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TECHNICAL EFFICIENCY ANALYSIS OF GRAIN MAIZE PRODUCTION: A CASE STUDY IN TÜRKİYE

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Abstract

The purpose of this study is to examine the input usage levels of grain maize farmers in Izmir province, Türkiye and to determine the efficiency of input utilization. The study was conducted in four districts of Izmir province, where maize farming is most prevalent. Data were collected through face-to-face surveys with 141 farmers, selected using a stratified random sampling method. The study employs Data Envelopment Analysis (DEA) to assess input usage efficiency. 33.33% of farms were fully efficient under CRS, and 43.26% were fully efficient under VRS. The average efficiency scores ranged between 0.86 and 0.99. The average technical efficiency (CRS) was determined as 0.90. Results indicate that the technical efficiency scores vary across farm sizes, with small farms being relatively more efficient in input use. The results highlight inefficiencies in seed, fertilizer, and irrigation usage, suggesting opportunities for optimization. Policy recommendations include promoting soil testing, increasing awareness of input management, and improving extension services. Enhancing efficiency in maize production could reduce costs, increase profitability, and improve sustainability in Turkish agriculture.

Key words: *grain maize, input usage, efficiency analysis, technical efficiency, data envelopment analysis*

INTRODUCTION

Grain maize is cultivated in many countries today due to its importance in human nutrition, its use as animal feed, and its role as a crucial raw material for industry, contributing significantly to economic growth. Globally, approximately 65-70% of produced grain maize is used as animal feed, 20% is directly consumed by humans, and the remaining 10-15% is utilized in industries. In the industry, many products are obtained from grain maize, including flour, oil, starch and sweeteners [4].

According to FAO's 2023 data, global grain maize production increased to 1.24 billion tons due to both the expansion of cultivation areas and the increase in yield. Grain maize ranks second in terms of cultivation area among cereal crops worldwide (208 million hectares), following wheat, but it is the leading crop in terms of production. Approximately 31% of global grain maize production occurs in the USA, 23% in China, and 14% in South America [22]. According to TURKSTAT data, Türkiye produced 9 million tons of grain maize on 958,017 hectares in 2023. These figures indicate that Türkiye accounts for 0.46% of the global grain maize cultivation area and 0.72% of global grain maize production. The examination of grain maize cultivation areas in Türkiye between 2012 and 2023 shows a decline in 2017, followed by an increase until 2023. In the same period, grain maize production increased by 65% [42]. It is thought that the policies of the Ministry of Agriculture and Forestry and Turkish Grain Board, the use of certified seeds and the developments in the use of technology in production have a significant impact on these increases. In 2023, 29% of Türkiye's grain maize production was obtained from the Western Anatolia region, 24% from the South-Eastern Anatolia region, 21% from Mediterranean region, 10% from Eastern Marmara region, and 7% from the Aegean region. Grain maize yield varies regionally within Türkiye. In 2023, the national average grain maize yield was 9,390 kg per hectare, exceeding the global average of 5,962 kg [42].

According to TURKSTAT data, Türkiye's self-sufficiency rate in grain maize was 96% in 2023. However, due to the development of the manufacturing industry, the demand for raw materials, and the increase in exports of finished goods, Türkiye imports grain maize in addition to domestic production. In 2023, Türkiye exported 3.35 million tons of grain maize and imported 3.27 million tons. Türkiye primarily imports grain maize from the Russian Federation, Ukraine, Romania, and Serbia [42].

In Türkiye, grain maize can be used as feed as well as in the production of starch, oil, glucose and bioethanol. Grain maize can be rotated with crops such as cotton, wheat, and oilseeds. Farmers decide between growing grain maize or alternative crops based on product prices and government support. Therefore, fluctuations in grain maize production can occur [35, 40]. Farmers may change the crops they cultivate on irrigable lands based on economic conditions, drought, or labour shortages. In recent years, declines in cotton, processing tomato, and wheat revenues have led farmers in Izmir province to shift towards grain maize production. In 2023, 89,677 tons of grain maize were produced on 12,088 hectares in Izmir province. The examination of grain maize production in Izmir province between 2012 and 2023 reveals an increase until 2017, followed by a decline in subsequent years. In 2023, grain maize production in Izmir province accounted for 15% of the Aegean Region's total production and approximately 1% of Türkiye's total grain maize production. The grain maize yield in Izmir province in 2023 was 8,960 kg per hectare, below the national average (9,390 kg/ha) [42].

Several studies have been conducted on the economic aspects of grain maize in Türkiye. Some of these studies have analyzed grain maize's cost and profitability [1, 28, 41, 20, 25, 21, 15, 3, 17, 14, 47], while others have focused on input usage [8, 32, 6, 27], the impact of government support [2, 33, 16, 18, 29, 23], efficiency analyses [11, 26, 43, 30, 31, 5, 19, 45], and marketing structures [39, 38].

Türkiye meets part of its grain maize demand through imports. Additionally, issues such as genetically modified (GMO) grain maize, ethanol production from grain maize, climate change impacts on agriculture, and fluctuations in national and international prices necessitate identifying sustainability issues in grain maize production and conducting scientific research to develop solutions. Natural and economic conditions can significantly impact the income of grain maize farmers.

Therefore, it is essential to determine farmer practices, input selection, and usage levels over time and at a regional level through research. The results of this research can serve as a guide for farmers in determining crop patterns and contribute to the preparation of production plans, the formulation of appropriate agricultural policies, and their implementation.

The purpose of this study is to examine the input usage levels of grain maize farmers in Izmir province, Türkiye and to determine the efficiency of input utilization.

MATERIALS AND METHODS

The primary data for this study were collected through face-to-face surveys with grain maize farmers in Izmir province, Türkiye. In addition, previous study results and statistical data published by institutions such as FAO and TURKSTAT were also used.

The study focused on the districts of Torbali, Menderes, Tire, and Bergama in Izmir province, where grain maize production is supported under the Agricultural Basins Support Model. According to TURKSTAT's data, these four districts accounted for 75% of Izmir province's grain maize cultivation areas and 77% of its grain maize production. The study planned to include four neighbourhoods from each district where grain maize production is most concentrated. The main population in 16 selected neighbourhoods consisted of 1,455 grain maize farmers registered in the Farmer Registration System in these neighbourhoods.

A stratified random sampling method was used to select a representative sample of farmers, employing the following formula [44]:

$$n = \frac{\sum(N_h.S_h)^2}{N^2.D^2 + \sum(N_h.S_h^2)} \quad (1)$$

$$D^2 = d^2/z^2 \quad (2)$$

where: n = Sample size, N = Number of farms in the population, N_h = Number of farms in stratum h, S_h = Variance of stratum h, D^2 = Permissible error margin, z = Standard normal distribution value for the given confidence level.

With a 10% error margin and a 90% confidence level (z = 1.645), the calculated sample size was 141.In distributing the sample volume to the strata, stratum variances were taken as basis, and the following formula was used for this purpose [44].

$$n_h = \frac{N_h.S_h.n}{\sum N_h.S_h} \quad (3)$$

Stratification was based on variance values, ensuring that each stratum contained at least 30 farmers for meaningful comparisons. Accordingly, farmers were categorized into three strata based on cultivated area: less than 4 hectares (Group 1), 4-13 hectares (Group 2), and more than 13 hectares (Group 3). The final sample included 41 farmers from Group 1, 62 from Group 2, and 38 from Group 3 (Table 1).

Table 1. Stratified sample size

Farmer groups	Strata (ha)	Frequency	Variance	Mean (ha)	Sample size	%
1	<4	1,119	89.34	1.67	41	29.08
2	4-13	294	524.38	6.79	62	43.97
3	>13	42	2,252.70	18.85	38	26.95

Source: Own Calculation.

The number of farmers interviewed in each settlement was determined based on their proportional representation in the total population. The final selection of farmers was made using a random number table. The study was conducted during the 2021 production season, with surveys administered between November 2021 and January 2022.

The study first examined the socio-economic characteristics of farmers, followed by input usage of grain maize production. At this stage, the average input amounts used per hectare were determined. To determine the technical efficiency of grain maize production, Data Envelopment Analysis (DEA) was used. The data were analysed under constant returns to scale (CRS) and variable returns to scale (VRS) models, generating efficiency scores for each assumption. The input-oriented model approach aimed to achieve the same output with minimal input usage, promoting resource efficiency. The output-oriented and variable returns to scale model was represented as follows [13]:

Maximum: η
$X_{0t} - X_{\mu} \geq 0$
$\eta y_{0t} - Y_{\mu} \geq 0$
$\mu \geq 0$

where:

- η represents the output factor weight vector
- y_{0t} is the output produced by the decision-making unit t
- Y is the total output produced by all decision-making units
- μ represents the output weight factor
- X_{0t} is the input consumed by the decision-making unit t
- X is the total input consumed by all decision-making units

The total efficiency (TECRS) obtained from the constant return to scale Data Envelopment Analysis (DEA) is divided into two components: scale efficiency and pure technical efficiency. When the values of technical efficiency (TEVRS) under constant returns to scale and variable returns to scale differ for a specific production unit, it indicates that the production unit has scale inefficiency. In this case, scale efficiency (SE) can be derived from the technical efficiency values obtained under two assumptions as follows [24]:

TECRS = TEVRS x SE (4)

Total Technical Efficiency =
Pure Technical Efficiency x Scale Efficiency (5)

Scale efficiency reveals the losses resulting from not operating at an optimal scale. If the efficiency value decreases with either a reduction or an increase in the scale of operations, it can be concluded that the relevant production unit has scale inefficiency. By decomposing scale efficiency, pure technical efficiency can be calculated. This decomposition also helps identify the source of inefficiency.

RESULTS AND DISCUSSIONS

Socio-Economic Characteristics of Farmers

The age of the farmers surveyed ranged from 23 to 71 years, with an average age of 47.91 years. Their education levels varied between 5 and 16 years, with an average of 7.94 years. The experience of farmers in grain maize farming ranged from 3 to 40 years, with an average of 15.52 years (Table 2). A similar study conducted in Kahramanmaras province, Türkiye found that the average experience of grain maize farmers was 11 years [34].

The total population in the surveyed farms was 560, with an average household size of 3.97 people. Women constituted 50.88% of the total population. It was observed that only 40% of the available family labour was utilized in agricultural activities, while the remaining 60% remained idle (Table 2).

Table 2. Socio-economic characteristics of farmers

Characteristics	Farm groups			
	Group 1 (<4 ha)	Group 2 (4-13 ha)	Group 3 (>13ha)	General
Age of farmer (year)	49.02	47.24	47.79	47.91
Education period of farmer (year)	7.78	7.87	8.21	7.94
Maize experience of farmer (year)	14.63	15.32	16.82	15.52
Household size	3.74	4.14	3.72	3.97
Family labour utilization rate (%)	35.26	35.45	53.84	40.00
Land size (ha)	6.61	15.18	31.80	17.17
Grain maize production area (ha)	2.20	6.98	22.04	9.65
Equity rate (%)	82.85	64.40	67.94	67.92
Cooperative participation rate (%)	63.41	66.13	71.05	66.67

Source: Results of this study.

The average farm size is 17.17 hectares. The most significant share of total land consists of fields (90.89%) and vegetable areas (4.57%). The primary crops grown on farmlands are grain maize and cotton. The grain maize production areas of farmers range from 0.3 to 54 hectares, with an average of 9.65 hectares (Table 2). A study conducted in Kahramanmaras province determined the average grain maize production area to be 8.15 hectares [34], while another study in Konya province, Türkiye found it to be 10.40 hectares [9].

The total average active assets of enterprises amount to 52.8 million TL, with 94.56% of these assets consisting of land ownership. Meanwhile, 67.92% of liabilities consist of equity capital. Among the examined enterprises, 66.67% of farmers are members of an agricultural cooperative, with most being affiliated with the Agricultural Credit Cooperative (Table 2). A study conducted in Konya province, Türkiye found that 87.77% of grain maize farmers were members of an agricultural cooperative [10].

Input Use in Grain Maize Growing

The inputs and quantities used by farmers in

grain maize production are presented in Table 3. It was determined that farmers carried out seed sowing between April 2 and May 24. The amount of seed used per hectare ranged between 20 and 35 kg, with an average of 30.10 kg. A study conducted in Konya province found that 29.40 kg of seed was used per hectare [9], while a study in Tokat province, Türkiye determined this amount as 20 kg [46].
According to study results, 65.96% of farmers (93 farmers) do not conduct soil analysis. When asked for their reasons, they stated that they were unaware of where to conduct analyses, found the costs too high, distrusted the results, or did not have time. Farmers used the following chemical fertilizers in grain maize production: compound fertilizers (15-15-15, 18-18-18, 20-20-20), ammonium nitrate (26%), DAP (18-46), ammonium sulphate, urea, potassium sulphate, and foliar fertilizers. The amount of plant nutrients applied per hectare was determined as 445.40 kg of nitrogen and 179.80 kg of phosphorus (Table 3). A study in Konya province, Türkiye found that 246.60 kg of nitrogen and 145.10kg of phosphorus were used per hectare [9].
Farmers use chemical pesticides to control weeds, leaf borers, grain maize earworms, and red spiders. The amount of herbicide used per hectare is 12.80 kg, while insecticide usage is 3.20 kg per hectare (Table 3). A study in Konya province found that 35.40 kg of chemical pesticides were used per hectare [9], whereas in Tokat province, Türkiye, 2 kg of pesticides per hectare was recorded [46]. A study in Izmir province, Türkiye found that 12 kg of herbicide and 2.80 kg of insecticide were used per hectare [36].

Table 3. Input use in grain maize production

Inputs	Farm groups			
	Group 1 (<4 ha)	Group 2 (4-13 ha)	Group 3 (>13ha)	General
Seed (kg/ha)	29.80	30.20	30.50	30.10
Fertilizer(kg/ha)				
N	439.00	443.50	455.30	445.40
P_2O_5	181.70	173.40	188.20	179.80
K_2O	71.90	70.20	80.30	73.40
Pesticide(kg/ha)				
Herbicide	10.20	13.50	14.20	12.80
Insecticide	2.90	3.20	3.40	3.20
Human labour (h/ha)	59.00	61.90	62.40	61.20
Sowing	12.00	12.60	12.40	12.30
Fertilization	2.90	3.10	3.40	3.10
Spraying	2.70	2.70	2.90	2.80
Irrigation	3.20	3.10	3.20	3.10
Tillage	24.10	23.90	24.20	24.00
Hoeing	7.60	7.70	8.20	7.80
Harvest	6.50	8.80	8.10	8.10
Machine labour (h/ha)	38.30	39.80	41.60	39.90
Number of irrigations	7.71	7.64	7.50	7.62

Source: Results of this study.

The amount of labour used per hectare varies between 35 and 90 hours, with an average of 61.20 hours. Labor is mainly used in soil preparation and planting stages. Farmers mainly use artesian wells for irrigation, and the number of irrigation cycles varies between 4 and 12, with an average of 7.62 irrigation cycles per production period (Table 3).
In grain maize production, mechanical power usage per hectare ranges between 24 and 70 hours, with an average of 39.90 hours (Table 3). A study conducted in Kahramanmaras province found that 23 hours of mechanical power and 50.80 hours of labour per hectare were used [12]. A study in Konya province found that 16.20 hours of mechanical power and 65.90 hours of labour per hectare were used [9], while another study in Tokat

province, Türkiye determined 80 hours of labour per hectare [46].

Input Use Efficiency in Grain Maize Growing

In this study, Data Envelopment Analysis (DEA) was used to determine efficiency scores. The analysis was conducted with one output and seven inputs, using an output-oriented approach. The output considered in the analysis was land productivity, while the inputs included grain maize production area, seed amount, nitrogen fertilizer amount, labour input, mechanical power usage, pesticide amount, and number of irrigations. The descriptive statistics for these variables are presented in Table 4. The grain maize yield per hectare varies between 11,000 and 17,000 kg, with an average of 13,879.30 kg/ha (Table 4).

Table 4. Descriptive statistics of output and input

Farm groups	Means							
	Yield (kg/ha)	Grain maize production area (ha)	Seed (kg/ha)	Fertilizer (N) (kg/ha)	Machine labour (h/ha)	Human labour (h/ha)	Pesticide (kg/ha)	Number of irrigations
Group1 (<4 ha)	13,920.20	2.20	29.80	439.00	38.30	59.00	13.10	7.71
Group 2 (4-13 ha)	13,850.10	6.98	30.20	443.50	39.80	61.90	16.70	7.64
Group 3 (>13 ha)	13.890.00	22.04	30.50	455.30	41.60	62.40	17.60	7.50
General	13,879.30	9.65	30.10	445.40	39.90	61.20	16.00	7.62
Farm groups	Standard errors							
Group 1 (<4 ha)	11,896.00	0.95	3.00	48.50	9.90	14.30	3.10	1.89
Group 2 (4-13 ha)	16,250.00	2.52	3.20	52.50	11.00	12.20	4.40	1.74
Group 3 (>13 ha)	13,546.00	11.50	2.70	64.80	6.70	10.70	4.20	1.50
General	14,290.00	9.96	3.00	55.00	9.70	12.50	4.40	1.71

Source: Results of this study.

The differences among groups in terms of variables indicate that different farm types were represented in the sample.

The efficiency scores were estimated under Constant Returns to Scale (CRS) and Variable Returns to Scale (VRS) assumptions, allowing for the calculation of Scale Efficiency (SE) as well. The efficiency scores for each farm group are presented in Table 5.

Table 5. Technical efficiency scores

Farm groups	CRS	VRS	SE	Max. (CRS)	Max. (VRS)	Max. (SE)	Min. (CRS)	Min. (VRS)	Min. (SE)	Rate of efficient farms		
										CRS	VRS	SE
Group 1 (<4 ha)	0.95	0.96	0.99	1.00	1.00	1.00	0.76	0.78	0.91	56.10	68.29	63.41
Group 2 (4-13 ha)	0.89	0.91	0.98	1.00	1.00	1.00	0.66	0.71	0.78	29.03	40.32	48.39
Group 3 (>13 ha)	0.86	0.88	0.98	1.00	1.00	1.00	0.67	0.69	0.86	15.79	21.05	50.00
General	0.90	0.91	0.98	1.00	1.00	1.00	0.66	0.69	0.78	33.33	43.26	53.19

Source: Results of this study.

According to the results:

-*In Group 1* (<4 ha), 56.10% of farms were fully efficient under CRS, while 62.29% were fully efficient under VRS.

-*In Group 2* (4-13 ha), 29.03% of farms were fully efficient under CRS, while 40.02% were fully efficient under VRS.

-*In Group 3* (>13 ha), 15.79% of farms were fully efficient under CRS, while 21.05% were fully efficient under VRS.

Overall, 33.33% of farms were fully efficient under CRS, and 43.26% were fully efficient under VRS.

The average efficiency scores ranged between 0.86 and 0.99.A study conducted in the Eastern Mediterranean Region, Türkiye estimated the technical efficiency of grain maize farms at 81% [30].

In another study conducted in Adana province, Türkiye, the average technical efficiency of grain maize farms under VRS was 0.887 [7].

Table 6 presents the scale efficiency of farms and their operational returns to scale. The results indicate that:

-*In Group 1* (<4 ha), 14.63% of farms operated under increasing returns to scale (IRS), 21.95% under decreasing returns to scale (DRS), and 63.42% under constant returns to scale (CRS).

-*In Group 2* (4-13 ha), 14.51% operated under IRS, 37.10% under DRS, and 48.39% under CRS.

-*In Group 3* (>13 ha), 15.79% operated under IRS, 34.21% under DRS, and 50.00% under CRS.

Overall, 14.89% of farms exhibited increasing returns to scale, 31.92% showed decreasing returns to scale, and 53.19% operated under constant returns to scale. Table 7 outlines the potential input reductions that could be achieved without reducing output levels. Since the analysis is output-oriented, these percentages indicate the extent to which input use could be reduced while maintaining the same level of grain maize production.

The results suggest that farms could reduce:

- Seed usage by 2.65%
- Fertilizer (nitrogen-N) usage by 1.12%
- Machine labour usage by 48.74%
- Human labour usage by 4.12%
- Pesticide usage by 34.87%
- Number of irrigations by 11.94%

The results indicate that small farms (<4 ha) were the most efficient in terms of input use, while larger farms (>13 ha) had the highest potential for input optimization.

Table 6. The working styles of farms according to scale

Farm groups	Description	Number of farms	%
Group 1 (<4 ha)	IRS	6	14.63
	DRS	9	21.95
	CRS	26	63.42
Group 2 (4-13 ha)	IRS	9	14.51
	DRS	23	37.10
	CRS	30	48.39
Group 3 (>13 ha)	IRS	6	15.79
	DRS	13	34.21
	CRS	19	50.00
General	IRS	21	14.89
	DRS	45	31.92
	CRS	75	53.19

Source: Results of this study.

Table 7. Input use reduction rates for efficiency limit (%)

Farm groups	Grain maize production area	Seed	Fertilizer (N)	Machine labour	Human labour	Pesticides	Number of irrigations
Group 1 (<4 ha)	1.25	0.53	0.73	35.47	2.03	19.18	4.74
Group 2 (4-13 ha)	14.21	3.60	1.28	38.29	4.11	33.80	10.02
Group 3 (>13 ha)	43.18	3.36	1.28	78.18	6.23	49.25	23.11
General	31.18	2.65	1.12	48.74	4.12	34.87	11.94

Source: Results of this study.

CONCLUSIONS

According to the study results, the average maize production area in farms was 9.65 hectares. The average grain maize yield was determined as 13,879.30 kg/ha. 33.33% of farms were fully efficient under CRS, and 43.26% were fully efficient under VRS. The average efficiency scores ranged between 0.86 and 0.99. The average technical efficiency (CRS) was determined as 0.90.14.89% of farms exhibited increasing returns to scale, 31.92% showed decreasing returns to scale, and 53.19% operated under constant returns to scale. Even if farms reduce machine labour usage by 48.74% and pesticide usage by 34.87%, they will be able to produce the same amount.

Ensuring efficiency in input use in grain maize-producing farms can have a positive impact on production costs. Therefore, programs should be developed to educate farmers and establish measures to optimize input combinations. The rising costs of agricultural inputs increase production expenses. To address this issue, area-based input subsidies should be increased, and tax reductions on agricultural inputs should continue. Maize is a crop that requires a lot of irrigation. Farmers have difficulty in covering water costs. Therefore, farmers should be informed about the use of alternative irrigation techniques and encouraged through financial methods [37].

A significant number of farmers do not conduct soil analysis. To prevent over-fertilization and its environmental impact, farmers should be encouraged to perform soil testing, and mobile soil testing services should be expanded. Grain maize production faces various pests and diseases. To enhance effective pest management, training programs should be developed, and the use of biological pest control methods should be promoted. Additionally, breeding pest-resistant grain maize varieties should be prioritized.

To reduce dependency on imported grain maize seeds, research institutes should continue developing domestic grain maize varieties, R&D investments should be increased, and adequate funding should be allocated to this area. The development and promotion of high-yield grain maize varieties should be emphasized. Many farmers do not keep records, which prevents them from monitoring and controlling costs. To address this, record-keeping systems should be developed, and farmers should be encouraged to use them. Farmers also seek more technical guidance on grain maize production. Therefore, extension services should be expanded, and provincial and district agricultural directorates should develop region-specific training programs.

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