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POTATO PRODUCTION STRATEGIES IN BRAZIL: THE INFLUENCE OF DETERMINANTS OF TECHNICAL AND ECONOMIC EFFICIENCY

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Abstract

The potato market in Brazil is unstable that results from the uncertainty of supply of and demand for, causing severe price fluctuations. The cost of production is high and average production is low, which resulting in low profitability and pointing to a lack of technical and economic efficiency. This study aimed to analyze the determinants of technical and economic efficiency in potato production in Brazil. A primary survey was done to collect primary data with a structured interview schedule. To measure technical and economic efficiencies, we use a stochastic method of the production frontier in which the inefficiency component is heteroscedastic, and to identify the determinants that affect these efficiencies we use a half-normal model. We found that the average technical efficiency was 82%, cost efficiency was 83%, and profit efficiency was 40%. Harvesting, processing, and commercialization, as well as the use of systems and procedures for farm management, are found to be the main determinants of these efficiencies in potato production in Brazil.
Keywords: *Management, Agribusiness, mechanical harvesting, production function, production systems.*
JEL Codes: *M11, M21, Q13, Q14*

1. Introduction

The efficiency of a rural company is obtained through its performance in the use of available resources (Bhende & Kalirajan, 2007; Tothmihaly & Ingram, 2019). The efficiency of a rural enterprise is analyzed by comparing the value of resources used (technical efficiency) with the production cost (cost efficiency) to achieve the highest possible output or production (Maurice, et al., 2015). Hyuha et al., (2007) and Tchale, (2009) claim that producers have to maximize profits and minimize production costs to avoid excessive use of resources for the same level of production. Similarly, less efficient producers obtain a lower production with the same level of resources used by efficient producers.

Therefore, the overall efficiency of rural enterprises has three ways to analyze. First, by looking at the technical efficiency which includes the number of factors of production (inputs, land, capital, labor, and technology) used and the volume of production obtained (Squires & Tabor, 1991). Second, calculating the cost efficiency determined by the prices of resources used and their influence on production costs (Sanusi, & Adesogan, 2014) and third, analyzing the profit efficiency, considering the sales prices and the quantity of output and the prices paid for the factors of production (Kumbhakar et al., 2015).

Some factors are decisive in the context of efficiency in agricultural production, as they determine the level of resources used and the production obtained. Identifying the determinants of efficiency is one of the important components of any strategy to increase production, as well as it is essential to understand the type of influence (positive, negative, or neutral) of these determinants on efficiency parameters. By knowing these determinants producers can make the right decision to improve their efficiency (Jote et al., 2018).

The efficiency of agricultural producers is improved as long as its determinants are known and measured (Fadzim et al., 2016). In this context, some factors can influence efficiency in potato production, such as the ones related to farm management. The lack of scientific studies that considered farm management practices with the efficiency levels obtained, is compromising the correct decision making of producers. Efficiency levels of production can be increased by appropriate use of productive resources and adequate management practices as well as controlling and monitoring the quantity produced in each production cycle (De Koeijer et al., 2003). Similarly, personal characteristics such as the age of producers is also a determinant of efficiency in agricultural production, as reported by Amaza et al., (2006) showing that the younger producers are more efficient than the older producers.

To understand the structure of potato production and its complex commercialization it is necessary a complete description of the production system and identification of commercialization channels. Potato production in Brazil, in general, is carried out by small rural producers (who cultivate up to 49.99 hectares and represent 91% of the total), whereas in the region of study (Campinas) the largest number of rural establishments (57%) are medium-sized (area from 50 to 200 hectares) and large (areas larger than 200 hectares) (BIGS, 2017). In table 1 is demonstrate a comparative analysis between Brazil and the five largest European producer countries.

It's possible to verify that production in Brazil is smaller than in European countries, both in the volume and cultivated areas. Potato productivity in Brazil is above that obtained by Russia Federation and Ukraine but is lower than other countries. In Brazil, the country's production is insufficient to domestic demand, with the need to import, a fact similar to what happens in Russia Federation and Ukraine. However, in the other countries analyzed, the country's production is sufficient to domestic demand and still export. Another interesting fact is that per capita consumption in Brazil is lower than in the five European countries, in which each Brazilian consumes, on average, 19.7 kg of potatoes per year, while in the analyzed European countries, this consumption is higher, being 51 kg per person in France and 126 kg per habitant in Ukraine. In this context, presents the scenario of exports, imports, and prices paid to producers, as shown in Table 2.

Table 1. Potato Market Analysis in Brazil and in the Largest European Producer Countries

2020	Production	Area	Yield	Domestic Supply	Losses	Processing	Seed	Food Supply
	(1000 tonnes)	(1000 tonnes)		(1000 tonnes)	(1000 tonnes)	(1000 tonnes)	(1000 tonnes)	(kg/capita/yr)
Ukraine	20.838	1.325	15,72	21.158	3.236	106	5.213	126,0
Russian Federation	19.607	1.178	16,64	21.757	1.420	111	4.037	87,2
Germany	11.715	274	42,83	9.008	456	60	565	67,1
France	8.692	215	40,52	6.192	1.243	447	437	51,0
Netherlands	7.020	165	42,68	4.028	181	696	306	93,4
Brazil	3.768	117	32,13	4.780	283	0	240	19,7

Source: Prepared by the authors, based on Faostat (2020).

Table 2. Import, Export and Price Analysis of Potatoes in Brazil and in the Largest European Producer Countries

2020	Export Quantity (tons)		Import Quantity (tons)		Producer Price (USD/ton)
	Potatoes	Potatoes, frozen	Potatoes	Potatoes, frozen	
Ukraine	2.844	35	301.668	19.881	189,30
Russian Federation	424.001	7.505	316.225	75.669	163,80
Germany	1.976.561	330.885	681.348	335.171	186,70
France	2.336.371	294.020	327.690	571.242	376,40
Netherlands	2.064.784	1.613.784	1.651.026	338.078	117,00
Brazil	9.078	781	13.146	371.303	282,30

Source: Prepared by the authors, based on Faostat (2020)

Likewise, it can be seen that Brazil exports a very small amount of potatoes (9,078 tons in 2020), while the analyzed European countries have a larger export volume, both natural and frozen potatoes. In this context, Brazilian imports are important, mainly frozen potatoes, which the country imported 371,303 tons in 2020. Another interesting fact is in relation to the prices paid for the product, which shows that in Brazil the average paid to the producer in 2020 was USD 282.3 per ton. This average value being higher than those paid in Ukraine, Russia Federation, Germany, and the Netherlands.

By analyzing the historical data presented in Figure 1, it is concluded that the potato production in Brazil increased, whereas the area under cultivation of this crop decreased from 1994 to 2019.

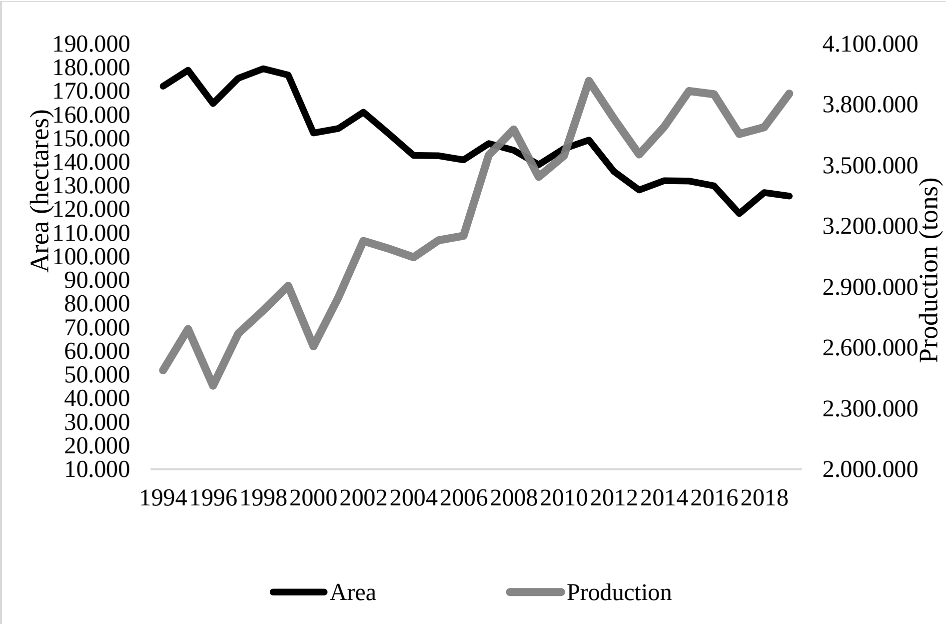

Figure 1. Area under Cultivation and Production of Potato in Brazil between 1994 and 2019

Source: Prepared by the authors, based on BIGS (2020).

In 1994, Brazil cultivated potatoes on 172.6 thousand hectares of land. After 20 years, in 2019, the cultivated acreage decreased to 124 thousand hectares. This area is larger than that cultivated in Netherlands, Great-Britain, Belgium, Spain, Denmark, among other European countries.

This decreased acreage was due to the low prices received by producers and the increased cost of production. In contrast to the decreased acreage, production grew gradually, possibly due to the adoption of new production technologies, and thus, the harvested volume increased to 3.85 million tons in 2019 from 2.48 million tons in 1994 (BIGS 2020). The average yield was 14450 kg per hectare in 1994, which increased to 30700 kg per hectare in 2019.

The Brazilian market consumes all domestic production, and there is still a deficit, causing the need to import, mainly seeds and frozen potatoes. In 2017, Brazil produced 3.7 million tons of fresh potatoes, imported 372 thousand tons (14 thousand tons of fresh potatoes, 349 thousand tons of frozen potatoes, and eight thousand tons of dehydrated potatoes), and used 227 thousand tons as seeds. The Brazilian market consumed 3.963 million tons of potatoes in 2017, which means that the per capita potato consumption in Brazil was 15.2 kg (Faostat 2020). Commercialization through wholesaler markets totaled 1.3 million tons, which is approximately 34% of the national production (NSC 2020).

The proportion of rural producers who develop soil conservation practices is still low, at around 40% of rural establishments, with emphasis on level planting. This demonstrates a scenario of environmental degradation, which can generate problems both in the short term and in the long term, such as erosion and silting, drop in productivity, impoverishment of the soil, etc. (Campos et al., 2017).

Likewise, another important aspect related to soil erosion control and conservation concerns the preparation of soil for planting in which 40% of agricultural properties in the state of São Paulo do not carry out soil preparation activities. However, in 48% of the potato area, soil preparation is carried out in a conventional manner, with the use of plowing and harrowing and in only 6% of this area direct planting is carried out (BIGS, 2020). According to Wadud (2003), soil conservation and permanent adoption of practices that avoid its degradation improve the efficiency levels of the properties.

The potato crop demands adequate mineral nutrition and requires a high supply of chemical fertilizers, mainly in macronutrients such as nitrogen, phosphorus and potassium. Phosphorus is one of the most important minerals required by the potato, due to its action on plant growth, starch formation and increased production yield, which must be supplied in an amount much greater than the plant's requirements, depending on the solubility of this element in the soil. Phosphorus is usually supplied at the time of planting, directly in the crop line, or before planting (Silva and Lopes, 2015). Nitrogen and potassium are supplied at the time of planting and in top dressing, and because they are more soluble, the quantities supplied must meet the nutritional and production requirements expected for each crop (Furlaneto et al., 2014). Therefore, soil sampling becomes essential for determining the fertilizations that should be carried out in the potato crop. Boulomytis and Bresaola Junior (2013) state that in almost 70% of the properties that cultivate potatoes in São Paulo, soil analysis is not carried out aiming at the proper use of fertilizers.

Care must be taken with the supply of fertilizers, as doses lower than necessary will not provide the correct development of the plants and the expected production volume. On the other hand, the excess supply of minerals, in addition to not being used and absorbed by plants, which can be leached or carried by runoff to water courses causing environmental pollution, can also cause damage to potato production, such as toxicity, abnormal development of plants, etc. (Furlaneto et al., 2014; Silva & Lopes, 2015).

This situation provides a substantial increase in the production costs of the potato, as well as generation of certain amount of fertilizer that is not used by the potato plant and remain in the soil after harvest. Normally, this residual fertilizer is used by another crop, reducing its costs of production (Silva et al., 2000). Thus, the use of chemical fertilizers in potato cultivation becomes relevant for production and increased productivity and an average per hectare of 110 kilograms of nitrogen, 84 kilograms of phosphorus and 103 kilograms of potassium are used (BIGS, 2020).

The potato crop is a major consumer of crop protection products and in 2014 it was identified the average consumption per hectare of 5.83 kilograms of herbicide, 22 kilograms of insecticide and 32 kilograms of fungicide. In summary, potato production in São Paulo used an average of 60 kilograms per hectare of agrochemicals (BIGS, 2020).

In the productive context, irrigation in the potato crop is very important, since the water supply is a condition for increasing productivity, as well as product quality. The plant is poorly tolerant to water stress due to its superficial root system and stomatal closure when under water deficit conditions. In São Paulo, only 50% of the area planted with potatoes uses irrigation (Mantovani et al., 2013).

Potato harvest starts about 90 to 120 days after planting, with the semi-mechanized harvest being the most common, using tractor pullers, which revolve the windrows and expose the tubers to the soil, with subsequent harvesting of these tubers manually, where the worker collects the potatoes and puts them in bags or big-bags, which are then collected in trucks to be taken for processing. Mechanized harvesting happens using self-propelled or towed harvesters, which revolve the soil, collect the tubers, separate the impurities, and dump the potatoes in carts or trucks for transportation until processing (Silva and Lopes, 2015).

The highest average yields of production in the region of Campinas are obtained in large properties (average of 35 tons per hectare), while medium producers obtain an average production of 32 tons per hectare, and small establishments obtain around 27 tons per hectare (BIGS 2020; 2017).

Potato production also faces the problem of high total costs over time with a deflated moving average above US$ 10 thousand per hectare between 2009 and 2019 (Casae, 2020). The most important components of costs are spending on inputs and harvesting, which is explained by the high volume of fertilizers, seeds, and pesticides needed in potato production, as well as the prices of these inputs and the form of semi-mechanized harvesting practiced. by most producers, which raises total costs for using a large amount of labor for this operation.

The processing consists of the brushing, washing, sorting, and packaging of potatoes, which can be accomplished by the producer on the property (as long as having the processing facility at the farm), or outsourcing with service providers specialized in this process. The marketing process is usually done by these providers that maintain links with wholesalers and retailers in various Brazilian regions, and actively participate in the fresh potato market, managing to commercialize the production they benefit. Another possibility of commercialization includes the delivery of the processed potato to a processing industry for the production of pre-fried frozen potatoes and potato chips.

Wholesale agents establish potato prices and they have a strategic position within the Brazilian potato production chain that concentrates the highest volume of production all through the year in the common market or with processing industries. The performance of the rural producer in the common market is characterized by the production, harvest, processing, and delivery of nature potatoes to the wholesale, or directly to the retail. Generally suffering the intermediation of companies outsourcing, which has a direct relationship with wholesalers from all over the country. According to the supply and demand at each moment of the harvest, those companies organize the potato distribution by the producers, in what period and quantities. The dynamics of this type of commercialization is simple, with no formal documentation in the execution of activities (contracts between the parties), in most cases solely verbal contacts between agents (beneficiary and producer).

Another marketing option is with the processing industry, which uses fresh potatoes to transform them into chips, frozen pre-fried, dehydrated flour, etc. In this respect, large processing industries (PepsiCo, McCain Foods, Bem Brasil Foods, Aviko Potato, etc.) establish long-term supply contracts with producers that meet their production requirements determined by them, which notably requires investments in infrastructure, larger areas of production, meeting strict quality criteria throughout the production process, among others. These requirements decrease the number of suppliers qualified to supply potatoes to these industries in each region. The advantages for the producer arise from the differentiated price, generally higher than in the common market, the guarantee of purchase of all production, technical assistance, long-term supply contracts, among others.

In economic terms, potato production is important for producing countries such as Brazil since the Gross Value of Production (GVP) in global terms was US $ 92.75 billion in 2017.

For South America, potato production generated a GVP of US $ 5.58 billion and for Brazil, the GVP in 2017 was US $ 2.09 billion (Faostat, 2020). This composition is mainly due to the states of Minas Gerais (which obtained a gross value of potato production of almost US $ 250 million), Paraná (US $ 199 million), and São Paulo (US $ 154 million) (BIGS, 2020).

There is a clear definition of the moments of production and commercialization of the producing states in the CEASAs (Supply Center), a central wholesaler market, mainly with production coming from the states of Sao Paulo (SP) and Paraná (PR). The production of Minas Gerais (MG) is constant throughout the year, due to several producing regions in this state, with the largest volumes of potatoes in the CEASAs occurring from January to May each year (9%), decreasing in the months of June to October (7%) and has a small increase in November and December (8%), as shown in Figure 2.

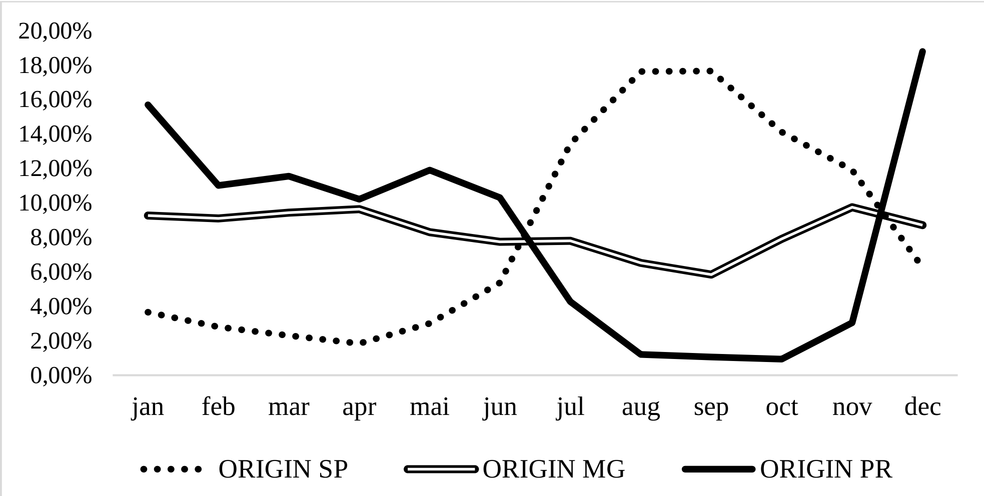

Figure 2. Potato Production in the Three Largest Brazilian Producing States in 2020

Source: Prepared by the authors, based on NSC (2020); BIGS (2020, 2017).

The Paraná state has the highest production and commercialization volumes between December and June (89% of production), with the highest quantity sold in December (19%), January (16%), and 10% on average in the remaining months. On the other hand, from July to November, potato production declined sharply.

Potato production in Sao Paulo State is the opposite of Paraná State, since most of production and commercialization takes place from July to November (75% of the total), with huge volumes being sold in August and September (18%), October (14%), November and July (13%). On the other hand, from December to June production declines, and an average of 3% of state production is market each month (NSC, 2020; BIGS 2020, 2017).

In this scenario of uncertainty, the prices received by producers, high cost of production, low profitability, the factors that determine the efficiency in potato production were identified specifically in the State of São Paulo. The main hypothesis suggests that producers who use management tools, that are members of cooperatives, use mechanized harvesting, have potato processing units at the farm and trade with potato processing industries, are the most technical and economically efficient. Therefore, this work aimed to estimate and analyze the determinants of technical and economic efficiency in potato production in Brazil.

2. Material and Methods

Primary information was collected from potato producers in the State of São Paulo, Brazil, with individual interviews with 50 (fifty) producers in the region of Campinas (see Figure 1). Data from SAPU (2019) indicate the existence of 141 farms under potato cultivation in the study region. For an empirical study in potato production, primary data were collected using face-to-face interviews with 50 producers located in three municipalities of the Campinas region, in the east-central part of the state of São Paulo, Brazil, as shown in the map in Figure 3.

The cities located at the ends of the perimeter marked as being the region of the study are: Mococa (21° 27'35 "South, 46 ° 57'43" West); Aguaí (22 ° 01'57 "South, 46 ° 58'05" West); São João da Boa Vista (21 ° 58'00 "South, 46 ° 47'56" West); Divinolândia (21 ° 39'27 "South, 46 ° 44'27" West) and White House (21 ° 46'45 "South, 47 ° 05'08" West).

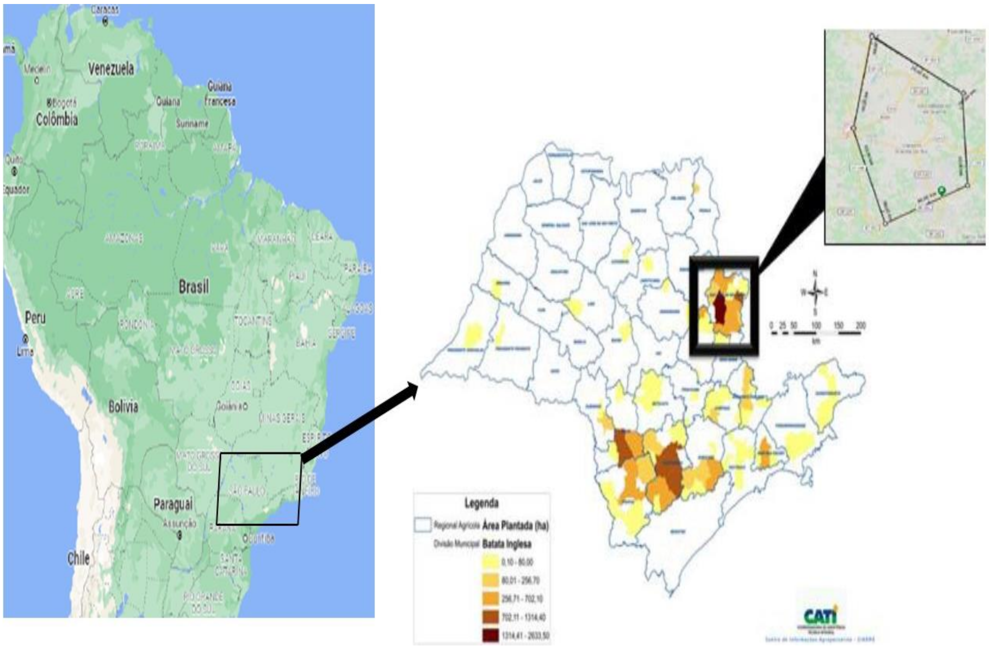

Figure 3. Map of the State of Sao Paulo, Brazil, pointing out the Region of Study

Source: Prepared by the authors based on Sapu (2019).

The collection of primary data was carried out through a structured questionnaire, with 20 questions, in a closed format on a multiple-choice scale, and with some open-ended questions.

This study has the characteristic of being association research with interference, a type of research that performs correlation tests between treatments, whereby the interference of one or more variables must interfere with others (Volpato, 2017). In the context of the efficiency study, some exogenous variables can influence the indicators of technical and economic efficiency in potato production, such as those described in Table 3.

Table 3. Determinants of Technical and Economic Efficiency

Variable	Type	Description
Processing (Z_1)	Dummy	Form of realization of the post-harvest processing (washing, sorting, packaging). If 0 = made by third parties or 1 = Own.
Biologic (Z_2)	Dummy	Uses organic products. If 0 = Do not use or 1 = Use.
Harvest (Z_3)	Dummy	Harvest embodiment (How the harvesting process takes place) If 0 = Semi-mechanized or 1 = Mechanized.
Commercialization (Z_4)	Dummy	As that commercializes the production of potatoes. If 0 = Common Market or 1 = Industry.
Cooperatives (Z_5)	Dummy	Producer is cooperative. If 0 = Do not participate or 1 = Participate.
Marital status (Z_6)	Dummy	Marital status of producers. If 0 = Single or 1 = Otherwise.
Management tools (Z_7)	Dummy	The management tools (softwares, excel sheets, cash flow control, machine maintenance, and production cost management) that the producer use.
Family Size (Z_8)	Discrete	The number of family members of the producers.

Source: Based on Kelemu and Negatu (2016).

The information on production was analyzed using a stochastic frontier function, considering that the measurement of potato producers' inefficiency may be affected by uncontrollable external factors. In this context, to determine the coefficients of these factors, maximum likelihood estimators were adopted following Abdul-Rahaman and Abdulai (2018); Ali et al. (2019) and Jote et al. (2018).

Parametric methods for calculating efficiency indicators are based on econometric procedures and enable the estimation of parameters for stochastic boundaries. Therefore, in this stochastic model, we consider the random error around the estimated production frontier. The stochastic frontier production function was described by Battese and Coelli (1995) as

$$Y_i = \exp\left(X_i\beta + V_{ij} - U_{ij}\right) \tag{1}$$

where Y_i denotes production of i-th farm, x_i is the vector of the production factors ; i indicates the number of farms and number of inputs, β is the vector of the parameter values to be estimated; V_i is the random error, which is independent and identically distributed (IDD), and U_i is the error term associated with technical inefficiency and is IDD with mean $z_{ij}\delta$ and variance σ^2; z_i denotes the vector of the variables that determine technical inefficiency, and d is the vector of the coefficients.

In technical inefficiency analysis, output is the dependent variable and the inputs are the independent variables. In our analysis, factor prices were disregarded by adopting only the quantity of each input used. In addition, to estimate the model, two orientations were possible, for output as well as for input. We adopted the orientation for output, with the stochastic frontier production model described in Equations 1 and 2 (Kumbhakar et al., 2015).

$$lnY_i = lnY^*{}_i - U_i \qquad U_i \geq 0 \tag{2}$$

$$lnY^*_i = f(x_{i,}\beta) + V_i \quad (3)$$

i = number of farms y_i =output of the i[th] farm
x_i = vector *jxl* of the inputs β = vector *of coefficients*

where y_j is the output of farm j, x_j is the vector of m inputs of farm j, such that x_j=(x_1j,x_2j,… x_mj), β is the vector of regression coefficients, *jxl* refers to each input analyzed in this model (extracted from Kumbhakar et al. 2015), V_i = error term $U_i \geq 0$ = production inefficiency

Thus, the empirical model used across the stochastic frontier of production (Cobb-Douglas) is specified in Equation 4.

$$ln(Y_i) = \beta_0 + \beta_1 \ln(Area_i) + \beta_2 \ln(Seed_i) + \beta_3 \ln(Fertilizers_i) + \beta_4 \ln(Pesticides_i) + \beta_5 \ln(Labor_i) + V_i - U_i \quad (4)$$

To identify the determinants of the efficiency of the sample farms, using the model developed by Battese and Coelli (1995), which determines the efficiency indicators and their determinants in a single stage, we have included a vector of determining variables.

$$U_{it} = z_{it}\delta + W_{it} \quad (5)$$

in which W_{it} is a random variable and these parameters are estimated using maximum likelihood procedures (Battese and Coelli, 1995). Likewise, Caudill et al.(1995) and Caudill and Ford (1993) show that a model that considers aspects of heteroscedasticity can define the determinants of efficiency. In this study, the one-step procedure was adopted, which estimates the parameters together (inefficiency and its determinants) using the MLE method. This procedure adopts the ui distribution as a function of exogenous variables (z_i):

$$E(u_i) = \sigma\left(\frac{\phi(0)}{\phi(0)}\right) = \sqrt{2/\pi}\exp(z_i'w) \quad (6)$$

$$\exp\left\{\frac{1}{2}\ln\left(\frac{2}{\pi}\right) + (z_i'w)\right\} \quad (7)$$

Thus, the determinants of efficiency are estimated by the equation Kumbhakar et al., (2015):

$$U_{it}=\delta_0+\delta_1(Z_{1it})+\delta_2(Z_{2it})+\delta_3(Z_{3it})+\delta_4(Z_{4it})+\delta_5(Z_{5it})+\delta_6(Z_{6it})+\delta_7(Z_{7it})+\delta_8(Zq_{8it}) + W_{it} \quad (8)$$

Equation (8) identifies the statistical error components, which leads to the use of models generally identified through parametric distributions, such as the truncated half-normal and half-normal models (Aigner et al. 1977). We used models with parametric frequencies to obtain inefficiency indicators and a residual test of ordinary least squares, as proposed by Lin and Schmidt (1984). This adopts that the residuals of the model of OLS must be tilted to the left (showing a negative value in the asymmetry). In the case of the sampling carried out, the value of asymmetry was *-0.6724*, corroborating model robustness and stating data consistency with the correct specifications. In the same test, the value of $p = 0.042$ is shown with statistical significance at 1%, through which the null hypothesis of non-asymmetry is rejected (H_0 = non-asymmetry).

The test proposed by Battese and Coelli (1995) was also adopted, which assumes that the residuals of OLS are asymptotically distributed, with an average equal to zero. The value found was *-1.941*, which confirms the rejection of the null hypothesis of non-asymmetry. Then, it is possible to adopt the half-normal and half-normal truncated models, confirmed by asymmetry tests, which proves the existence of inefficiency. However, for the medium-normal model, it is necessary to carry out the likelihood ratio test (LR test) proposed by Battese and Coelli (1995), which adopts the critical values of Kodde and Palm (1986).

We found a value of 27.94, with 1 df (only one parameter is restricted to the test), and when consulting with Kodde and Palm (1986), we found an observed value of 5.412 (statistically significant at the level 1%). Therefore, the rejection of the null hypothesis of the non-existence of inefficiency is confirmed (H_0 = non-inefficiency). However, Aigner et al. (1977) indicate that the values of *ui* and *vi* are homoscedastic, which affects the estimators, providing inconsistent estimates.

Therefore, it is appropriate for the model to present heteroscedasticity. When performing the LR test considering the parametric models with heteroscedasticity, we found that the relevance of the half-normal model with heteroscedasticity This situation is analogous to the work by Quiroga et al. (2017).

3. Results and Discussion

Within the determinants of technical and economic efficiency in potato production (Table 4), it was identified that adoption of biological control of pests and diseases is low in potato production, with only 46% of producers adopting this practice. Also, 94% of the producers are married (marital status), with a family of four members (family size), which revealed the presence of two children, on average. Regarding the use of management tools, in particular cash flow control, machine maintenance, and production cost management, 46% of producers adopt these tools is 46%, while 94% of producers are associated with rural producers` cooperative`.

Table 4. Descriptive Analysis of the Determinants of Technical and Economic Efficiency

Variable	Observations	Average	Standard Deviation	Minimum	Maximum
Processing	50	0,44	0,50	0	1
Biologic	50	0,46	0,51	0	1
Harvest	50	0,22	0,42	0	1
Commercialization	50	0,24	0,43	0	1
Cooperatives	50	0,94	0,24	0	1
Marital status	50	0,94	0,32	0	1
Management tools	50	0,46	0,5	0	1
Family Size	50	4	0,82	2	7

Source: Research information from data compiled by the authors.

In the variables related to harvesting, processing, and commercialization, only 22% of the analyzed producers use mechanized harvesting and 44% use their property for processing activities. Regarding the commercialization of production, 24% of the interviewed producers trade with potato processing industries, and 76% trade with the actors in the common markets, preferably through a broker, who often receives benefits from production.

The average technical efficiency obtained was 82% (Table 5), which is similar to the Benedetti et al. (2019); Huy and Nguyen (2019); Kiptoo et al. (2016); Mwalupaso et al. (2019); Zulfiqar et al. (2017). However, the newness in this research is the association of the efficiency value with the determinants involved in the potato production process.

Table 5. Determinants of Technical and Economic Efficiency

Variable	Technical Efficiency	Costs Efficiency	Profits Efficiency
Processing	0.15***	0.015**	(0.62)***
Biologic	0.11***	(0.096)***	-
Harvest	0.14***	0.29**	-
Commercialization	0.24***	-	(0.83)***
Cooperatives	0.31***	-	-
Marital status	-		(0.17)***
Management tools	-		(0.36)***
Family Size	-	-	(0.21)***
Average Efficiency	0.82	0.83	0.40

Notes: Half Normal Model with Heteroscedasticity; ***1%; **5%.
Source: research information from data compiled by the authors.

Concerning harvesting, processing, and marketing, the results indicate that these operations provide differentials for producers in the context of technical efficiency. These three operations are strongly influenced by technical efficiency (statistically significant at 1%). Producers who carry out mechanized harvesting become 14% more efficient than those who adopt semi-mechanized harvesting.

Likewise, producers who make potato post-harvest treatment at the farm or themselves are 15% more technically efficient than those who outsource this activity. We found that producers who carry out the harvest in a fully mechanized system, as well as self-processing, are the ones with the highest technical efficiency indicators.

Also, producers who trade production with the common market are 24% more technically efficient than those who trade with industry. In the same analysis, producers that have a cooperative membership presented the highest technical efficiency indicators. On the other hand, producers that do not belong to a cooperative presented 31% more technical inefficiency (less technical efficient), a similar result found by Abdul-Rahaman and Abdulai, (2018) and Khanal et al. (2018). As for pest and disease control, the use of biological control provides an 11% increase in technical efficiency indicators over the percentage of producers who use only chemical pesticides.

When analyzing the influence of exogenous variables for cost efficiency, an average value was 0.83, which means that potato producers are facing a 17% cost inefficiency. These results are similar to the efficiency research studies done by Alem et al. (2018), but lower than the percentages found in the studies by Ouedraogo (2015) and higher than Ali et al., (2019) and Tchale (2009).

The cost efficiency indicators are determined by three variables (harvesting, processing, and biological control), and producers who carry out mechanized harvesting and self-processing can increase cost efficiency by 29% and 1.5%, respectively. This result corroborates the results found by Gwebu and Matthews (2018) and Huy and Nguyen (2019).

Likewise, producers who adopt biological control to combat pests and diseases show improvements in cost efficiency indicators, with estimates from 9.6% (if increases in the use of biologic products by 100%). This is possible due to a reduction in cost with the main application of pesticides.

In the context of profit inefficiency, all exogenous variables are statistically significant (at 1% level of significance) and all reduce profit inefficiency. When examining the exogenous variables that are determinants of profit efficiency, it’s seen that. the variables related to processing and commercialization, as well as management tools, marital status and family size were found to be statistically significant. In this way, producers who are married and have children (larger families) increased profit efficiency by 17% and 21% respectively, compared to other producers. This result is consistent with the result found by (Ali and Jan (2017); Aminu et al. (2017) and Pena et al. (2018).

The potato processing executed within the farm provides an increase in efficiency up to 62%, and commercialization with the industry allows reduction of profits inefficiency by 83% (increasing profit efficiency). This shows the possibility of increased profits since the costs are reduced considerably (even considering the high investment required for such a process). The same occurs when the potato is commercialized, which offers some advantages for the producer such as less uncertainty, and less risk, especially related to producer price. This fact is corroborated by producers in our sample that trade with the industry and are more economically efficient. The adoption and use of management procedures for cost and cash control, and machine maintenance control, lead to a reduction in profit inefficiency up to 36% (increasing profit efficiency). This fact is reports in the studies of Alem et al. (2018); Exposito and Velasco (2020) and Lakner et al. (2018). In this research, the producers who adopt other management tools, such as technical controls, spreadsheets, and management software are the ones that presented the highest indicators of technical and economic efficiency.

4. Conclusions

The potato producer in Brazil is trapped in a dynamic and complex production chain, and because the producer is at the beginning of the chain, it ends up facing the effects of uncontrollable natural (rainfall, drought, hail, etc.), as well as economic (prices, demand, supply, etc.), social and technological determinants of efficiency. The uncertainties, mainly concerning potato prices exert direct influence on the decisions that are crucial for production permanence, likewise the lack of investments, high costs and scarce options for diversification.

The average technical efficiency found for potato production was 82%, cost efficiency was 83% and profit efficiency 40%. These potato production efficiency values are related to the significant determinants analyzed, where 46% of the producers adopt biological control, 46% use management tools and 90% are linked to an agricultural cooperative. Also, 22% of the producers carry out mechanized harvesting, 44% execute post-harvest processing on their farms and 24% trade with potato processing industries. Potato producers using any one of these practices showed higher values of both technical and economic efficiency.

The performance of potato producers about the results obtained, as well as the achievement of high levels of efficiency in potato production are related to the proper practice of production and management processes. The determinants of efficiency guide the successful business management strategies and efficient practices of potato production.

The analysis of exogenous variables shows that the producers who perform are the most efficient, as their influence is always positive for efficiency, and the adoption of these variables provides an increase in efficiency indicators.

Harvesting, post-harvesting (processing), and commercialization provide differentials for producers in the context of efficiency. In this research, the producers who carry out the harvest in a fully mechanized way, with their processing and commercialization with a processing industry, are the ones that presented the highest efficiency indicators. This shows the possibility of increasing profits by reducing total costs by using mechanized harvesting (even considering the high investment required), as well as in own processing. The possibility of further studies focusing on these variables will enable advances in this field of knowledge and add value to potato producers.

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