initial energy, energy consumption rate, and message delivery reliability.

- **Simulation Results Storage:** Code simulates Hybrid Firefly-Artificial Bee Colony algorithm, evaluating metrics, and storing results.

Results and discussion

Table 3 and Figure 3 present the Average Packet Delivery Ratio (PDR) results for both the Multi Hop LEACH and HFABC algorithms. The "Number of Rounds" column indicates the rounds or iterations of the simulation, while the "Multi Hop LEACH" and "HFABC" columns indicate the PDR values achieved at a particular round. The "Percentage of Improvement" column shows the percentage improvement of HFABC over Multi Hop LEACH in terms of PDR (Cheng et al., 2022; Sharp et al., 2020; Khan et al., 2013).

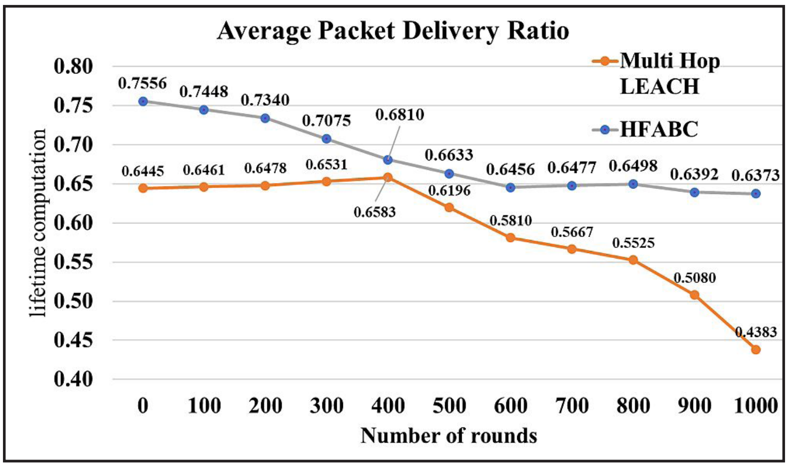
Average Packet Delivery Ratio: Comparative analysis

The PDR is an important metric that measures the ratio of successfully delivered packets to the total number of packets sent. At the beginning of the simulation, HFABC achieved a PDR of 0.7556, 17.24% higher than Multi Hop LEACH's PDR of 0.6445. This indicates that HFABC outperforms Multi Hop LEACH in terms of packet delivery, providing a higher percentage of successful packet transmissions. HFABC consistently achieves a higher PDR than Multi Hop LEACH, resulting in percentage improvements ranging from 3.45% to 45.39%. For example, at round 400, HFABC achieved a higher PDR of 0.6810, representing a 3.45% improvement over Multi Hop LEACH. As the rounds continue, the percentage improvement increases, indicating that HFABC consistently achieves a higher PDR than Multi Hop LEACH.

Number of Rounds	Multi Hop LEACH	HFABC	Percentage of improvement (%)
0	0.6445	0.7556	17.24
100	0.6461	0.7448	15.26
200	0.6478	0.7340	13.30
300	0.6531	0.7075	8.34
400	0.6583	0.6810	3.45
500	0.6196	0.6633	7.05
600	0.5810	0.6456	11.13
700	0.5667	0.6477	14.29
800	0.5525	0.6498	17.62
900	0.5080	0.6392	25.82
1000	0.4383	0.6373	45.39

Source: Own processing

Table 3: Average Packet Delivery Ratio.



Source: Own processing

Figure 3: The variation of Average Packet Delivery Ratio: Multi-Hop Leach and HFABC.

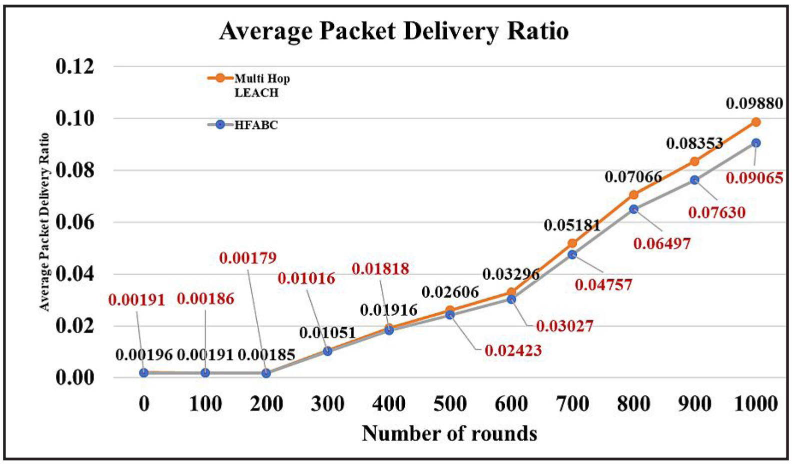
Multi Hop LEACH's PDR dropped significantly to 0.4383 by round 1000, while HFABC maintained a much higher PDR of 0.6373, resulting in a 45.39% improvement over Multi Hop LEACH. HFABC optimizes fireflies and artificial bees' movement to improve data transmission efficiency, resulting in higher packet delivery percentages. This enhances reliability and performance in IoT networks, supporting various agricultural applications and enhancing data transmission (Sharp et al., 2020; Cheng et al., 2022).

The optimum results of Table 3, which presents the Average Packet Delivery Ratio (PDR) for the HFABC algorithm compared to the Multi Hop LEACH algorithm, can be observed at the highest number of rounds (round 1000). At this point, HFABC achieves a PDR of 0.6373, while Multi Hop LEACH only achieves a PDR of 0.4383. HFABC significantly outperforms Multi Hop LEACH in packet delivery performance, with a high PDR value of 0.6373 indicating successful delivery of a large percentage of packets. HFABC algorithm is crucial for reliable IoT data transmission in agriculture, ensuring accurate collection for decision-making and monitoring, supporting smooth agricultural applications.

Average End-to-End Delay: Comparative analysis

Table 4 and Figure 4 show average End-to-End Delay for Multi Hop LEACH and HFABC algorithms, with HFABC showing a percentage improvement over Multi Hop LEACH. Number of rounds: simulation iterations; Multi Hop LEACH: average End-to-End Delay achieved for given number of rounds.

Percentage of improvement (%): The percentage improvement of HFABC over Multi Hop LEACH, calculated as ((*Multi Hop LEACH - HFABC) / Multi Hop LEACH*) * 100.



Source: Own processing

Figure 4: The variation of Average End-to-End Delay: Multi-Hop Leach and HFABC.

Number of Rounds	Multi Hop LEACH	HFABC	Percentage of improvement (%)
0	0.00196	0.00191	2.20
100	0.00191	0.00186	2.57
200	0.00185	0.00179	3.51
300	0.01051	0.01016	3.29
400	0.01916	0.01818	5.10
500	0.02606	0.02423	7.03
600	0.03296	0.03027	8.15
700	0.05181	0.04757	8.18
800	0.07066	0.06497	8.05
900	0.08353	0.07630	8.66
1000	0.09880	0.09065	8.25

Source: Own processing

Table 4: Average End-to-End Delay.

The Table 5 compares HFABC algorithm to Multi Hop LEACH in terms of average End-to-End Delay. HFABC consistently achieves lower delays for increasing rounds, with a percentage improvement column indicating superior performance. The numerical values represent average delays for different simulation rounds.

For 0 rounds, Multi Hop LEACH achieves an average End-to-End Delay of 0.00196, while HFABC achieves a slightly lower value of 0.00191. HFABC outperforms Multi Hop LEACH in reducing average End-to-End Delay by 2.20%. As rounds increase, both algorithms decrease, indicating increased efficiency in packet transmission, resulting in reduced delays.

Looking at specific data points, for example, when there are 500 rounds, Multi Hop LEACH achieves an average End-to-End Delay of 0.02606, while HFABC achieves a lower value of 0.02423. This indicates that HFABC performs significantly better in this case, with an improvement of 7.03% over Multi Hop LEACH. The HFABC algorithm consistently outperforms Multi Hop LEACH in average End-to-End Delay reduction, with percentage improvements ranging from 2.20% to 8.66%. The HFABC algorithm outperforms Multi Hop LEACH in optimizing network routing and transmission mechanisms, resulting in lower average End-to-End Delay. This improvement is due to its hybrid nature, combining firefly optimization and artificial bee colony algorithms for efficient packet routing and transmission solutions.

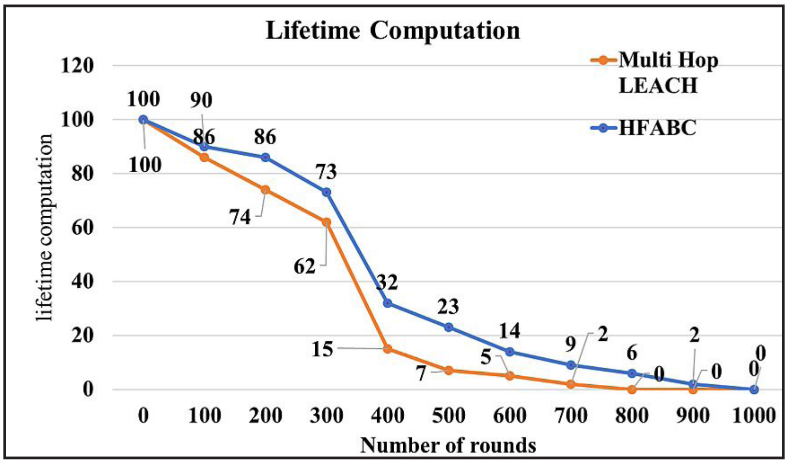
Lifetime computation: Comparative analysis

Table 5 and Figure 5 depict the lifetime computation results for the Hybrid Firefly-Artificial Bee Colony (HFABC) algorithm compared to the Multi Hop LEACH algorithm. The "Number of Rounds" column indicates the number of rounds or iterations

Number of Rounds	Multi Hop LEACH	HFABC	Percentage of improvement (%)
0	100	100	0
100	86	90	0.047
200	74	86	0.162
300	62	73	0.177
400	15	32	1.133
500	7	23	2.286
600	5	14	1.800
700	2	9	3.500
800	0	6	-
900	0	2	-
1000	0	0	-

Source: Own processing

Table 5. Lifetime computation for HFABC.



Source: Own processing

Figure 5: The variation of life time computation: Multi-Hop Leach and HFABC.

of the simulation, while the "Multi Hop LEACH" and "HFABC" columns represent the number of alive edge sensor nodes for each algorithm at a specific round. The "Percentage of Improvement" column shows the percentage improvement of HFABC over Multi Hop LEACH in terms of the number of alive nodes (Sun et al., 2022; Zhang et al., 2019).

HFABC had higher active edge sensor nodes than Multi Hop LEACH, indicating improved energy efficiency and longer network lifetime, with both algorithms having 100 active nodes. HFABC has a longer network lifetime due to its higher number of alive nodes. By round 400, HFABC had 32 active nodes, a 1.133% improvement. By round 500, it had 23 active nodes, a 2.286% improvement. HFABC consistently outperforms Multi Hop LEACH in terms of alive nodes, with 6 and 2 active nodes achieved at rounds 800 and 900, respectively. HFABC outperforms Multi Hop LEACH in terms of alive nodes. At rounds 800 and 900, HFABC achieves 6 and 2 alive nodes, respectively, while Multi Hop LEACH has no remaining nodes. The optimum result is observed at round 900, where HFABC achieves a network lifetime of 2.

Conclusions

According to the simulation results for average End-to-End Delay, average Packet Delivery Ratio (PDR), and Lifetime computation for the Multi Hop LEACH and HFABC algorithms over varying numbers of rounds.

- HFABC algorithm consistently achieves lower average End-to-End Delay values than Multi Hop LEACH, with a percentage improvement from 2.20% to 8.66%, demonstrating its superiority in reducing delays.
- HFABC outperforms Multi Hop LEACH in terms of Average Packet Delivery Ratio (PDR) for most rounds, ranging from 3.45% to 45.39%, indicating its ability to deliver more packets successfully.
- HFABC shows a significant improvement in lifetime compared to Multi Hop LEACH, with a percentage improvement ranging from 0.047% to 2.286% across rounds.

The HFABC algorithm outperforms Multi Hop LEACH in terms of average End-to-End Delay, Packet Delivery Ratio, and Lifetime computation. It achieves lower delays, higher PDR, and improved lifetime compared to Multi Hop LEACH. This highlights the effectiveness of the hybrid firefly-artificial bee colony algorithm in optimizing IoT data transmission in agricultural systems. HFABC improves overall performance and efficiency, leading to better decision-making and resource management, making it a promising choice for IoT applications in agriculture.

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