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Efficiency of European Union wheat producers on world market and analysis of its determinants based on the data envelopment analysis method

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Abstract: The war in Ukraine has shown that the worldwide food security can be easily shaken. This article focuses on an evaluation of European Union (EU) wheat producers on the world market. Would EU producers maintain their competitive position without direct payments? What changes need to be introduced to improve the position of EU producers on the world market? To answer these questions, a data envelopment analysis has been applied. It is indicated that the competitive position of EU wheat producers is still strongly dependent on direct payments and that mechanisation costs are a key area for improved efficiency in wheat production in Europe.

Keywords: competitiveness; data envelopment analysis; direct payments; Luxembourg Common Agricultural Policy (CAP) reform; super-efficiency data; super-efficiency model; wheat production

Contemporary civilization is based on cereals as a staple food source, since most of the energy and protein sustaining the global population originates from grain (Shiferaw et al. 2013). How important this topic is nowadays is shown by the war in Ukraine and its consequences for the food security of the whole world (Schmidhuber et al. 2022). Wheat is the main cereal for human consumption, and its production and demand have continuously increased. The present level of wheat production and consumption worldwide is approximately 770 million tonnes, whereas the world trade in this cereal amounts to approximately 190 million tonnes (data for 2021; Collier 2022). According to the Organisation for Economic Co-operation and Development/Food and Agriculture Organization (OECD/FAO 2021) forecasts, wheat production and consumption in 2030 will amount to approximately 840 million tonnes, and its trade will amount to 220 million tonnes. We may observe an increasing competitive pressure on the wheat market, together with an increase in the production, use, and trade in wheat. In recent years, new players have appeared among the primary wheat exporters. The main players include the USA, Canada, Argentina, Australia, the European Union (EU), and the group of countries from the Black Sea basin, that is, Russia and Ukraine, which, in recent years, joined the so-called Great Five leading wheat producers (FAO 2022). It may be assumed that the competitive situation on this market will become aggravated, together with a further increase in production and demand for wheat. Thus, efficient wheat production will have a major effect on the competitive capacity. It is necessary to reform the common agricultural policy (CAP) assumptions to agricultural production to make agricultural produc-

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tion more efficient. As a result, the Luxembourg CAP reform was carried out in 2003 [Regulation (EU) No. 1306/2013, Official Journal of the European Union, L 347: 549–607; Swinnen 2008].

Thus, the question arises if, after a dozen years of the adoption of the Luxembourg CAP reform, the competitiveness of wheat production by the main EU producers improved in relation to other world participants in those markets. The aim of this study is to analyse the efficiency of the production for the main producers and, at the same time, exporters of wheat on the world market, as well as to indicate the factors determining this competitiveness. In particular, the study attempts to answer the question if EU producers would maintain their competitive position without the present system of EU support in the form of direct payments. Additionally, the study indicates which changes need to be introduced to improve the position of EU producers on the world market.

The novelty of the approach adopted in this study is shown by the type of data used in the calculations. Analyses were conducted based on the data derived from the agri benchmark Cash Crop database (Cash Crop 2021). As a result, in contrast to other studies conducted in this respect, which are typically based on averaged aggregates generated within the farm accountancy data network database (FADN), this study is based on data regarding specific farms, considered by experts to be typical while also being decision-makers. Adoption of the data may eliminate the effect of averaging the values of individual inputs and outputs in the agriculture of the investigated countries (Barnes and Revoredo-Giha 2011).

The manner of the data presentation constituting the basis for the calculations is consistent with the assumptions of the data envelopment analysis (DEA), applied in this study, especially the super-efficiency DEA model. The use of this model allows one to compare the technical efficiency of farms for which the data were received from the agri benchmark Cash Crop database. As a result of the dual application of this model, two rankings of world wheat producers/exporters were obtained. In the first ranking, the output variable was profit with subsidies. In the second ranking, the output variable was profit without subsidies.

The contribution of this work to the theory and current state of research in this field is also evidenced by the fact that the DEA results were contrasted with the level of inputs using a Pearson correlation analysis. This made it possible to pinpoint which changes should be made to improve the efficiency of wheat production.

MATERIAL AND METHODS

Data. The data used in this study originated from the agri benchmark Cash Crop database. The agri benchmark is a global network of agricultural economists, advisors, and producers. The main aim of the agri benchmark database is to reliably present the applied production technologies, organisation of farms, framework conditions, under which the farms operate, and includes prospects for their development (Zimmer 2015). Owing to the collection of authentic information from farms, it was possible to compare the cultivation costs and obtained financial outcomes for the production of a specific crop, which is grown in various parts of the globe. Using the data, we may, for example, compare the cultivation technology of wheat or rape in different worldwide regions. In their comparative analyses, the agri benchmark uses data coming from so-called typical farms.

A typical farm is an actual operating farm or a set of characteristics describing a farm located in a specific region, having a considerable share in the production of the investigated products, applying a system of production characteristics to a given product and being a combination of land, capital resources, and adequate labour organisation. To maintain the best possible representativeness of the farms, typical farms were selected in cooperation with researchers and advisors from a given region or country, since they know the measures required to characterise such a farm. The selection of a typical farm is based on the following values: level of generated revenue, production system, farm size, and management method. Typical farms may be those in which over 50% of the revenue is generated by the farm or when the farm may support at least one member of the household. The crop production system in the farm is the characteristic of a given region. Moreover, a typical farm has at least a minimum size for a given region or is large, where such a farm is also characterised by a medium or high management level (Zimmer and Deblitz 2005).

In view of the limited volume of this study and the availability of data from the agri benchmark Cash Crop database, for the purpose of analysis, a total of 35 wheat-growing farms were selected in such countries as Argentina (3 farms), Australia (3 farms), Canada (5 farms), the USA (3 farms), Russia (3 farms), and Ukraine (2 farms). Among the EU countries, this analysis included data regarding French (2 farms), German (6 farms), Polish (3 farms), and British (4 farms) farms. Farms producing wheat in the United Kingdom (UK)

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in view of the period under study were included in the groups of the EU countries.

To avoid the effect of annual seasonal fluctuations on the obtained results, this study used the means for 2016–2018. The presented farms were compared with respect to the incurred costs and generated financial outcome per 1 ha of cropped area.

One of the weaknesses of the DEA method is its sensitivity to the correlation of variables. Due to this, the available detailed crop cost data had to be grouped (see the second column in Table 1). As a result, a limitation of the research carried out is that the conclusions were related only to the groups of inputs thus grouped and not to the individual input items.

Methods. The DEA approach consists in solving a series of linear equations, based on which the threshold of the maximum technical efficiency is identified. This is undertaken by comparing the vectors of the results–products q_i (outputs; a profit with or without subsidies in this paper; $i = 1, 2, \ldots, R$) and outlays x_i (input; many categories of costs; $i = 1, 2, \ldots, N$) in all the investigated units (typical farms; $i = 1, 2, \ldots, I$). In the case of the assumption that the production generates variable returns to scale and is focused on the minimisation of the used inputs x_i, required to produce outputs q_i, the DEA method makes it possible to determine the technical efficiency by solving linear equations for each investigated unit in the program [the Charnes-Cooper-Rhodes (CCR) model (Charnes et al. 1978; Coelli et al. 2005)]. Consequently, the super-efficiency model (SE-CCR) is an extension of the CCR model (Andersen and Petersen 1993). For the i^{th} unit it takes the following form:

$$\text{Objective function: } \mathrm{Min}_{\theta\lambda}\,\theta_i$$
$$\text{Limiting conditions: } Q\lambda \geq q_i\,;\ \theta_i x_i \geq X\lambda\,;\ \lambda \geq 0\,;\ \lambda_i = 0 \qquad (1)$$

where: θ_i – scalar, named the efficiency index; λ – vector of constants.

Matrices X and Q correspond to inputs and outputs, respectively, for all the units participating in the analysis. Consequently, vectors x_i and q_i refer to incurred outlays (inputs) and produced outputs in the i-th unit, respectively. It needs to be stated here that the SE-CCR approach presents one of the methods to improve the efficiency in farms, which consists in reaching a given production level at the lowest possible involvement of the factors of production.

The technical efficiency of the i^{th} unit determined using the SE-CCR model is investigated compared to the group of the other units excluding the i^{th} unit, and values of the technical efficiency obtained by solving the set of linear equations may be greater than 1. The value of coefficient $\theta_i \geq 1$ indicates the relative advantage of the i^{th} unit over the other units in the investigated group. The higher the multiplier θ_i, the more effectively the unit realises the assumed production target, since it attains assumed outcomes at lower involved inputs. Consequently, if $\theta_i < 1$, it means that competitors of the i^{th} unit would reach the

Table 1. Results of applied n-sphere (hypersphere) method for grouping the individual costs of wheat production

Group of inputs	Individual costs of wheat production
Input 1	seeds, nitrogen, potash, lime, other fertiliser costs, herbicides, fungicides, and other pesticides
Input 2	phosphorus, dry energy cost, irrigation cost, crop insurance net cost, other direct costs, and finance cost equity field inventory
Input 3	insecticides and finance cost debt field inventory
Input 4	hired labour
Input 5	gamily labour
Input 6	contractor
Input 7	machinery depreciation cost, machinery finance equity, and machinery finance debt, machinery repairs, diesel, and other energy costs
Input 8	land cost
Input 9	buildings depreciation, buildings finance equity, buildings finance debt, and buildings repairs
Input 10	farm tax, farm insurance (related to inventory), farm insurance (related to activities), farm advisory cost, farm accounting cost, farm office cost, and other farm costs

Source: Own calculation

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Table 2. Mean values in the analysed groups of cost (EUR/ha)

Variables	Total	EU countries	Non-EU countries
Financial outcome, excluding direct payments	536.9	523.46	548.22
Financial outcome, including direct payments	422.4	275.98	545.75
Input 1	286.4	429.94	165.55
Input 2	49.6	51.81	47.88
Input 3	8.1	9.75	6.77
Input 4	54.4	87.80	26.33
Input 5	67.2	125.81	17.92
Input 6	31.8	43.14	22.21
Input 7	238.8	353.18	142.45
Input 8	226.1	332.86	136.23
Input 9	35.2	67.29	8.24
Input 10	40.9	62.24	22.85

For input overview, see Table 1
Source: Own calculation.

same production level at lower inputs. Thus, such a unit is not efficient. The method of determining the technical efficiencies for each unit in a sample in the SE-CCR model provides a ranking of units, in which the leaders–model units have an efficiency $\theta_i \geq 1$, whereas the other units have efficiencies within the range of (0; 1).

One of the scarce drawbacks of the DEA method relates to the sensitivity to the correlation of variables. It may be prevented using a grouping of variables. In the current study, the *n*-sphere (hypersphere) method was applied that was developed by the Polish team of Bukietyński et al. (1969) in the 1960s. Currently, it is promoted in literature, among others, by Młodak (2013). In these methods, the starting point is the matrix of distances between the individual objects. In this article, it was established based on Pearson's correlation matrix using the dependence as follows:

$$d_{ij} = \left[2\times\left(1 - r_{ij}\right)\right]^{0,5} \quad (2)$$

where: r_{ij} – Pearson's correlation coefficient between the i^{th} and j^{th} inputs.

Objects found in the individual subspaces form groups. The radius of the hypersphere (d^*) was established based on the following formula:

$$d^* = \max\left[\min\left(d_{ij}\right)\right] \quad (3)$$

where: d^* – radius of the hypersphere, d_{ij} – distance between *i* and *j* object.

It also needs to be stressed that the DEA method is typically used to assess the efficiency of decision-making units. Nevertheless, comparisons were also conducted for the efficiency determined based on the DEA method for the aggregated units, such as the average farms at regional or national levels (Coelli et al. 2005; Zhu et al. 2012; Galluzzo 2016). In the presented study, due to the selection of the data, being the individual farms considered by experts to be representative, the above-mentioned condition for the application of DEA was fully met. It also needs to be stressed that the DEA is made available in many commercial statistical programs. In the present study, the potential of the Solver function available in the Excel program was used for the SE-CCR model.

Preparation of the data. As a result of grouping the variables, a total of ten groups of inputs were distinguished and are presented in Table 1. The direct costs were divided into three groups. However, it may be stated that group 1 is formed by most of the key direct inputs, such as the seed, nitrogen and potassium fertilisation, liming, herbicides, and fungicides. Labour costs did not constitute one group, and the analysed farms differ significantly with respect to the type of labour used (Table 2). A separate group was also formed by the service costs.

RESULTS AND DISCUSSION

Realisation of the Luxembourg CAP reform assumptions has been extended to the subsequent years (European Commission 2021). However, the literature on the subject presents the opinion that the competitive position of EU agricultural producers (especially the bigger one) is, first of all, a consequence of the implemented

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common agricultural policy, particularly the system of direct payments and subsidies binding in the EU (McCloud and Kumbhakar 2018; Ciliberti et al. 2022).

Research on the efficiency of agriculture using non-parametric methods is relatively extensive. Such studies concern the specialisation (Scippacercola and Sepe 2014), scale of production (Błażejczyk-Majka et al. 2011), size of the farm (Staniszewski and Borychowski 2020), direction of the production (Błażejczyk-Majka et al. 2013), and the effect of public subsidies on the attained outputs (Minviel and Latruffe 2016). Some publications used other quantitative methods (Førsund and Sarafoglou 2002; Minviel and Latruffe 2016; Scippacercola and Sepe 2014; Staniszewski and Borychowski 2020).

Another category of papers refers to the assessment of wheat production efficiency depending on the incurred inputs on a national scale (Alemdar and Oren 2006; Wang et al. 2017; Hussain et al. 2012; Tozer 2010). Some articles also discuss the assessment of the wheat production efficiency depending on energy consumption (Moradi et al. 2018) or greenhouse gas emissions (Syp et al. 2015).

However, there is a scarcity of studies analysing the international efficiency of wheat production, specifically taking all the costs involved in the production process into consideration. This results from the detailed character and methodology of their collection in individual countries. In view of the above, the presented paper is an attempt to fill this gap.

In view of the research problem posed in this study, a DEA was conducted both including direct payments to wheat production and excluding them. Table 3 presents the results.

The conducted analyses indicate a huge discrepancy in the attained efficiency of the wheat production. When including direct payments, the most efficient farms among all the analysed units ($\theta_i > 3$) included one farm from the USA, one from Germany, and two farms from Russia. Their productivity was almost three-fold greater than the mean level of productivity. In the group of farms from non-EU countries, only four ran the production in a non-efficient manner; which were two Canadian farms, one farm from the USA, and one farm from Argentina. However, it needs to be stressed that these farms would run their production efficiently if they increased their efficiency by slightly over 17%. In contrast, in the group of EU farms, these proportions are opposite, that is, only 5 out of 16 farms produced wheat efficiently.

The average level of productivity in the non-EU farms was 1.72, and their efficiency was over 70% (over 1.5-fold) greater than the efficiency of farms producing wheat in EU countries. Consequently, the average level of productivity in wheat-producing farms in the EU was 0.97. Even greater differences in the efficiency were observed in the case of the outcomes excluding direct payments. In such a situation, only two farms producing wheat in the EU were doing it efficiently. The difference between the average efficiency in non-EU and EU countries increased from 0.75-fold (production including direct payments) to 2.11-fold (production excluding direct payments). This conclusion confirms the general opinion presented in the literature on the subject that subsidies lead to a deterioration in the efficiency of the agricultural production. Minviel and Latruffe (2016) and McCloud and Kumbhakar (2018) reviewed these opinions.

A comparison of the ranking position in the case of determining the technical efficiency including direct payments and excluding them made these differences even more evident. If subsidies are excluded from the analysis, the ranking position of farms located outside the EU improved on average by almost two positions, whereas that of the EU farms decreased on average by more than two ranking positions.

These results confirm earlier studies conducted based on FADN data in relation to the input productivity in farms specialising in cereal production. It was shown that since 2013, the total cereal farm output has remained systematically below the value of total input; hence, the only factor producing a positive economic outcome is the receipt of subsidies under the EU's common agricultural policy (European Commission 2019).

Based on the presented list, it may be stated that the technical efficiency of the analysed farms was most strongly related to the financial outcomes and the consumption of main direct inputs (input 1), family labour (input 5), mechanisation (input 7), buildings (input 9), and other costs (input 10). Apart from the above-mentioned direct costs, the efficiency of wheat production is negatively correlated with the fixed costs incurred by the farms, such as maintenance of the machinery and buildings. This confirms the generally accepted regularity that the elasticity of capital production in agriculture is much lower than the elasticity of material inputs (Cechura et al. 2015) It needs to be stated that the other costs, comprised of group 10 in this study, despite their apparent fragmentation, also have a significant effect on the attained production efficiency.

A comparison of the results of the correlation analysis between the analysis including subsidies and excluding them showed that the subsidies lead to a decrease in the correlation between the value of the technical efficiency of farms with their financial outcomes (Table 4). When

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Table 3. Values of θ_i efficiency indexes established for farms representing major wheat producers and exporters

Country	Producer	Excluding direct payments		Including direct payments	
		θ_i	ranking position	θ_i	ranking position
USA	US1215INS	3.75	1	3.69	1
Russia	RU16000KUR	2.42	4	3.14	3
Russia	RU20000BS	3.08	2	3.12	4
Russia	RU21000KRA	2.74	3	2.75	5
Canada	CA2000SAS	2.39	5	2.39	6
Ukraine	UA7100PO*	1.83	7	1.81	7
Argentina	AR700SBA	1.73	8	1.73	8
Australia	AU2800SA	1.67	9	1.67	9
Australia	AU5500WA	1.65	10	1.64	10
Australia	AU4000WB*	1.53	11	1.53	12
Canada	CA6000SAS	1.22	14	1.22	15
Canada	CA1100NWM	1.16	15	1.16	17
Ukraine	UA2600WU	1.24	13	1.15	18
Argentina	AR900WBA	1.05	16	1.05	19
USA	US2025KS	1.04	17	1.04	20
Canada	CA2000RRV	0.95	18	0.95	22
USA	US1300ND	0.85	21	0.89	24
Argentina	AR330ZN	0.87	20	0.87	25
Canada	CA1700CAB	0.82	22	0.82	26
Germany	DE360OW*	2.24	6	3.31	2
France	FR230PICB*	1.26	12	1.61	11
Germany	DE250KAB	0.89	19	1.27	14
Poland	PL2100ST*	0.73	23	0.97	21
Germany	DE1100VP	0.68	24	1.18	16
Poland	PL730WO	0.50	25	0.72	29
Great Britain	UK270SCO	0.46	26	0.81	28
Great Britain	UK800CAM*	0.43	27	0.61	30
Germany	DE150FP	0.34	28	1.37	13
Great Britain	UK440SUFF	0.29	29	0.44	33
France	FR110ALS	0.26	30	0.90	23
Poland	PL300LU	0.23	31	0.51	31
Germany	DE120HI	0.17	32	0.82	27
Great Britain	UK310WASH	0.15	33	0.30	34
Germany	DE160UE*	0.04	34	0.48	32
France	FR110VGAV	0.00	35	0.22	35
Mean for non-EU farm		1.68	11.37	1.72	13.21
Mean for EU farm		0.54	25.88	0.97	23.69
Mean for all farms		1.16	18	1.38	18

*leading farms in a given region with respect to size and management level; θ_i – efficiency index
Source: The authors' calculations based on the agri benchmark Cash Crop database (2021).

comparing the DEA results in both cases with the share of direct payments in the financial outcome, it may be stated that the higher the share of subsidies in the financial outcome, the greater the drop in the position in the efficiency ranking. This observation supplements conclusions by Cechura et al. (2015) that fewer than one-third of the EU countries, in which farms specialise in cereal production, improved their position in the efficiency ranking after the implementation of new CAP regulations.

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Table 4. Pearson's correlation coefficients for values of technical efficiency and values of variables included in the analysis.

Variables	Excluding direct payments			Including direct payments		
	total	EU farm	non-EU farm	total	EU farm	non-EU farm
Outcome	0.68	0.69	0.30	0.43	0.54	0.37
Input 1	–0.63	–0.19	–0.15	–0.45	–0.23	–0.15
Input 2	–0.33	–0.56	–0.27	–0.41	–0.60	–0.28
Input 3	0.10	0.07	0.45	0.13	–0.11	0.47
Input 4	–0.29	0.08	0.20	–0.23	–0.12	0.22
Input 5	–0.51	–0.29	–0.22	–0.30	–0.01	–0.25
Input 6	–0.22	0.09	–0.25	–0.15	0.11	–0.22
Input 7	–0.58	–0.69	0.11	–0.48	–0.64	0.09
Input 8	–0.32	0.16	0.13	–0.16	0.25	0.06
Input 9	–0.62	–0.47	–0.27	–0.46	–0.32	–0.27
Input 10	–0.60	–0.49	–0.27	–0.52	–0.46	–0.31

For input overview, see Table 1
Source: Own calculations.

In farms producing wheat in the EU, the relationship between the production efficiency and the generated financial outcome is much stronger. In those farms, the technical efficiency is also influenced by the level of direct costs, the long-term effects (phosphorus fertilisation), drying and irrigation, and insurance and financing of inputs (input 2). However, the greatest differences may be observed in the case of the effects on the efficiency of wheat production generated by the mechanisation costs (input 7). Smaller, but significant, differences are found in relation to cost groups 9 and 10 (buildings and other costs).

In the non-EU farms, it is difficult to indicate a correlation between the level of incurred outlays and the attained efficiency. The only exception in this respect is the positive correlation with input 3.

Another interesting observation is also connected with the fact that the realisation of all the tasks based on the services does not guarantee a high efficiency either. However, the analyses showed that the use of hired services does not always lead to improved efficiency. Such an organisation of the production is mainly found in Argentinian farms, which took positions 8, 16, and 20 (in the ranking excluding subsidies).

CONCLUSION

Despite the ambitious assumptions of the Luxembourg CAP reform, most analysed EU farms turned out to produce wheat inefficiently compared to wheat producers outside the EU. Moreover, their position in the efficiency ranking dropped drastically when only the financial outcome excluding direct payments was considered. This means that despite the CAP reform assumptions stipulating that production should be run following market rules, the amount of received subsides continued to have a considerable effect on the level of the efficiency of wheat producers and their position in the efficiency ranking. Nevertheless, it needs to be remembered that even when comparing the efficiency of wheat production including subsidies, a vast majority of EU farms took the lowest positions in this ranking.

When considering all the analysed farms, it may be observed that the value of the attained efficiency directly depends on the level of financial outcome (a positive correlation), with the relationship being relatively stronger in the EU farms. This is related with the fact that these farms are forced to strive to maximise profits to cover the incurred high production costs. Consequently, the current expenditure has an opposite effect on the efficiency. Its level differs significantly in both groups of analysed farms (Table 3). A similar situation was recorded in relation to the level of labour inputs. Their level, apart from the level of the input related to the labour man-hours, is also influenced by the hourly rate, which is determined by the level of wages received in the other sectors of the national economy in the country, in which the farms produce wheat (the higher the standard of development in a given country, the higher the hourly rate).

Moreover, the analyses showed that a high efficiency of wheat production was recorded for the farms char-

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acterised by relatively low levels of three inputs, which were comprised of the costs of the machinery, buildings, and other costs. In relation to the labour costs, their level depends mainly on the decisions made at the farm level. Such a situation is found in the case of the most efficient wheat producers. These included, for example, a German farm, which indicates that despite specific historical and cultural conditions, adoption of such solutions is also possible in European agriculture. Still, it needs to be stressed that the complete limitation of the machine pool and all the farming processes being based on hired services is not a sufficient condition required to attain the high efficiency of wheat production. An example in this respect may be provided by Argentinian agriculture.

Thus, the advantage of wheat-producing farms in these countries depends not only on the level of involvement of individual inputs, but also on the organisation of the production process, which influences their mutual relationships. A change in the position of EU agriculture in the global wheat production is, thus, possible only through long-term changes in the ratios of fixed costs to direct costs, as well as more the efficient use of the family labour force (increased employment outside agriculture).

Based on the conducted analyses, it may be attempted to indicate the required direction of changes in the organisation of wheat production in EU farms, which would improve the production efficiency compared to the main world producers and exporters. As indicated above, the costing of some inputs results from the specific character of the country of production. In this respect, we may mention the level of wages, interest on capital, and the level of rent. Agricultural producers in the EU may determine the level of direct and operating outlays. The level of the former per ha is the highest among the analysed farms; however, these differences are greatly reduced when these inputs are calculated per tonne of the product. The mechanisation of EU wheat production is a key area with the greatest potential for improvement, which could lead to a considerable increase in the efficiency. The number of owned farm machines also determines the level of costs generated by the maintenance of the buildings. We also need to remember the level of other costs. Although their level is relatively lower than that of the above-mentioned inputs, they are also correlated with the level of technical efficiency reached by a given farm. Actions aimed at the optimisation of the incurred machinery-related inputs and other costs need to be undertaken.

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