Technical efficiency of potato production in Turkey by Stochastic Frontier Analysis

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Abstract

This study aims to determine the technical efficiency of potato production enterprises and develop proposals to increase their efficiency by determining the factors that cause inefficiency. Afyonkarahisar province, one of the significant potato production centres in Turkey, was opted for this examination. The data constitute from the statistics obtained from 79 enterprises selected through the stratified random sampling method. "Stochastic Frontier Analysis" (SFA) techniques were utilised to estimate farm-level efficiency values, and the factors affecting the efficiency of potato production were determined by "A Model for Technical Inefficiency" methods. The variables used in the analysis of efficiency models are potato yield, labour, machine operating time, electricity, pure nitrogen, pure phosphorus, and seed usage levels. According to the research findings, it was determined that the technical efficiency scores calculated with the SSA method ranged between 0.244 and 0.999, and the average technical efficiency score was 0.690. It was found that potato enterprises can increase the amount of output by 31.00% without changing the existing inputs. The potato area and plot numbers that cause inefficiency were found statistically significant. For enterprises to increase their efficiency score, expanding their land and reducing the number of plots was proposed.

Keywords*:* Turkey. Potato. Technical efficiency. Efficiency analysis. Stochastic frontier model.

1. Introduction

Potato production activity is essential due to the high amount of product obtained from the unit area, the possibility of storage during periods of excess supply, and the short production period. In addition, potato is food product with high nutritional value.

The amount of potato production in Turkey was 4 million 980 thousand tons in the field of 1 million 409 thousand decares in 2019 (TURKSAT, 2021). In terms of potato production area and production amount, Afyonkarahisar province was the third rank. Potatoes produced by many farmers in Afyonkarahisar province are important in terms of employment and production value provided to the region.

The production process transforms human and material factors used for the product into goods and services by changing shape or turning into output. Efficiency is the ratio of a given output obtained as a result of production to the input used for that production activity. Efficiency indicates the degree or distance of the factors used for production to reach the targeted output. These concepts are important to reveal the productivity levels of enterprises (Parlakay, 2011).

Due to the unique characteristics of the agricultural sector, the effective and efficient use of the factors used for production has become compulsory. Suppose the enterprises do not work effectively at the end of the agricultural production process. In that case, it is necessary to determine the problems and analyse them in order to use the resources and factors used for production more effectively (Bozdemir, 2017).

This study aimed to analyse the technical efficiency of potato production enterprises in Afyonkarahisar province. In addition, it was aimed to develop suggestions for increasing the efficiency of enterprises by determining the factors that cause inefficiency.

2. Literature Review

There are many studies on the economic analysis of potato production in the literature, but the survey of the technical efficiency of potato production is limited. In this section, literature reviews on the technical efficiency of potato production were summarised.

Wilson et al. (1998) conducted a study entitled “Measuring and explaining technical efficiency in UK potato production”. They estimated the technical efficiency of potato producers in England using the SSA method. The data of the study were obtained by interviewing 140 potato producers producing potatoes. They stated that the data belong to the 1992 production season. According to the research results, they determined that the technical efficiency of potato production varies between 33.22% and 97.29%, and the average technical efficiency was 89.50%.

Amara et al. (1999) carried out research titled “Technical efficiency and farmers’ attitudes toward technological innovation: The case of the potato farmers in Quebec”. They

determined the technical efficiency of potato production enterprises in Quebec, Canada, using the SSA method. The data of the research were obtained from 82 farmers producing potatoes. According to the research findings, it was determined that the technical efficiency scores calculated with the SSA method ranged between 0.193 and 0.999, and the average technical efficiency score was 0.803. They decided that the factors affecting the efficiency were potato land width, farming experience, land ownership, and environmental factors in agricultural activities.

Azizi and Moghaddasi (2012) conducted a study entitled "Potato production efficiency: Evidence from Firoozkuh, Iran". They determined the technical, allocation and scale efficiency of potato producers in Firuzkuh in the Tehran province of Iran using the SSA method. The data of the research were obtained by interviewing 150 randomly selected enterprises from 20 villages. In SSA model, as output; potato cultivation area (ha), as input; seed amount (kg/ha), fertiliser amount (kg/ha), labour (h/ha), number of irrigation, machinery (h/ha) and pesticide amount (kg/ha) were used. According to the research results, they determined the technical efficiency of the potato enterprises in the region as 93.00%, the allocation efficiency as 51.00% and the economic efficiency as 47.00%.

Jwanya et al. (2014) carried out a research titled "Technical efficiency of rain-fed Irish potato farmers in Plateau State, Nigeria: A Stochastic Frontier Approach". The data of the study were obtained by interviewing 227 randomly selected potato producing enterprises. As a result of the research, they stated that the technical efficiency in the enterprises varied between 0.024 and 0.956, and the average efficiency was 0.740. They determined that the factors affecting the efficiency were the farmer's education level, the duration of farming experience, potato variety, and participation in extension activities.

Dube et al. (2016) carried out a research titled "Technical efficiency and profitability of potato production by smallholder farmers: The case of Dinsho District, Bale Zone of Ethiopia". They determined the efficiency of potato producers in the village of Dinsho, located in the Bale region of Ethiopia, using the SSA method and the Cobb-Douglas production function. The data of the study were obtained by interviewing 147 randomly selected potato producing enterprises. As a result of the research, they stated that the technical efficiency in the enterprises varied between 0.51 and 0.98, and the average efficiency was 0.89. The factors affecting the efficiency were determined as the farmer's age, education level, ownership of the land, participation in extension activities, number of parcels, livestock breeding in the enterprises and the size of the household.

Al-Hachami et al. (2020) carried out research titled "Measuring the technical efficiency of potato production and its determinants in Iraq (Baghdad province as a case study)." They estimated the technical efficiency of potato producers in Baghdad, Iraq, and the factors affecting the efficiency using the SSA method. They reported that the data belong to the 2016 production season and that potato production was carried out in the region for two periods. They stated that the data of 79 producers belong to the spring production period, while the data of 94 producers belong to the autumn production period. According to the SFA efficiency results, they determined that the average technical efficiency of potato production was 50.00%. They reported that the most critical factors affecting the effectiveness were the production period and the seed varieties used.

Andaregie and Astatkie (2020) conducted a study entitled "Determinants of technical efficiency of potato farmers and effects of constraints on potato production in Northern Ethiopia". They estimated the technical efficiency of potato producers in Northern Ethiopia using the SSA method and the Cobb-Douglas production function. The data of the study were obtained by interviewing 368 potato producers producing potatoes. They stated that the data belong to the 2018 production season. According to the SSA efficiency results, they determined that potato production's average technical efficiency score was 75.00%.

Bashir et al. (2020) carried out research titled "Estimation of economic and production efficiency of potato production in central Punjab, Pakistan". Using the Data Envelopment Analysis (DEA) method, they determined the technical efficiency of potato production enterprises in Okara District, Punjab, Pakistan, using the Data Envelopment Analysis (DEA) method. The data of the research were obtained from 100 farmers producing potatoes. According to the research findings, it was determined that the average technical efficiency score was 0.874.

There are also studies in the literature that use Data Envelopment Analysis (DEA) or Stochastic Frontier Analysis (SFA) methods to investigate the causes of inefficiency on farms other than potato farms. Some of these studies were listed as follows; Gül, 2005; Gül, 2006; Dağıstan et al., 2009; Gül et al., 2009; Gül et al., 2018; Örmeci Kart et al., 2018; Günes and Güldal, 2019.

3. Materials and Methods

3.1. Materials

In this study, both primary and secondary data were used to calculate the efficiencies of potato production in Afyonkarahisar province. The study's primary material comprised original data obtained via face-to-face survey method from 79 potato production farms at the Sandıklı and Şuhut district Afyonkarahisar province. Afyonkarahisar province has a 10.09% potato production area and 10.69% in potato production in Turkey. Sandıklı and Şuhut district constitutes 55.04% of the potato production area and 53.89% of the potato production quantity of Afyonkarahisar province (TURKSAT, 2021). The data included the 2019 production period. The research area was given in Figure 1.

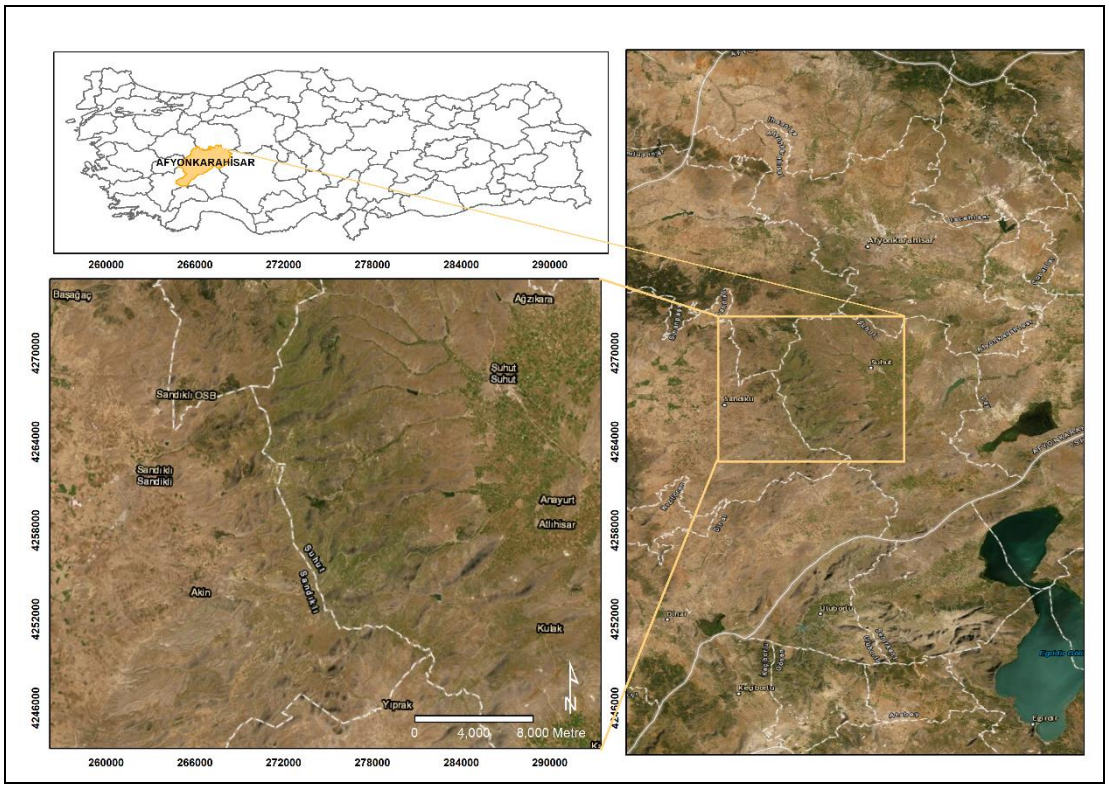

Figure 1. Research area

3.2. Methods

The total number, size and addresses of farms involved in potato production were obtained from the Afyonkarahisar Directorate of Provincial Agriculture and Forestry. Neyman Method was used to determine the sample volume of the survey (Yamane, 2001). The number of samples was calculated with the formula given below.

$$n = \frac{(\sum N_h S_h)^2}{N_2 D_2 + \sum N_h S_h^2} \quad (1)$$

n; Sample size, N; Total number of units in the population, N_h; Number of units in group h, S_h; Standard deviation of group h, S_h^2; Variance of group h, D_2; d_2/z_2, d_2; Allowed error from population average, z_2; Value of the allowed safety limit in the distribution table.

The data constitute from the statistics obtained from 79 farms selected through the stratified random sampling method.

SFA is also known as an econometric approach in the literature. In this approach, a functional relationship is established between explanatory variables such as input, output and environmental factors during production and variables such as cost, profit and production. The error term is also included in this model (Berger and Humphrey, 1997). This approach is based on the assumption that some enterprises do not use their resources effectively.

The estimated technical efficiency of potatoes enterprises could be defined as:

$TEt= Yt/Yt*$

Where TEt is the technical efficiency, Yt is the potato production amount per unit area, Yt* is the potentially obtainable potato production amount per unit area.

Aigner et al. (1977) defined the stochastic frontier production function as:

$Yi = Xi, \beta + (Vi - Ui)$ i= 1, 2, 3, …., N

Where Yi is the output, Xi is indicating the input variables of the i^{th} potato enterprise, β is the parameters, Vi is the measurement errors, random factors that are not under the control of the enterprise, and other inputs that are not included in the production function, Ui is a random variable that is non-negative and represents inefficiency.

Ordinary Least Square (OLS) and Maximum Likelihood (ML) methods to be used in the estimation of the results obtained by the stochastic frontier analysis method were calculated with the one-sided generalised likelihood ratio (LR) equation (Coelli et al., 2005).

$LR = -2\{\ln[LR(Ho)] - \ln[LR(H1)]\}$

Where H_0 is OLS logarithmic likelihood value, H_1 is the ML logarithmic likelihood function value.

In this study, functional analysis of potato production was performed using the Cobb-Douglas type production function. This type of function is suitable for the analysis of applied research such as agricultural production (Heady and Dillon, 1961; Zoral, 1984; Özçelik, 1994; Semerci, 2020), and this production function was widely used in the SSA method in the literature (Kaçıra, 2007; Parlakay, 2011; Gündüz et al., 2016; Parlakay et al., 2017; Dube et al., 2018; Jote et al., 2018; Andaregie and Astatkie, 2020; Şahinli and Özçelik, 2020; Yilmaz and Gül, 2020). For these reasons, the functional analysis of potato production was investigated using the Cobb-Douglas type production function.

In the Stochastic Frontier Analysis, which was used to measure the technical efficiency of potato farms in the region, inputs used extensively in production and had a significant impact on efficiency were included. The analysis included one output and six inputs. In the efficiency analysis, the amount of potato yield (kg/decares) output, labour (hour/decares), machine operating time (hour/decares), electricity (kW/decares), pure nitrogen (kg/ decares), pure phosphorus (kg/decares), seed quantity (kg/decares) as input were used. While yield, which is the dependent variable, was determined as 3 658 kg per decare on the average of all enterprises, the minimum yield was calculated as 1 175 kg and the maximum yield as 6 000 kg. The independent variables were determined as 95.10 hours of labour per decare, 3.83 hours of machine power, 864.30 kilowatts (kW) electricity, 48.85 kg of pure nitrogen, 14.64 kg of pure phosphorus and 337.78 kg of seeds per decare in potato production (Table 1).

Table 1: Summary statistics of variables used in the SFA model for technical efficiency analysis

Output/Inputs Variables	Minimum	Maximum	Mean	Standard Deviation
Yield (kg/da*)	1175.00	6000.00	3658.00	1095.99
Labour (h/da*)	14.62	734.40	95.10	117.95
Machine (h/da*)	0.53	46.37	3.83	9.54
Electricity (Kw/da*)	0.01	6404.66	864.30	1127.37
Pure nitrogen (kg/da*)	0.13	157.50	48.85	34.66
Pure phosphorus (kg/da*)	0.01	69.00	14.64	21.16
Seed quantity (kg/da*)	150.00	1000.00	337.78	157.49

*1 decares = 0.1 hectares

The variables that caused technical inefficiency were the potato land width (decare), farmer age (years), the farmer education level (years), farmer experience with potato production (years), potato plot (number) and debt (1-yes, 0-no). While the average land width of the enterprises was determined as 104.94 decares, the minimum land width was calculated as 6 decares and the maximum land width as 500 decares. The minimum, maximum and average values of the other variables were determined as the age of the farmer as 21.00, 69.00 and 47.65 years, the training period of the farmer as 5.00, 16.00 and 8.27 years, the potato experience period as 3.00, 40.00 and 19.14 years, the number of potato plots as 1.00, 25.00 and 5.72, respectively (Table 2).

Table 2: Summary statistics of variables used in the technical inefficiency model

Output/Inputs Variables	Minimum	Maximum	Mean	Standard Deviation
Potato land (da*)	6.00	500.00	104.94	115.31
Age (years)	21.00	69.00	47.65	11.01
Education (years)	5.00	16.00	8.27	3.33

Potato experience (years)	3.00	40.00	19.14	9.07
Potato plot (number)	1.00	25.00	5.72	6.21
Farmer debt (1-yes, 0-no)	0.00	1.00	0.91	0.29

*1 decares = 0.1 hectares

Stochastic efficiency frontier estimates were made using FRONTIER 4.1 developed by Coelli (1996).

4. Results and Discussion

It is expected that the relationship between the independent variables added to the model in econometric methods will not be strong. The presence of one or more high correlations between the independent variables creates the multicollinearity problem in the model. This problem causes errors and misdirections in the interpretations to be made according to the model results. For this reason, the multicollinearity problem among the independent variables included in the model was examined by calculating the correlation.

It was determined that the correlation coefficients between the independent variables ranged between -0.178 and 0.345, and the correlation coefficients were far from 1.000 (Table 3). In other words, no strong correlation was found between the labour force, machine power, electricity, nitrogen, phosphorus and seed variables. The high correlation coefficient between the two variables indicates the existence of a multicollinearity problem in the model. If this value is generally above 0.80, such a possibility can be mentioned (Alpar, 2017). As a result of the calculation, it could be said that the correlation coefficients are well below this value, and there is no multicollinearity problem in the model.

Table 3: Correlation between independent variables

Variables	Labour	Machine	Electricity	Pure nitrogen	Pure phosphorus	Seed quantity
Labour	1.000	0.278	0.303	0.094	0.164	-0.174
Machine	0.278	1.000	-0.178	-0.106	-0.127	0.135
Electricity	0.303	-0.178	1.000	0.345	0.088	-0.017
Pure nitrogen	0.094	-0.106	0.345	1.000	0.302	0.229
Pure phosphorus	0.164	-0.127	0.088	0.302	1.000	-0.082
Seed quantity	-0.174	0.135	-0.017	0.229	-0.082	1.000

The coefficients of the SFA model was created using the Maximum Likelihood method. Variance parameters (sigma square and gamma) in the model were statistically significant at the 1% level. Accordingly, it was determined that inefficiency in potato enterprises was not accidental, some socio-economic variables had an effect, and technical efficiency (inefficiency) had a significant impact on yield. In addition, the high gamma value

of 99.90% showed that the farms were inefficient, and it was determined that this situation caused significant differences in potato yield between the farms (Table 4).

The effect of the variable of labour force used extensively in potato production on potato yield was negative and statistically significant at the 1% level. A 1.00% increase in labour use will result in a 0.12% decrease in productivity. The machine draft power variable will have a decreasing effect on potato yield, and this situation was found to be statistically significant at the 1% level. It was determined that a 1.00% increase in machine usage decreased the potato yield by 0.09%. According to this result, it could be said that the use of labour and machinery in potato enterprises is more than it should be. It was determined that the electric variable had a positive effect on potato yield, but it was not statistically significant. The impact of the pure nitrogen variable, which is one of the important inputs of potato production, on potato yield was negative and statistically significant at the 1% level. A 1.00% increase in the use of pure nitrogen will cause a 0.03% decrease in yield. The effect of the pure phosphorus variable, another essential input, on potato yield was positive and was found to be statistically significant at the 1% level. It was determined that a 1.00% increase in the use of pure phosphorus would increase the yield by 0.03%. It was determined that the variable of seed amount, which is the most critical input of potato production, had a positive effect on potato yield but was not statistically significant (Table 4).

Table 4: Maximum likelihood estimate for technical efficiency parameters in the stochastic frontier production model

Variables	Parameters	Coefficient	Standard Deviation	t-ratio
Stochastic frontier production				
Constant	β0	8.983	0.256	35.032***
Labour (h/da)	β1	-0.119	0.018	-6.530***
Machine (h/da)	β2	-0.087	0.018	-4.921***
Electricity (Kw/da)	β3	0.003	0.005	0.742
Pure nitrogen (kg/da)	β4	-0.028	0.010	-2.802***
Pure phosphorus (kg/da)	β5	0.031	0.004	8.689***
Seed quantity (kg/da)	β6	0.055	0.047	1.171

*** Significant at 1%, ** Significant at 5% level of statistical

The inefficiency factor model determined the factors affecting the inefficiency of the enterprises. According to this, from the socio-economic variables to the technical efficiency scores of potato enterprises; the effect of potato land width, farmer's age, education level, potato experience period, number of potato land parcels and indebtedness were examined (Table 5).

The effect of the potato field width variable on the technical efficiency score was positive (ineffectiveness was negative), and it was determined that it had a statistically significant effect at the 1% level. Accordingly, it was determined that the shrinkage of the potato land width increased the technical inefficiency. Amara et al. (1999), Parlakay and Alemdar (2011) and Tiruneh and Geta (2016) found statistically significant in their studies that shrinking the width of the land would negatively affect technical efficiency scores.

It was determined that the effect of the potato parcel number variable on the technical efficiency score was negative (positive ineffectiveness), and it had a statistically significant effect at the 5% level. Accordingly, it is determined that as the number of parcels increases in potato fields, technical efficiency will decrease. Dube et al. (2018) found the effect of the fragmentation of the potato land on the technical efficiency score to be positive and statistically significant at the 5% level. The difference between the two studies may be due to the different research regions, and the variables added to the model.

The inefficiency factor model determined that age and education variables had a negative effect on technical inefficiency. In contrast, the variables of experience and debt status had a positive effect on technical inefficiency. There are also studies in the literature that found a statistically significant relationship between some variables and inefficiency. The decrease in farmer age will affect inefficiency positively (Bozoğlu and Ceyhan, 2007). Increasing the farmer's education level will negatively affect the inefficiency (Bozoğlu and Ceyhan, 2007; Alam et al., 2012; Jwanya et al., 2014; Bayav, 2020). Increasing agricultural experience will negatively affect inefficiency (Bozoğlu and Ceyhan, 2007; Jwanya et al., 2014).

The LR test was calculated as 27.359 and showed an effect of non-random variables in terms of potato production in the enterprises.

Table 5: Maximum likelihood estimates of the inefficiency variables

Variables	Parameters	Coefficient	Standard Deviation	t-ratio
Inefficiency model				
Constant	δ0	3.858	1.771	2.179**
Potato land	δ1	-0.995	0.268	-3.712***
Age	δ2	-0.632	0.402	-1.570
Education	δ3	-0.019	0.235	-0.082
Potato experience	δ4	0.232	0.301	0.772
Potato plot	δ5	0.618	0.244	2.528**
Farmer debt	δ6	0.147	0.228	0.645
Sigma-square	σ2	0.820	0.216	3.795***
Gamma	γ	0.999	0.000	4971.874***
Ln likelihood		-22.185		
Ln likelihood function		-8.506		
LR test		27.359***		

*** Significant at 1%, ** Significant at 5% level of statistical

Table 6 shows the technical efficiency's frequency distribution of the sampled potato farmers. On average, the farmers were 69 percent technically efficient, ranging from 0.24 to 0.99. The estimated results declared that the potato growers had still the potential to raise their potato production by 74 percent with the existing technology. The efficiency's score for every sampled respondent was estimated and categorised into four groups. The statistics showed that most potato farmers (45.57%) were in the range of 0.76 and 0.99 efficiency's score, 29.11 percent had a technical efficiency range of 0.51 and 0.75, 24.05 percent had efficiency within the range of 0.26 and 0.50. In contrast, 1.27 percent efficiency ranged from 0.01 to 0.25.

Table 6: The SFA model obtained frequency distributions of technical efficiency scores.

Variables	Frequency	Percentage
Technical efficiency		
0.01-0.25	1	1.27
0.26-0.50	19	24.05
0.51-0.75	23	29.11
0.76-0.99	36	45.57
Total	79	100.00
Mean technical efficiency	0.690	
Minimum	0.244	
Maximum	0.999	

5. Conclusions and Recommendations

The average technical efficiency of potato enterprises was determined as 0.690. While the efficiency values of 45.57% of the enterprises were between 0.751-0.999, it was determined that the efficiency values of 29.11% were between 0.501-0.750. According to this result, it was determined that potato enterprises could achieve the same yield by using 31.00% less input.

In the inefficiency model, potato land width at the level of 1% and the number of potato parcels at the level of 5% were statistically significant. The negative relationship between potato land width and inefficiency indicated to increase in the amount of potato land worked more effectively than enterprises with smaller land widths. The positive relationship between the number of potato parcels and inefficiency indicated to inefficiently than those with fewer parcels.

The low amount of production per unit area is one of the important problems of Turkey's agriculture. In order to increase the amount of production per unit area, operators

should be given training on the technical side of potato production. Thus, the input use of enterprises will decrease, and their efficiency will increase.

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