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ASSESSING POTATO PRODUCTION EFFICIENCY IN CAMPINAS, BRAZIL: A PATH TO IMPROVING PRODUCER GAINS

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Abstract

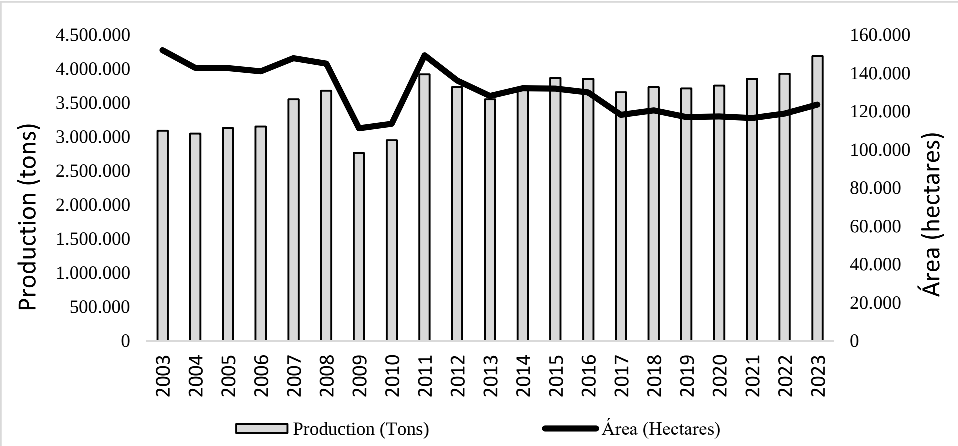
Potato production in Brazil is commercialized under an unstable domestic market, supply seasonality, and price volatility. These factors together with high costs of production, low yields, and revenues indicate the incidence of inefficiency in potato production. This study aimed to estimate the technical efficiency and its determinants in Brazilian potato production. We identified the factors that affect the technical efficiency of production through the analysis of primary data, which were collected through interviews with potato farmers and, analyzed by using a semi-normal model with heteroscedasticity. We found that the most efficient producers with efficiency above 90%, produce 39 t of potato per hectare, producers with less than 90% and above 70% of efficiency, obtain 35 t per hectare, and producers with an efficiency below 70% presented an average yield of 24 t per hectare. Assuming the use of the same technology of production, these results indicate yield differences between 12% and 39% from the more efficient to the less efficient potato producers. The main determinants of this efficiency were the use of soil analysis and credit, participation in training activities, and producer associations, with potato producers who practice these determinants reaching high efficiency in potato production.
Keywords: *Agricultural productivity, tubers production, competitiveness, costs management*
JEL Codes: *M11, M21, Q13, Q14*

1. Introduction

Producers' performance in the use of resources determines their efficiency, and by using resources intensively, efficient rural producers maximize output, while less efficient producers attain production levels below the production frontier. This explains why the use of greater amounts of inputs or technology to attain a certain level of production indicates the efficiency achieved in any agricultural production activity. However, efficiency is determined not only by the use of physical resources and available technology but also by the management strategy of enterprises (Mamiit, Yanagida & Villanueva, 2020; Rahman, (2003).

The theories of efficient frontiers proposed by Debreu (1951), Farrell (1957) & Koopmans (1951) deal with building frontiers of efficiency, and using them to identify the inefficiency levels of farms that do not operate on the production frontier. Some farms cannot reach this production frontier, which presents the maximum possible production with certain quantities of inputs like the available technology and given production factors (Kumbhakar & Lovell, (2000).

A producer operating on the production frontier is considered efficient because with available technology and production factors, it is not possible to increase the volume of production beyond the frontier. By contrast, producers operating at some point below the frontier present some level of inefficiency, and can still increase production using a different combination of technology and production factors. The analysis of historical data presented in Figure 1 indicates that from 2003 to 2023, potato production in Brazil had significant growth with a reduction in the cultivated area for this crop. However, this is not enough to indicate efficiency in Brazilian potato farming. Other determinants have to be analyzed as well, as we describe in the following chapters of this article.



Source: Compiled by the authors based on data from BIGS (2020).

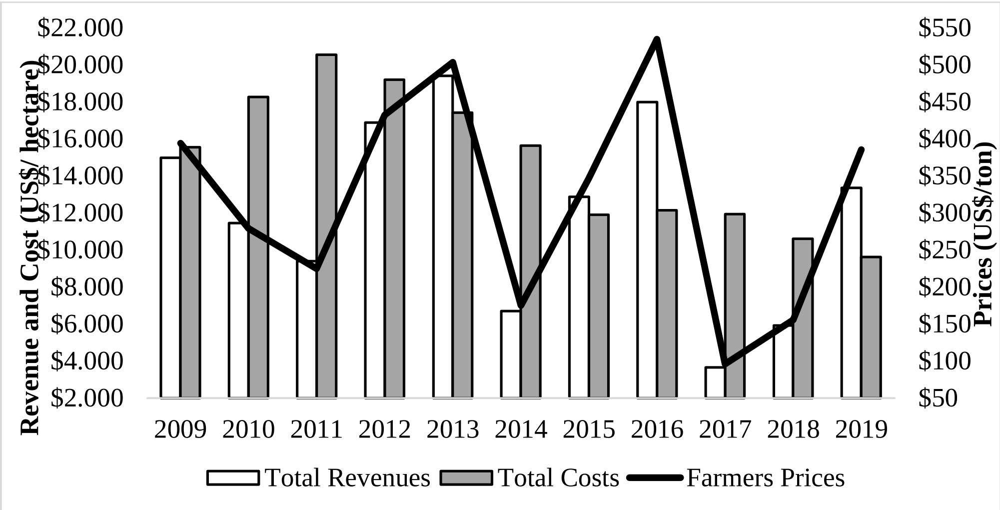
Figure 1. Area Under Cultivation and Production of Potato in Brazil between 2003 and 2023

In 2003, Brazil cultivated potatoes on 151.98 thousand hectares of land. After 20 years, in 2023, the cultivated acreage decreased to 123.45 thousand hectares. 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 4.188 million tons in 2023 from 3.08 million tons in 2003 (BIGS, 2020). The average yield was 20032 kg per hectare in 2003, which increased to 33930 kg per hectare in 2023.

The Brazilian market consumes all domestic production and there is still a deficit, causing the need to import, mainly frozen potatoes. In 2022, Brazil produced 3.926 million tons of fresh potatoes, imported 379 thousand tons (15.61 thousand tons of fresh potatoes and 363.7 thousand tons of frozen potatoes). The Brazilian market consumed 4.860 million tons of potatoes in 2022, which means that the per capita potato consumption in Brazil was 19.69 kg

(Faostat, 2023). Commercialization through wholesaler markets totaled 1.279 million tons, which is approximately 33% of the national production (NSC, 2020).

Brazilian farmers face numerous market uncertainties due to the seasonality in the supply of and demand for potatoes across the year (García-Salazar, Skaggs & Crawford, 2014). In addition, the cost of potato production was over US$ 9,600 per hectare from 2009 to 2019, as shown in Figure 2, questioning whether the commercialization of potato production will be sustainable in future. Figure 2 shows the cost increase in potato production from 2009 to 2011, followed by a cost decrease until the end of the study period (2019). There are fluctuations in total revenue, with higher values in 2009, 2012, 2013, and 2016, the lowest value being in 2017 (BIGS, 2020), BIGS (2017), CBB (2020), CASAE (2020) & Hortifrutibrasil Magazine (2020). Considering the 11-year period, the average accumulated net operating loss stood at US$ 30,210 per hectare.

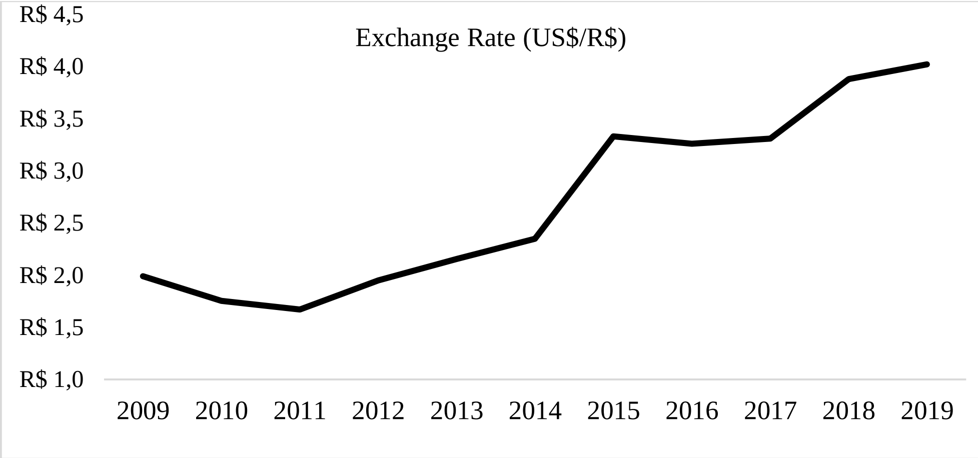


Source: Compiled by the authors based on data from BIGS (2020), BIGS (2017), CBB (2020), CASAE (2020) & Hortifrutibrasil Magazine (2020).

Figure 2 Total Revenue, Total Costs, and Farmers' Prices of Potato Production in Campinas between 2009 and 2019

However, the question arises as to why revenues are decreasing even with decreasing total costs. The answer to this question is related to seasonality, instability of potato prices, and the exchange rate. The potato market is unstable and regulated with great uncertainty regarding the prices received by farmers (Garcia-Salazar et al. 2014). This situation results in year-on-year price fluctuations because in years in which the supply is huge, the price decreases. As a result, in the following year, a few producers decrease the area under cultivation, which in turn decreases the supply of potatoes in the market, increasing the prices received by producers (Ramos 2003).

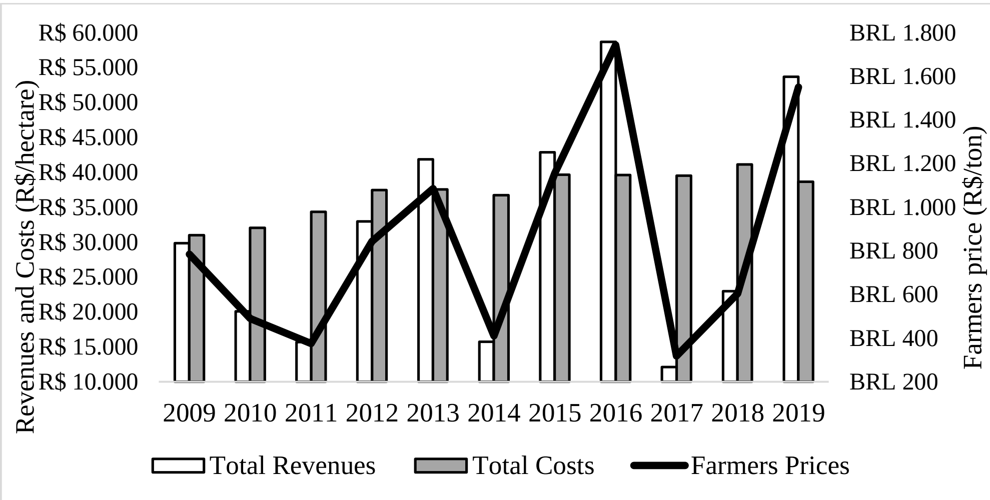
As shown in Figure 2, the total costs were US$ 20,556 in 2011, decreased in 2012, and reached US$ 9,613 in 2019. However, this scenario does not show a decrease in the amount spent by producers but an increase in the exchange rate, as presented in Figure 3.



Source: Compiled by the authors based on data from BIGS (2020)

Figure 3 R$–US$ Exchange Rate between 2009 and 2019

In 2011, the exchange rate was R$ 1.67 for US$ 1.00, with the Brazilian currency depreciating to R$ 4.02 for US$ 1.00 in 2019, which gives a false impression of a decrease in total production costs. When analyzing the costs and revenues in Brazilian currency, in 2011, the total costs were R$ 34,355 per hectare, and in 2019, they were R$ 38,647 per hectare, as shown in Figure 4.



Source: Compiled by the authors based on data from BIGS (2020), BIGS (2017), CBB (2020), CASAE (2020) & Hortifrutibrasil Magazine (2020).

Figure 4 Total revenue, Total Costs and Farmers' Prices of Potato Production in *R$*, in Campinas between 2009 and 2019

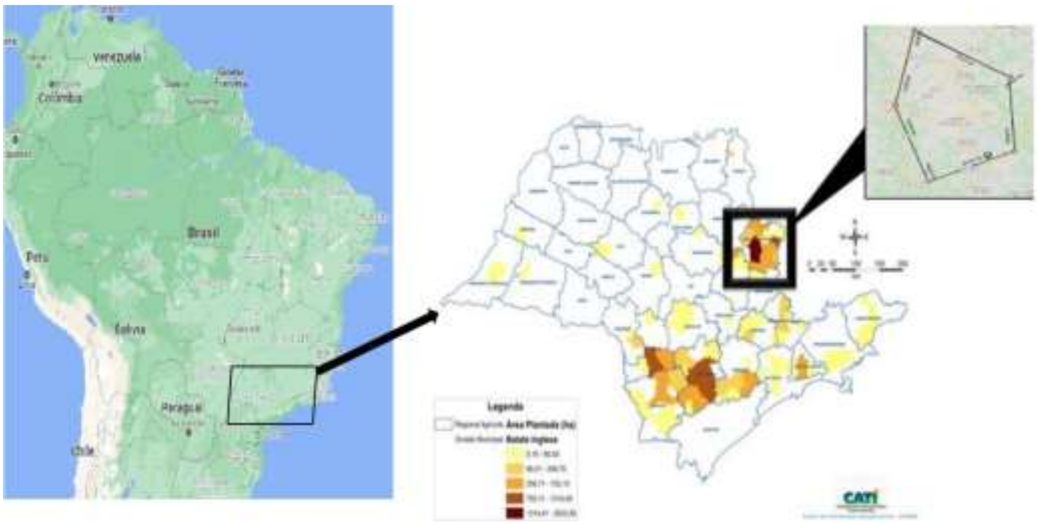
The production of potatoes follows a cycle of about 120 days, and the main and essential components of costs are related to the use of fertilizers, pesticides, and seeds, regardless of the volume harvested and market conditions. Seeds contributed to the increased costs of potato production. A producer starts potato cultivation without a clear understanding of the market behavior. Producers cannot reduce the quantity of inputs being used as they do not know the behavior of the market at the time of planting, because the prices are only set by the supply of and demand for potatoes at the time of harvesting. Reducing the quantity of inputs in production results in low production, resulting in an unfeasible potato production.

The scenario of low average production yield, uncertainty in prices, high costs, low profitability, and poor management reflects the economic inefficiency in potato production in Campinas, state of São Paulo. Therefore, we tested the hypothesis that potato producers have a low production efficiency due to an inadequate use of factors of production and lack of efficiency determinants. Therefore, this study aimed to estimate the technical efficiency and determinants of potato production in Campinas, Brazil.

2. Material and methods

According to data provided by SAPU (2017) the study area includes a total of 141 farms dedicated to potato cultivation, and for the empirical study on technical efficiency in potato production, primary data were collected through face-to-face interviews with 50 producers distributed across in the Campinas region, located in the east-central part of the state of São Paulo, Brazil, as illustrated in Figure 5.

Potato production in this region is affected by the temperature and soil type. The minimum temperatures were 9.6 °C, 8 °C, 5 °C, 10 °C, 14 °C and 15 °C, respectively, from May to October in 2020. During the other months of a normal year, the minimum temperatures range between 14 °C and 17 °C. The maximum temperatures are normally 30 °C in May, 29 °C in June and July, 33 °C in August, and 34 °C in September and October, whereas in the other months of the year, the maximum temperature ranges between 33 °C and 36 °C. The rainy season starts in November (227 mm total), after a dry period from May to October. The volume of rain is minimal in December, but it is still considerably high at 111 mm total (NIMET 2020).



Source: Elaborated by the authors based on data from NIMET (2020).

Figure 5. Localization of the Analyzed Region

Potatoes are cultivated in soils classified as latosoils and argisoils. Latosoils are predominant in the Campinas region, which consist of mineral, non-hydromorphic soils and are generally deep soils, with colors ranging from dark red to yellowish. These are soils with a small granular structure, a clay content between 15% and 80%, and a tendency to form superficial crusts when they dry out. Most of these soils have an acidic pH and very low levels of phosphorus, and are considered soils of low fertility.

The acquisition of information and analysis associated with the technical efficiency both were carried out using the variables described in Table 1. The production data were analyzed using a stochastic frontier function, considering that the inefficiency of potato producers could be influenced by external factors beyond their control. To estimate the impact of these factors maximum likelihood estimators (MLE) were employed, providing the basis for determining the relevant coefficients (Abdul-Rahaman & Abdulai 2018; Ali, Khan & Khan (2019) & Jote, Feleke & Tufa (2018)).

Table 1.Variables Used to Measure Technical Efficiency in Potato Production.

Variables	***Type***	***Description***
Y = Output	Continuous	The original logarithm of the total potato production in each farm (in tons).
Labor	Continuous	The original logarithm of man-days per hectare.
Area	Continuous	The original logarithm of area under potato cultivation (in hectares).
Fertilizer	Continuous	The original logarithm of the supply of fertilizers used (in tons per hectare)
Pesticide	Continuous	The original logarithm of the spending by a farmer on pesticides (in R$ per hectare).
Seeds	Continuous	The original logarithm of the quantity of potato seeds used by a producer (in tons per hectare).
Pest sampling (z_1)	Dummy	Use of sampling of pest incidence in the crop, with 0 representing no pest sampling and 1 representing pest sampling done.
Soil sampling (z_2)	Dummy	Use of soil sampling, with 0 representing no soil sampling and 1 representing soil sampling done.
Association (z_3)	Dummy	The producer is an active member in cooperatives or associations, with 0 representing no active membership and 1 representing an active membership.
Communication (z_4)	Dummy	Use of cell phones, computer and internet. Value 0 indicates these are not used, and value 1 indicates these are used.
Soil conservation (z_5)	Dummy	Use of soil conservation practices. Value 0 indicates absence of these practices, and 1 indicates their presence.
Credit (z_6)	Continuous	Credit amount used in the year 2018 (in R$).
Education (z_7)	Dummy	Schooling level of producers. Value 0 indicates that a producer pursued undergraduate studies, and 1 indicates a producer went to a graduate School.
Training (z_8)	Dummy	Training in 2018. Value 0 implies no training received, and 1 implies training was received

Source: Authors' elaboration

Primary data were collected using a structured questionnaire with closed-format questions on a multiple-choice. This study is explanatory in nature because of the lack of scientific studies on technical efficiency in potato production in Brazil, as well as on identifying the determinants that promote the efficiency of potato producers. Informed consent was obtained from all individual participants included in the study and the study was reviewed by the Ethics Committee in Research at the University of Campinas (UNICAMP) under CAAE: 84035518.0.0000.5404 and Technical Advice No. 2.610.889.

2.1 Measurement of technical efficiency

Parametric approaches to calculating efficiency indicators are based on econometric techniques, considering the estimation of parameters related to stochastic frontiers. In this model, random error surrounding the estimated production frontier is considered and the stochastic frontier production function was outlined by Battese & Coelli (1995) as

$$Y_{ij} = \exp(X_{ij}\beta + V_{ij} - U_{ij}) \quad (1)$$

in this context Y_{ij} represents production, x_{ij} is the vector of factors of production; β is the vector of the parameter to be estimated; V_{ij} is the random error, which is assumed to be independent and identically distributed (*i.i.d.*), and U_{ij} is the error term related with technical inefficiency which is also *i.i.d.* with a mean of $z_{ij}\delta$ and variance σ^2. z_{ij} denotes the vector of the variables affecting technical inefficiency, and *d* represents the vector of the coefficients.

In the analysis of technical inefficiency, output is the dependent variable and the inputs are treated as independent variables. For our analysis, factor prices were disregarded by adopting only the quantity of each input used. Furthermore, the model could be oriented either towards output or input. We chose to adopt the output-oriented approach, utilizing the stochastic frontier production model outlined in Equations 1 and 2 (Kumbhakar, Wang & Horncastle, 2015):

$$lnY_i = lnY^*{}_i - u_i \qquad u_i \geq 0 \quad (2)$$
$$lnY^*{}_i = f(x_{i,}\beta) + v_i \quad (3)$$

i = number of farms y_i =output of the ith farm
x_i = vector *jxl* of the inputs β = vector *jxl*

where *jxl* refers to each input analyzed in this model (extracted from (Kumbhakar, Wang & Horncastle, 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.

$$ln(Y_{it}) = \beta_0 + \beta_1 \ln(Area_{it}) + \beta_2 \ln(Seed_{it}) + \beta_3 \ln(Fertilizers_{it}) + \beta_4 \ln(Pesticides_{it}) + \beta_5 \ln(Labor_{it}) + V_{it} - U_{it} \quad (4)$$

To determine the factors influencing the efficiency of the sample farms have utilized the methodology Battese & Coelli (1995), who approach allows for the simultaneous definition and estimation of efficiency indicators and their determinants in a single analytical framework described in Equation 5.

$$U_{it} = Z_{it}\partial + W_{it} \quad (5)$$

In Equation 5, W_{it} is a random variable, and the parameters are estimated using the maximum likelihood method Battese & Coelli (1995). Likewise Caudill & Ford (1993) & Caudill, Ford & Gropper (1995) indicate that when the adopted model factors in heteroscedasticity, it allows to define the inefficiency determinants. Therefore, we adopted this one-step procedure, which estimates the parameters together (inefficiency and its determinants) using the maximum likelihood method. This procedure assumes u_i 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 using Equation 8 (Kumbhakar, Wang & Horncastle, 2015):

$$U_{it} = \delta_0+\delta_1(z_1 it) +\delta_2(z_2 it) +\delta_3(z_3 it) +\delta_4(z_4 it) +\delta_5(z_5 it) +\delta_6(z_6 it) +\delta_7(z_7 it) +\delta_8(z_8 it) + W_{it} \quad (8)$$

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, Lovell & Schmidt 1977). In this study, we used models with parametric frequencies to obtain inefficiency indicators and a residual test of ordinary least squares.

3. Results and Discussion

The analysis of descriptive statistics for output variables, production factors (area, seed, fertilizers, pesticides, and fixed and temporary employees), and exogenous factors showed that the average productivity of potato farms was approximately 33 tons per hectare, ranging from 17 to 49 tons per hectare, while the average cultivation area was 109 hectares per farm, ranging between 6.55 and 500 hectares per farm, indicating the presence of small, medium, and large producers.

The average quantity of seeds used for potato planting was 3,147 kg per hectare, ranging from 1,648 to 4,665 kg per hectare, demonstrating the adoption of different planting strategies. Similarly, the average amount of fertilizer applied in potato production was 977 kg per hectare, with a minimum of 218 kg per hectare and a maximum of 2,086 kg per hectare. Average spending on pesticides was approximately R$ 3,257 per hectare. With regard to the use of labor, farms showed a wide range from 28 man-days per hectare to 3,700 man-days per hectare. These values reflect the preference for mechanization or manual labor in agricultural tasks.

Concerning exogenous variables, it was verified that 84% of producers adopted at least one soil conservation practice, showing concerns on the potential damage in the form of soil erosion. The study found that 58% of potato producers used pest control and 78% used soil sampling as part of production management. About 76% of the respondents participated in training programs, and 90% of the respondents were members of at least one producer association. In respect of education levels, 60% of the producers had an undergraduate level of education, while the others had completed primary or secondary schooling. The data also showed that 92% of the producers used the Internet and cell phone communication daily to stay up to date or obtain information on potato production and commercialization.

The asymmetry value of the data sample was -0.6321, corroborating the model of Aigner, Lovell & Schmidt (1977), and showing data consistency with the production frontier specifications. In the same test, the value of p was 0.042, with statistical significance at the 1% level, through which the null hypothesis of non-asymmetry is rejected (H_0 = non-asymmetry). The test proposed by Battese & Coelli (1995) was adopted, which assumes that the residuals of ordinary least squares are asymptotically distributed with an average value equal to zero. The value found in this study was *-3.291*, which confirms the rejection of the null hypothesis of non-asymmetry.

The adoption of half-normal and truncated half-normal models is validated by asymmetry tests that prove the existence of inefficiencies. However, for the medium-normal model, it was necessary to carry out the likelihood ratio (LR) test proposed by Battese & Coelli (1995), which adopts the critical values of Kodde & Palm (1986). The value thus obtained was *27.94*, with one degree of freedom (only one parameter is restricted to the test), and it was *5.412* (p-value statistically significant at the 1% level) in the table of Kodde & Palm (1986). Consequently, rejection of the null hypothesis of the non-existence of technical inefficiency is confirmed (H_0 = non-technical inefficiency).

Table 2 shows the values of technical inefficiency and the determinants using the Cobb-Douglas function. It also shows the exogenous variables that determine the percentage of technical efficiency.

Table 2. Measurement of Technical Inefficiency in Potato Production by The Method of Production Frontier (n=50)

Technical Inefficiency		
Variable	**Cobb-Douglas**	**E(u)**
Constant	7.77	
Area	0.067***	
Labor	0.0063***	
Fertilizer	0.45***	
Seeds	(0.3544) ***	
Pesticides	(0.0004) ***	
Pest Sample (z_1)		0.17**
Soil Sample (z_2)		(0.045) **
Association (z_3)		0.15***
Communication (z_4)		(0.48) ***
Soil conservation (z_5)		0.27***
Credit (z_6)		(0.20) ***
Education (z_7)		0.20***
Training (z_8)		0.18***
Variance parameters		
δs^2	0.12***	
ϒ	0.833***	
Log-Likelihood	22.62	
Wald Chi^2	145.35***	
Average efficiency	0.8185	

Source: Data compiled by the authors
Note: [a]Half-normal model with heteroscedasticity; ***1%; **5%

Evaluating the parameters of variance, we found that δs^2 = 0.12 and ϒ = 0.833 are statistically significant at 5% level because the values of ϒ reveal that 83.3% of the deviations of the farms around the production frontier arise from inefficiency (the remaining 16.7% are due to error) and the term of inefficiency is significant to explain these deviations. These results are similar to those found by Kiptoo, Xia & Kipkemboi (2016) and to the average technical efficiency of *0.8185*, which is similar to the values found by Amara, Traore & Landry (1999); Lakner, Kirchweger & Hoop (2018) & Mehmood, Rong & Bashir (2018).

The results of the Cobb-Douglas function indicate the scale elasticities of each factor of production, as revealed by the coefficients. The factors of production, such as area, labor, and fertilizers, show positive elasticities, indicating that an increase in the quantities of these factors will increase the amount of output. Thus, if a producer increases the area under cultivation of potatoes by 100%, it will result in an increase of 6.7% in output (ceteris paribus), which is similar to the results of Binam, Tonyè & Wandji (2004); Mwalupaso et al (2019) & Unakitan & Kumbar (2018). Similarly, an increase of 100% in the amount of labor will increase potato production by 0.63%, other factors being constant, which shows a low impact of this variable on production levels. This result is similar to that found by Ahmad & Afzal (2019), Binam, Tonyè & Wandji (2004), whereas in Hossain, Hasan & Naher (2008); Lakner, Kirchweger & Hoop (2018) the relationship between labor and output was the opposite.

The results related to the use of fertilizers in potato production, also show a positive and significant relationship between this production factor and output. If a producer increases the use of fertilizers by 100%, the output will increase by up to 45%, showing the highest elasticity of scale for this input and reinforcing the importance of using fertilizers in potato production. Ahmad & Afzal (2019) & Khanal, Wilson & Lee (2018) also described this positive and significant influence of fertilizer use on output. By contrast, the results for the quantities of seeds and defensives used for potato production prove that both have significant and negative relationships with output. The analyzed model indicates that a 100% increase in the quantity of potato seeds results in a 35% decrease in the output. This is because producers use a large quantity of seeds per hectare (about 4,000 kg), promoting seed competition for soil nutrients and not allowing a normal growth of potato plants. However, this effect was different from that found by Ahmad & Afzal (2019). Jote, Feleke & Tufa (2018) and Mwalupaso et al. (2019) where increases in the quantity of potato seeds used for planting resulted in increases in output.

The effects of exogenous variables such as the level of education, monitoring of pests and diseases, soil sampling, membership of cooperatives, and use of cell phones on inefficiency became explicit in the analyzed model. First, producers with an education level up to high school are associated with a higher technical inefficiency compared with producers with an undergraduate education level. This implies that producers with university degrees tend to be 20% more efficient technically than those with high school education. These results were similar to those reported by Amara, Traore & Landry (1999), Ji, Jin & Wang (2019) and Rahman (2003).

Second, producers who carry out monitoring of pests and diseases along with periodic sampling and acting in the field at the right moment before the pets and diseases cause economic damage, achieve technical efficiency that is 17% higher than that achieved by producers who do not adopt these techniques (significant at the 5% level). Similarly, carrying out soil sampling allows for improvements in the technical efficiency parameters of potato producers, causing a reduction of 0.045% in technical inefficiency (significant at the 5% level).

In the same context, producers who are not members at even one producer association show a 0.15% increase in technical inefficiency compared with those who are (significant at the 1% level). These results were consistent with those reported by Abdul-Rahaman & Abdulai (2018), Hao, Bijman & Gardebroek (2018) and Ji, Jin & Wang (2019). The potato producers interviewed in this study with active memberships in cooperatives or associations had the highest technical efficiency indicators. In addition, producers who are members of the boards of these organizations are more efficient technically than other members. Producers who participate in training, assemblies, and meetings of these organizations are more efficient technically than those who do not participate in these events.

Another influential variable is credit, which is obtained from financial agents and used in production, machinery investments, or commercialization. Producers who have contracted agricultural credit see their technical inefficiency reduce by up to 20% by increasing the value of credit by 100%. The producers interviewed in this study, who used credit resources to finance up to 50% of the production costs, presented the highest indicators of technical and economic efficiency. Other efficiency studies have also demonstrated a similar relationship between credit and technical efficiency (Ahmad & Afzal (2019), Binam, Tonyè & Wandji (2004). Furthermore, increasing the use of cell phones and internet for communication by 1% reduces the inefficiency of potato producers by 0.48%. This result is consistent with the results presented by Mwalupaso et al (2019).

Adoption of soil conservation practices such as level planting, maintenance of the dead layer, no till, and minimum cultivation, allows to increase the technical efficiency indicators up to 27%. We found that producers who performed more than three of these practices were the most efficient technically and economically, as corroborated by Amara, Traore & Landry (1999). In addition, a 1% increase in the participation of producers and employees in training sessions on the management of rural enterprises shows a 0.18% increase in technical efficiency. The producers in our study who adopted training, both for employees and owners, presented the highest technical and economic efficiency indicators, which was also evidenced in the studies by Jara-Rojas, Bravo-Ureta & Solís (2018).

Table 3 shows the percentage of potato producers according to their technical efficiency, with most producers (72%) presenting technical efficiency values greater than 70%. Similar results were reported by Amara, Traore & Landry (1999), Hossain, Hasan & Naher (2008) and Mehmood, Rong & Bashir (2018). The table also shows that 22% of producers have technical efficiency values above 90%, and 24%, between 50% and 70%, with only 4% of the sample showing efficiency values lower than 50%. As the average efficiency value was 81.85%, approximately 45% of the producers had an above-average efficiency.

Table 3. Distribution of Producers by Technical Efficiency Indicator

Technical Efficiency (%)	***Number of Producers***	***%***	***Y***	***Seeds (kg/ha)***	***Fertilizer (kg/ha)***	***Pesticides (R$/ha)***
up to 50%	2	4%	20.56	2.566	1.478	2.087
50.1<x<70	12	24%	23.9	3.162	870	3.201
70.1<x<80	13	26%	33.29	3.313	970	3.931
80.1<x<90	12	24%	38.08	3.069	923	3.099
>90,1	11	22%	39.2	3.127	1.071	2.909

Source: Compiled by the authors.

From the analysis of the output, it appears that the less efficient producers produce about 20.56 tons per hectare, while the most efficient producers reach about 39.20 tons per hectare. Significant differences are also observed in the use of the factors of production, as the most efficient producers (efficiency above 90%) use larger amounts of seeds, lower volumes of fertilizers, and spend more on pesticides than less efficient producers do (efficiency below 50%).

4. Political Implications: The Way Forward for Potato Production in Brazil

The value of efficiency in potato production offers scope for defining promotion and support policies for producers in this sector, aiming to increase yields, produce sustainably, and achieve a higher level of efficiency. These policies should provide incentives for the formation of producer groups who can make decisions to purchase bulk fertilizers and agrochemicals, thus reducing the costs of these inputs. Similarly, these policies need to promote potato seed research and production with studies determining the optimal quantities of seeds to be used according to variety and growing seasons. Studies that prioritize these actions are scarce; therefore, producers determine the quantities of potato seeds to be used based only on their own experience, disregarding the technical and cultivation aspects of each individual variety. The policy measures mentioned above would make it possible to plant more consistently, using fewer quantities of seeds and other inputs, increase production, and reduce the overall production costs.

Promoting producer participation in associations and cooperatives would help accelerate the adoption of improved technologies in the production processes provided by these organizations. In this context, these organizations could also create support mechanisms to obtain financing for the production and commercialization of potatoes, contributing to the stability and growth of the entire sector. Likewise, producer cooperatives or associations must implement strategies and policies to promote greater use of soil conservation practices and encourage producers to maintain the soil in good chemical, physical, and biological conditions.

5. Conclusions

This study estimated technical efficiency and its determinants in the production of potatoes in Campinas, Brazil. The average technical efficiency obtained was 81.85%. We found that approximately 22% of the producers in the sample had efficiency values above 90%, and 45% had above-average technical efficiency. These values indicate that most potato producers are efficient in the use of available resources (inputs), considering the amount produced (output).

About 55% of the potato producers in the sample achieved below-average technical efficiency. When analyzing yield differences among potato producers in the three efficiency groups, it was found that the most efficient producers with an efficiency value above 90% produced 39 tons of potatoes per hectare, producers with efficiency less than 90% and above 70% obtained 35 tons per hectare, and producers with efficiency below 70% presented an average yield of 24 tons per hectare. Assuming the use of the same production technology, these results indicate yield differences between 12% and 39% from the more efficient to the less efficient potato producers.

Hence, in this case, strategies needed to promote efficient potato production are related to managing and controlling pests and diseases, performing soil testing, farmers' participation in producer associations and training, adoption of soil conservation practices, and the use of credit and information technology in potato production and commercialization processes.

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