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ABSTRACT

This research analyzes the productivity efficiency of soybean, corn, cotton, peanuts, oil palm, sunflower and canola, which are exploited in the production of biodiesel in Brazil. The data were treated using the technique Data Envelopment Analysis - DEA. Of the 23 soybean producing municipalities, 13 achieved efficiency (56%), however, from an environmental point of view, soybean is not the best choice for biodiesel production, as it has one of the lowest yields in oil per kg/ha (51%) and the lowest energy balance (1.3:1). However, its production scale ensures its participation in the biodiesel production chain. Of the 19 corn producing municipalities, six are efficient (31%), it is the second best average productivity (5,760 kg/ha), with a yield in kg/h of 14.17% and an energy balance of 1.42:1. In the seven municipalities producing cotton plume (processed), their productivity reaches 1/3 of the productivity of the five seed cotton producers (efficient, the third best average productivity with 4,290 kg/ha), yield in kg/ha of 45% and energy balance of 1.77:1. In peanuts, ten municipalities are efficient (37%). In oil palm, eight municipalities are efficient and this one has the best average productivity: 25,780 kg/ha, the second best yield in kg/ha (280%) and the best energy balance (5.6:1), in addition to generating two oils (the palm of the mesocarp and the palm kernel of the endocarp). In sunflower and canola, seven municipalities are efficient. The costs of inputs with SMFA (acronym in Portuguese for seeds, seedlings, fertilizers and pesticides) limit efficiency in productivity.

Keywords: Bioenergy. Oilseeds. Energy Efficiency.

RESUMO

Esta pesquisa analisa a eficiência produtiva de soja, milho, algodão, amendoim, palma oleaginosa, girassol e canola, que são exploradas na produção de biodiesel no Brasil. Os dados foram tratados utilizando-se a técnica Data Envelopment Analysis - DEA. Dos 23 municípios produtores de soja, 13 alcançaram eficiência (56%), no entanto, do ponto de vista ambiental, a soja não é a melhor escolha para a produção de biodiesel, pois tem um dos menores rendimentos em óleo por kg/ha (51%) e o menor balanço energético (1,3:1). No entanto, sua escala de produção garante sua participação na cadeia produtiva do biodiesel. Dos 19 municípios produtores de milho, seis são eficientes (31%), é a segunda melhor produtividade média (5.760 kg/ha), com rendimento em kg/h de 14,17% e balanço energético de 1,42:1. Nos sete municípios produtores de pluma de algodão (processado), sua produtividade chega a 1/3 da produtividade dos cinco produtores de algodão semente (eficiente, a terceira melhor produtividade média com 4.290 kg/ha), rendimento em kg/ha de 45% e balanço energético de 1,77:1. Em peanuts, dez municípios são eficientes (37%). No óleo de palma, oito municípios são eficientes e este tem a melhor produtividade média: 25.780 kg/ha, o segundo melhor rendimento em kg/ha (280%) e o melhor balanço energético (5,6:1), além de gerar dois óleos (a palmeira do mesocarpo e a palmeira do endocarpo). Em girassol e canola, sete municípios são eficientes. Os custos dos insumos com SMFA (sigla em português para sementes, mudas, fertilizantes e pesticidas) limitam a eficiência na produtividade.

Palavras-chave: **Bioenergia. Oleaginosas. Eficiência energética.**

INTRODUCTION

Global warming, resulting from the consumption of fossil fuels, such as petroleum derivatives, mineral coal and natural gas, and the possibility of depletion of these energy sources demand the search for renewable sources. In this context, the National Biodiesel Production and Use Program (PNPB/2005) and the National Biofuels Policy (Renovabio, 2017) postulate to meet the commitments assumed by Brazil in the Conference of the Parties of the United Nations Framework Convention on Climate Change (Paris/2015 and COP/2021), which has as its main goal the decarbonization of the fuel sector in order to increase the share of sustainable bioenergy in the Brazilian energy matrix from the current 14% (EPE, 2022) to 18% by 2030, with a reduction of 10% of its CI (Carbon Intensity).

Seeking to achieve this regulatory framework, one of the alternatives found was the use of biodiesel (biofuel from renewable sources), whose use contributes to economic development in a sustainable and to the achievement of decarbonization targets.

Despite advances in national biodiesel production, there are different oilseed crops, regionalization of inputs, different forms of production, planting areas and cultivation conditions that impact production in different ways.

In order to solve these questions related to the efficiency in the production of these renewable plant sources that condition productivity, a technique was used that calculates the relative efficiency between the productive units (municipalities) from their production inputs, which provides quantitative data on possible directions to improve the performance of inefficient units.

In this research, Data Envelopment Analysis – DEA – was adopted as the most applicable to make this estimation because it is a technique widely used in the areas of Agricultural Engineering, Agronomy, Production Engineering, Economics, Accounting, Education, Health, among others.

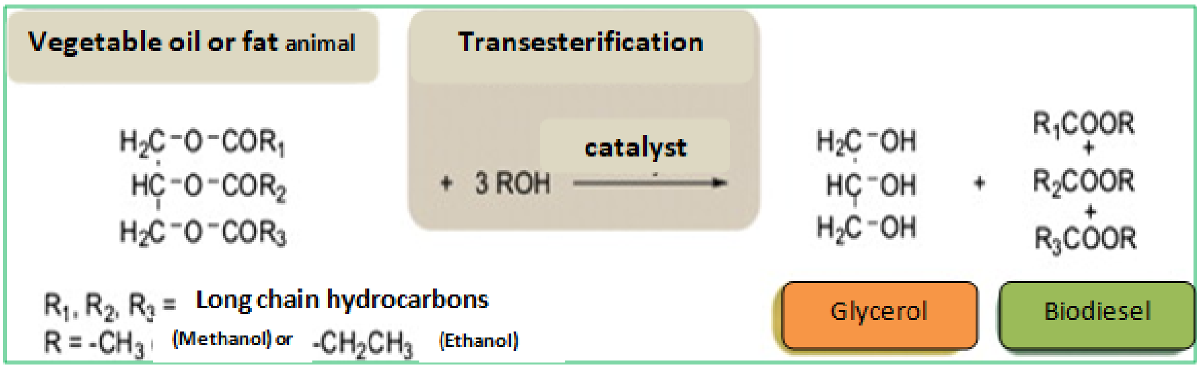
This technique consists of using relative efficiency, without prejudice to small units. Thus, more than one unit can be classified as efficient, serving as a reference for the performance of the other units. The factors that contribute to low performance can be broken down, suggesting specific points of action.

This research was guided by the identification of inputs and productivity of oilseeds used in biodiesel in Brazil, with the objective of analyzing the efficiency in the production of these oilseeds. Results showed 56 efficient and 55 inefficient municipalities in the production of oilseeds exploited for biodiesel and the prevalence of SMAF (acronym in Portuguese for seeds, seedlings, pesticides and fertilizers) costs in inefficiency.

BIODIESEL PRODUCTION IN BRAZIL

Biodiesel is a biofuel of renewable origin obtained from a chemical process called transesterification (Figure 1), by which the triglycerides present in vegetable oils and animal fat react with alcohol, methanol or ethanol, generating ester and glycerin. After purification, it is commercialized (ANP, 2021).

Figure 1 | Biodiesel production: transesterification reaction



Source: Leoneti, Aragão-Leoneti e Oliveira (2012), modified by author.

Biodiesel can be pure or mixed with diesel in different proportions. The mixture was optional in 2003 and became mandatory at 2%, since January 2008, by Law nº 13.263/2016, with increasing additions annually, with the possibility of reaching 15% by 2023 (CNPE, 2021), due to the established schedule.

The mandatory additions, besides allowing Brazil to be among the largest producers and consumers of biodiesel in the world (Oliveira e Coelho, 2017; EPE, 2022), contributed to the drop in imports and allowed a significant reduction in the emission of pollutants, especially of CO2 (carbon dioxide), HC (hydrocarbons) and particulate matter, in addition to reducing sulfur emissions because it does not have sulfur in its composition, unlike petroleum diesel.

According to EPE – Energy Research Company (2022) – Brazil is among the three largest producers and consumers of biodiesel in the world, behind Indonesia and the USA (17%, 14.4%, 13.7% of world production, respectively), with 49 production plants concentrated in the Central-West and South regions of the country, due to the abundant availability of the main raw materials (soybean and tallow), although the largest volume of sales/consumption is concentrated in the Southeast region, which produces 7.9%, the Northeast region, 7.4%, and the North region, 2.3% (EPE, 2022). EPE (2022) also reports that the installed capacity of these 49 plants corresponds to 10.4 billion liters, however, production in 2020 was 62% of that capacity. It also highlights that, in 2019, 5.9 billion liters of biodiesel were consumed in Brazil, which represented an increase of 11.3% compared to 2018, and 6.4 billion liters in 2020, 10% increase compared to 2019.

Production growth and the increase in the addition of biodiesel to fossil diesel influenced the drop in net diesel imports (Table 1). However, there is potential for increasing the share of this biofuel in the economy, due to the range of available biomass, ongoing research and idle capacity (38% in producing plants).

Table 1 | Production and import of diesel and biodiesel in (M^3) and in (%)

Year	Diesel production	Net import of diesel (M^3)	Biodiesel production	Diesel production	Net import of diesel (%)	Biodiesel production
2008	41.134.038	4.272.609	1.167.128	88%	9%	3%
2009	42.898.667	1.505.482	1.608.448	93%	3%	3%
2010	41.429.263	7.461.713	2.386.399	81%	15%	5%
2011	43.388.313	8.223.058	2.672.760	80%	15%	5%
2012	45.504.004	7.178.583	2.717.483	82%	13%	5%
2013	49.539.186	9.253.367	2.917.488	80%	15%	5%
2014	49.675.057	10.338.797	3.422.210	78%	16%	5%
2015	49.457.609	6.172.222	3.937.269	83%	10%	7%
2016	45.369.807	7.086.011	3.801.339	81%	13%	7%
2017	40.581.202	12.268.465	4.291.294	71%	21%	8%
2018	41.880.465	10.221.057	5.350.036	73%	18%	9%
2019	40.914.849	12.407.590	5.923.868	69%	21%	10%
2020	42.215.122	11.678.965	6.432.037	70%	19%	10%

Source: EPE (2022).

In the thirteen years described (Table 1), the volumetric production of biodiesel increased six times and its share in the biodiesel market in Brazil went from 3% to 11%. From 2008, when additions became mandatory, until 2010, this share stabilized, increased and stabilized again, from 2011 to 2014, and, then, got to a successive growth from 2015 to 2020.

According to RAMOS *et al*. (2017), the use of Brazilian biomass contributed decisively to the reduction of GHG (greenhouse gas) emissions. In liquid biofuels, emissions avoided by the use of ethanol and biodiesel, compared to their equivalents (gasoline and diesel), amounted to 69.6 $MtCO_2$[1] in 2019 and 64.9 $MtCO_2$ in 2020.

The raw materials most used in the production of biodiesel, from 2011 to 2020, were soybean oil, animal fat (in decline in 2019/2020), cotton oil (in rise in 2019/2020), and other fatty materials, in which corn oil, palm oil, peanut oil, turnip (fodder type) oil, sunflower oil and palm kernel oil stand out (Table 2).

1 Million tons is the standard measure used to quantify CO2 emissions.

Table 2 | Raw materials used in the production of biodiesel in Brazil – 2011-2020

Raw materials	Raw materials used in the production of biodiesel in Brazil (B100) (m³) 2011 – 2020										20/19
	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	%
Total	2.682.178	2.677.384	2.790.766	3.327.898	3.773.016	3.715.680	4.221.104	5.346.754	6.035.126	6.503.916	7,77
Soybean oil	2.170.198	2.050.371	2.123.488	2.573.331	2.960.687	2.828.765	2.964.246	3.743.316	4.093.319	4.644.045	13,45
Cotton oil	99.646	119.093	62.763	71.350	73.125	39.402	12.715	48.487	66.879	109.387	63,56
Animal fat1	361.123	454.627	549.850	640.454	687.992	620.181	715.273	862.505	831.168	737.547	-11,26
Others2	51.210	53.294	54.665	42.763	51.213	227.332	528.870	692.446	1.043.759	1.012.937	-2,95

Source: ANP (2021). EPE (2021).

[1]Includes beef, chicken and pork fat; [2]Includes palm oil, peanut oil, turnip (fodder type) oil, sunflower oil, canola oil, corn oil, palm kernel oil, used frying oil and other fatty materials.

According to ANP (2021), soybean is the main raw material for biodiesel production, equivalent to 71.4% of the total, with an increase of 5.3% in 2019/2020. The second largest quantity of these raw materials is classified in others, they are vegetable oils: palm, peanut, turnip (fodder type), sunflower, canola, corn, palm kernel, used frying oil and residual fats. This group is equivalent to 15.6% of the total (despite the rigino 2.95% in 2019/2020), followed by 11.3% of animal fat, (which decreased by 11.26% in 2019/2020), and 1.7% cotton oil (which increased 63.56% in 2019/2020).

In the Brazilian Statistical Yearbook of Petroleum 2020, ANP (2021) reported that, in the period from 2011 to 2020, the vegetable raw materials that were at the basis of biodiesel production were: soybean oil, cotton oil, palm oil, palm kernel oil, peanut oil, turnip (fodder type) oil, canola oil, sunflower oil and corn oil.

In the Biofuels Conjuncture Analysis 2017 report, EPE (2018) reported that increasing production and adding higher levels of biodiesel to fossil diesel require the diversification of raw materials in crops with higher productivity yield per rig, by scale of production, and the rigino appropriation of costs, which can lead to a drop in the final rigi of the rigino and favor its competitiveness. However, a technical-economic assessment of the efficiency of the inputs applied in the production of raw materials is necessary.

Table 3 | Yield and energy balance of oilseeds used for biodiesel in Brazil

rigino f oil	Oil Content %	Harvest months	Oil yield (t/oil/ha)	Average oil production (kg/ha)	Energy Balance[2]
Soybean	17	3	0,2 – 0,4	51	1,30:1
Corn	3,5-7	3	0,18 – 0,36	14,17	1,42:1
Cotton	15	3	0,1 – 0,2	45	1,77:1
Peanut (consortium)	40-45	3	0,6 – 0,8	297,5	2,93:1
Oil Palm (mesocarp)	20-22	12	4,0 – 6,0	105	5,60:1
Oil Palm (endocarp)	55	12	4,0 – 6,0	275	5,60:1
Canola	40-48	3	0,5 – 0,9	308	2,90:1
Sunflower	38-48	3	0,5 – 1,9	1032	2,37:1

Source: Santos *et al.* (2012); Embrapa (2015); Luz, Mainier e Monteiro, (2015); Suassuna *et al.* (2014); Collares (2011); Moretto e Fett, (1998); Tomm (2005); Santos *et al.* (2014); Soares *et al.,* (2008); Macedo e Nogueira (2005); Ramos *et at.* (2017); Albuquerque *et al.* (2008).

Although soybean is the oilseed most used in the production of biodiesel, it has the lowest oil yield in kg/t (51%) and the lowest energy balance (1.3:1). Under one of the tripods of sustainability, the environmental one, soybean is not the best choice, once the greatest reducer of the energy balance are pesticides and fertilizers, widely used in soybean production. Oil palm, in turn, which generates palm oil and palm kernel oil, is the second best yield in kg/t (380) and has the best energy balance (5.6:1). Although sunflower has the highest kg/t yield, its energy balance is less than half that of oil palm.

The oilseeds most used in the production of biodiesel in Brazil are those with the lowest yields kg/t (soybean: 51; corn: 14.17; cotton: 45) and the lowest energy balances (soybean: 1.3:1; corn: 1.42:1; cotton: 1.77:1), however, they have a high production scale.

MATERIALS AND METHODS

Aiming to estimate the technical efficiency of the production of seven oilseeds: soybean, corn, cotton, peanuts, oil palm, canola and sunflower, the methodological procedures were divided into three stages, as follows: 1st stage - identification of the seven oilseeds exploited for biodiesel in Brazil, in the period 2011/2020 (ANP, 2021); 2nd stage - construction of the matrix of agricultural costs (fixed and variable) of the seven oilseeds, based on the matrices of inputs of CONAB/2021, CEPEA/ESALQ/USP/2015, and summary spreadsheet of operational costs of IMant - Mato Grosso Cotton Institute (2020) (Box 1).

2 Energy balance is an indicator of the relation between the energy invested in production and that one contained in it. The factors that make it possible for the energy balance to be positive are, above all, crop yield and lower consumption of nitrogen fertilizers.

Box 1 | Variable and fixed production costs of vegetable raw materials

Variable Costs	
1 - MJS: machinery, interest and services	Operations with animals, planes, machines, rents, labor, transport, administrative and storage expenses, processing, insurance, technical assistance, taxes and fees, interest on financing.
2 - SMFA: seeds/seedlings, fertilizers and pesticides	Seeds/seedlings, fertilizers and pesticides.
Fixed Costs	
3 - MDE: maintenance, depreciation and social security charges	Depreciation of improvements and facilities, machinery, implements and irrigation sets, exhaustion, maintenance of facilities, social charges, fixed capital insurance, leasing.
4 - RF: factor income	On fixed capital and on cultivation, own land.

Source: adapted from CONAB (2021), INMAT (2020), CEPEA (2015).

In 2nd stage, the matrix of agricultural production costs was organized into fixed and variable costs of oilseeds, in kg/ha productivity and in 34 possible production cost elements, for the four major cost groups (Box 1). These materials were extracted from the productive sector and from official bodies, such as state secretariats of agriculture, CONAB, EMATER, IEA/SP (Institute of Agricultural Economy of the State of São Paulo), IPP – Producer Price Index of the Ministry of Economy/2021 – and IBGE indicator panel/2022.

In 3rd stage, three calculations were performed: the vertical analysis ($VA = \frac{oilseed\ cost\ subgroup}{oliseed\ total\ cost}\ x\ 100$), to understand the participation of the cost subgroups (MJS, SMFA, MDE and RF) in the total costs of each oilseed per municipality, and the horizontal analysis to compare the cost subgroups (MJS , SMFA, MDE and RF) of all oilseeds among themselves ($HA = \frac{oilseed\ cost\ subgroup\ x}{oilseed\ cost\ subgroup\ y}\ x\ 100)$; productivity costing coefficient (PCC $= \frac{Production\ total\ Costs}{Productivity}$) (ASSAF NETO, 2020); and efficiency in the production of the seven oilseeds through the technique Data Envelopment Analysis – DEA – with the use of the software DEAP (Data Envelopment Analysis Program), version 2.1, with FC and VC as inputs and productivity (kg/ha) as outputs.

A THE DATA ENVELOPMENT ANALYSIS TECHNIQUE (DEA)

Data envelopment analysis (DEA) is a non-parametric technique that uses PPL – mathematical linear programming – to analyze the efficiency of Decision-Making Units (DMUs). Through the use of DEA, it was possible to produce a certain output Y using X inputs in the producing municipalities, classifying the efficient ones. The relative efficiency of a DMU is defined by the ratio of the weighted sum of outputs to the weighted sum of inputs, which generates an efficiency index for a given DMU from a linear combination. This technique provided the comparison of all DMUs that used the same inputs and generated similar outputs (FARREL, 1957 and SCHEEL, 2001).

The mathematical model used in the calculation of production efficiency originated from Farrel (1957) proposed by Charnes, Cooper and Rhodes, called Constant Returns to Scale – CRS –, known as CCR, according to equation 1 represented:

$$ER_j = \frac{\sum_r u_r Y_{rj}}{\sum_i v_i X_{ij}} \quad ....n \qquad Eq.\ 1$$

X_i = inputs; Y_r = outputs; *v* and *u* = discretionary weights of each input and each output.

The values of variables v_i and u_r are the relative importance of each variable (weights), which maximize the weighted sum of the outputs divided by the weighted sum of the inputs of the DMU under analysis, subject to the restriction that this ratio is less than or equal to 1, for all DMUs, so that the efficiencies vary from 0 to 1. The weights, v_i and u_r, that are found, refer to the DMU that is being analyzed. This calculation was repeated for each of the *n* DMUs under analysis, generating different values for the weights.

From what was described above, the VRS model (variable returns to scale) for the output orientation is obtained. The model was generalized for cases with multiple inputs and outputs, transforming it into a linear programming model, as described in equation 2 below:

$$\sum^{m} v_i x_{ik} - \sum^{s} u_j y_{jk} - u_* \leq 0,\ K = 1,\ 2,..n\ ... \qquad Eq.\ 2$$

$$u_j\ e\ v_i \geq \forall j,i$$

y = outputs; x = inputs; u and v = weights; the term u_* represents the possibility of variable returns to scale with the possibility of negative or positive values, that is, the maximum level of productivity can vary depending on the level of production, being able to use units of different sizes; k =1, 2,.....n DMUs; i = 1,2,....m inputs of each DMU (fixed and variable costs of each oilseed) ; j = 1,2,.... s ouputs of each DMU (productivity of each oilseed).

The efficiency in the production of oilseeds was obtained considering the concepts adopted by Soares de Mello *et al.* (2005) in which the observed productivity[3] and the maximum productivity that could be achieved were compared between what was produced, given the available resources, with what could have been produced with the same resources.

From the point of view of the mathematical models used in DEA calculations: there are the CCR models by Charnes, Cooper and Rhodes, in 1978 (CRS – Constant Returns to Scale) which work with constant returns to scale, that is, any variation in the inputs produces proportional variation in the outputs, and the BCC model, proposed by Banker, Charnes and Cooper, in 1984, which considers variable returns to scale, also known as VRS – Variable Returns to Scale. The latter replaces the axiom of proportionality between inputs and outputs with the axiom of convexity. Through this model, it was possible to identify, for each inefficient unit, their benchmarks[4].

The mentioned models can be designed in two ways to maximize efficiency: reducing the consumption of inputs, maintaining the production level (input-oriented), or increasing production maintaining the input levels (output-oriented) (FERREIRA E GOMES, 2009). The latter was adopted in this research. The linear programming model used was the one in Equation 3, below:

$$\max \emptyset$$

Subject to:

$$\begin{gathered} -\phi Y_i + Y\lambda \geq 0 \\ x_i - X\lambda \geq 0 \\ N_1'\lambda = 1 \\ \lambda \geq 0 \end{gathered} \qquad \textit{Eq. 3}$$

3 Productivity is the ratio between outputs that the firm produces and inputs that it uses: Productivity = outputs / inputs

4 Reference of best practices among competitors that can be adapted and transformed into opportunities for their own business.

Where: ϕ is a scalar, whose value is between one and infinity, and the technical efficiency (θ) of the DMU is obtained by the ratio $1/\varphi$; λ is a vector, whose values are calculated in order to obtain the optimal solution; yi are outputs; e xi are inputs. This problem is solved for each unit, generating its relative efficiency rate.

RESULTS AND DISCUSSION

THE PRODUCTIVITY COST COEFFICIENT

Based on the productivity cost coefficient (PCC) data, it was possible to identify the best appropriation of total production costs in productivity performance (Table 4).

Table 4 | Productivity Cost Coefficient

Oilseed	Average productivity (kg/ha)	Variable Cost (R$)				Fixed Cost (R$)				TC (R$)	PCC (R$)
		1 MJS	2 SMFA	TVC	%	3 MDE	4 RF	TFC	%		
Soybean	3.270	913,6	2.074,90	2.988,50	78	641,1	180,1	821,1	21	3.809,60	**1,17**
Corn	5.760	1.000,40	1.881,50	2.881,90	80	549,3	150	699,4	19	3.581,30	**0,62**
Cotton plume (processed)	1.680	2.735,40	7.409,30	10.144,80	88	1.078,80	229,2	1.308,10	11	11.452,80	**6,82**
Seed cotton	4.290	857	1.220,30	2.077,30	73	553,3	211,1	764,5	26	2.841,70	**0,66**
Peanut	3.654	1.746,50	4.136,40	5.883,10	87	659,6	195,5	855,1	12	6.738,20	**1,84**
Canola	1.531	864,5	2.712,40	3.576,90	79	833,2	108,6	941,8	20	4.518,70	**2,95**
Oil palm	25.780	10.661,30	8.424,10	19.085,40	88	1.737,40	632,4	2.369,90	11	21.455,20	**0,83**
Sunflower	1.822	731,4	1.854,90	2.586,30	73	717,9	198,8	916,7	26	3.503,00	**1,92**

Source: Research data, 2022.

1 - MJS: Machinery, interest and services; 2 - SMFA: Seeds/seedlings, fertilizers and pesticides; 3 - MDE: Maintenance, depreciation and social security charges; 4 - RF: Factor income.

In absolute values, oil palm and cotton plume (processed) are the most expensive, R$ 21,455.20 and 11,452.80, respectively, and sunflower and corn are the least expensive, R$ 3,503.00 and R$ 3,518.30, respectively. In terms of productivity, oil palm is absolutely the most profitable (25,780 kg/ha), followed by corn (5,760 kg/ha) and seed cotton (4,290 kg/ha).

The best PCC (lower costs per kg produced) are corn (R$ 0.62/kg), seed cotton (R$ 0.66/kg) and oil palm (R$ 0.83/kg). The worst PCC (highest costs per kg produced) were cotton plume (processed) (R$ 6.82/kg), canola (R$ 2.95/kg) and sunflower (R$ 1.92/kg). The PCC for soybeans (R$ 1.17/kg) and peanuts (R$ 1.84/kg) are in intermediate positions.

In the best PCC (corn, seed cotton and oil palm), there are the lowest relative levels of SMFA costs to the SMFA costs of the other oilseeds. With emphasis on oil palm as the only one whose SMFA variable costs are lower than its MJS variable costs, with a relatively high productivity, which places its PCC among the best. Cotton plume (processed) represented the highest PCC (R$ 6.82/kg), with the highest relative and absolute SMFA costs. With the exception of oil palm, the SMFA variable costs impacted PCC in diferente, but decisive ways.

Although there are equivalent fixed cost components, variable cost values fluctuate among regions, especially when it comes to SMFA. However, in some oilseeds, there is greater use of fixed costs due to the scalability of production, which reduces their fixed unit cost.

EFFICIENCY IN PRODUCTION

According to Ramos *et al.* (2017), the selection of the raw material to be used in the biodiesel production process has a great impact on the cost of the industrial production of biodiesel, so that, finding the efficiency of the production of raw materials to offer it in abundance can be strategic for reducing final costs of biodiesel production.

THE TECHNICAL EFFICIENCY OF SOYBEAN PRODUCTIVITY

Among the 23 municipalities analyzed, 13 obtained efficiency (maximum efficiency score = 1.000), 56% of the sample (Table 13). The municipalities identified as efficient may serve as a benchmark for the others, as the analysis of their cost structures – MJS, SMFA, MDE and RF – may generate important information to improve the performance of other inefficient municipalities. The cities considered as references were Pedro Afonso/TO, Ijuí/RS, São Luiz Gonzaga/RS, Boa Vista/RR, Uruçuí/PI, Sorriso/MT, Primavera do Leste/MT, Campo Novo do Parecis/MT, Dourados/MS, Chapadão do Sul/MS, Barreiras/BA, Brasília/DF and Campo Verde/GO (excluded from Table 5).

Table 5 | Technical efficiency of soybean producing municipalities, in 2021

VRSTE - Variable Return to Scale			Projected efficiency		Gap on inputs (R$)				Cost per kg		Unit Dif.
Municipalities	P. kg/ha	Efficiency *Score*	P. kg/ha	%	MJS	SMFA	MDE	RF	Current	Projected	%
Assis – SP	3000	0.899	3.335	11	0	0	307,64	0	1,13	0,93	18,15
Cruz Alta – RS	2700	0.739	3.655	35	0	0	36,43	2,75	1,2	0,88	27,03
Fco Beltrão - PR	3300	0.939	3.515	6,5	737,11	0	0	0	1,18	0,9	23,82
Guarapuava - PR	3500	0.912	3.836	9,6	0	0	423,59	62,2	1,42	1,17	17,66
Ponta Grossa - PR	3800	0.974	3.900	2,6	159,8	6,31	31,04	94	1,01	0,91	9,93
Londrina – PR	3600	0.923	3.900	8,3	196,29	1.164,00	1.012,00	55,4	1,66	0,91	45,12
C. Mourão – PR	3650	0.971	3.760	3	10,7	329,65	0	185	1,06	0,89	16,09
Unaí – MG	3300	0.933	3.536	7,2	27	0	53,31	0	1,24	0,89	28,99
Cristalina – GO	3150	0.852	3.699	17	154,9	221,64	0	0	1,16	0,89	23,59
Balsas – MA	3120	0.832	3.751	20	0	0	465,85	0	1,43	1,07	25,51
Mean									1,25	0,94	23,59

Source: Research data, 2022.

1 - MJS: Machinery, interest and services; 2 - SMFA: Seeds/seedlings, fertilizers and pesticides; 3 - MDE: Maintenance, depreciation and social security charges; 4 - RF: Factor income.

Ponta Grossa and Londrina are the ones that require elimination of gap in the four subgroups of costs to achieve efficiency, and increase in projected productivity (Table 5). Such actions would generate an average reduction of 23.59% in the cost of kg, and increase in productivity of 3,767 kg/ha, equivalent to the efficient ones. The MJS and SMFA inputs are the ones that most hinder efficiency in the municipalities.

The municipalities in the state of Paraná obtained the best productivity averages, however, none of the analyzed municipalities achieved efficiency. The municipalities of Paraná need to increase their productivity from 3.02% (Campos Mourão) to 9.60% (Guarapuava). However, other municipalities, such as Assis/SP and Balsas/MA, need to increase by 11.19% and 20.26%, respectively. The municipality that incurs the greatest need for adjustment in the volume to be produced/ha is Cruz Alta/RS, an increase of more than 35% to achieve efficiency.

In their studies on technical efficiency in soybean production in the state of São Paulo, Soares and Spolador (2017) identified that the main variables that contributed to efficiency gains were climatic and relief conditions, use of direct planting, technical assistance agriculture, integrated pest management and green manure.

Among the efficient municipalities, the average unit cost per kg is R$ 1.09, and, among the inefficient ones, the average unit cost per kg/ha is R$ 1.25 (14.67% higher).

THE TECHNICAL EFFICIENCY OF CORN PRODUCTIVITY

Of the 19 municipalities, six (31%) achieved maximum efficiency (efficiency score 1.000). They are: Pedro Afonso/TO, Vilhena/RO, Cristalina/GO, Caldas/MG, Sorriso/MT and Chapadão do Sul/MS (excluded from Table 6). The inefficient municipalities of PR, Rio Verde/GO and Assis/SP require adjustments in the four groups of inputs to achieve efficiency. The MJS, SMFA and MDE inputs are the ones that delimit the inefficiency.

Table 6 | Technical efficiency of corn producing municipalities, in 2021

VRSTE - Variable Return to Scale			Projected efficiency		Gap on inputs (R$)				Cost per kg		Unit Dif.
Municipalities	P. kg/ha	Efficiency *Score*	P. kg/ha	%	MJS	SMFA	MDE	RF	Current	Projected	%
Assis - SP	4.500	0.699	6.436	43,02	73.06	0,000	455.	89.67	0,80	0,36	55,57
F. Beltrão - PR	6.600	0.932	7.083	7,32	0,00	880.45	284.	167.32	0,70	0,46	33,66
A. Chat. -PR	6.000	0.848	7.079	17,99	0,00	394.37	56.9	290.74	0,67	0,47	30,82
Ubiratã - PR	5.400	0.750	7.200	33,33	282.98	252.83	5.90	194.65	0,75	0,46	38,64
C. Mourão - PR	6.500	0.903	7.200	10,77	42.80	750.39	61.1	302.20	0,69	0,46	32,89
Londrina - PR	5.700	0.792	7.200	26,32	98.79	564.27	831.	179.35	0,87	0,46	47,26
Rio Verde - GO	6000	0.873	6.871	14,53	17.58	334.89	0,00	51.77	0,61	0,47	22,32
Balsas - MA	4250	0.773	5.500	29,43	0,00	0,000	253.	39.48	0,62	0,42	30,98
Unaí - MG	6000	0.909	6.598	9,98	0,00	0,000	334.	25.58	0,56	0,45	18,81
C. Verde - MT	6000	0.907	6.617	10,30	0,00	17.853	160.	9.15	0,57	0,49	14,3121
CN Parecis-MT	6000	0.913	6.568	9,48	0,00	0,000	529.	5.18	0,61	0,47	22,03
P. do Leste- MT	6000	0.960	6.246	4,12	0,00	0,000	119.	6.45	0,52	0,48	7,86
Dourados- MS	5400	0.966	5.591	3,54	271.79	0,000	412.	23.84	0,62	0,47	24,40
Mean									0,66	0,45	29,20

Source: Research data, 2022.

1 - MJS: Machinery, interest and services; 2 - SMFA: Seeds/seedlings, fertilizers and pesticides; 3 - MDE: Maintenance, depreciation and social security charges; 4 - RF: Factor income.

The other inefficient ones require adjustments in at least one of their inputs (mainly in MDE). Such an action would generate an average reduction of 29.20% (greater than the reduction for soybean) in the average unit cost per kg through an increase in productivity (Table 14), corresponding to 11,839 kg, that is, two harvests in an efficient municipality. Among efficient municipalities, the average cost per kg is R$ 0.54, and among inefficient municipalities, the average cost per kg is R$ 0.66 (22.22% higher).

THE TECHNICAL PRODUCTIVITY EFFICIENCY OF COTTON PLUME (PROCESSED) AND SEED COTTON

According to CONAB (2021), between 20% and 30% of the costs of producing cotton plume (processed) can be used to generate its seed, which can be used to produce biodiesel. From the municipality of Barreiras - BA to the municipality of Cristalina - GO, there are cotton plume (processed) producers, all inefficient compared to seed cotton producers: Coromandel, Unaí, Presidente Olegário, Paracatu and São Romão (all efficient, excluded from Table 7). The productivity levels of cotton plume (processed) is 1/3 of the productivity of seed cotton.

Table 7 | Technical efficiency of cotton plume (processed) producing municipalities, in 2021

VRSTE - Variable Return to Scale			Projected efficiency		Gap on inputs (R$)				Cost per kg		Unit Dif.
Municipalities	P kg/ha	Efficiency *Score*	P kg/ha	%	MJS	SMFA	MDE	RF	Current	Projected	%
Barreiras-BA	1.620	0.331	4.900	202,47	896	5.651	451	64	6,61	2,25	66
Chap. do Sul- MS	1.800	0.444	4.057	125,39	591	5.392	1.35	0	6,99	2,92	58
C. Verde - MT	1.500	0.492	3.048	103,20	289	749	75	0	7,17	6,42	10
Rondonóp. - MT	1.600	0.340	4.710	194,38	1.402	3.948	0	362	5,15	2,19	58
Sorriso - MT -	1.500	0.430	3.488	132,53	1.027	3.010	109	0	7,91	5,14	35
Cristalina-GO	1890	0.608	3.109	64,50	716	88	46	0	5,40	4,95	8
Mean									6,53	3,97	39

Source: Research data, 2022.

1 - MJS: Machinery, interest and services; 2 - SMFA: Seeds/seedlings, fertilizers and pesticides; 3 - MDE: Maintenance, depreciation and social security charges; 4 - RF: Factor income.

The efficiency levels of cotton plume (processed) producers oscillate between 30 and 60% of the efficiency found in seed cotton producers (Table 7), considered very low, although the crop has different purposes from those of seed cotton.

To achieve the efficiency of the five seed cotton producing municipalities, cotton plume (processed) producers need to increase their productivity between 65 and 200%, and eliminate existing gaps in all inputs, mainly in SMFA (Table 15). Such actions would generate an average reduction of 39% in the average cost per kg, and an increase in production of 15,292 kg/ha, about three harvests in a municipality that is efficient in the production of seed cotton. With the exception of Campo Novo do Parecis–MT (excluded from Table 7), the other six cotton plume (processed) producers did not match the efficiency of seed cotton producers.

Among seed cotton producing municipalities, the average cost per kg of seed cotton is R$ 0.74, and, among inefficient municipalities, the average cost per kg of cotton plume (processed) is R$ 6.53 (660% higher).

According to Castro *et al.* (2017), Bahia, São Paulo, Paraná, Mato Grosso do Sul, Mato Grosso and Goiás were the most relevant states in the cotton farming scenario between 1995 and 2015, whose gross production value grew and was marked by relevant gains in productivity. However, prices fell, generating lower remuneration, which stimulated the continuous search for greater efficiency and competitiveness.

THE TECHNICAL EFFICIENCY OF PEANUT PRODUCTIVITY

Among the 27 municipalities analyzed, those that obtained efficiency were 37% of the sample (ten municipalities), which serve as a benchmark for the others: Marília, Presidente Prudente, Catanduva, Dracena, Votuporanga, Ourinhos, Franca, Avaré, São João da Boa Vista and Piracicaba (excluded from Table 8). Analysis of their cost structures – MJS, SMFA, MDE and RF – can generate important information to improve the performance of other municipalities.

Table 8 | Technical efficiency of peanut producing municipalities in the state of São Paulo, in 2021

VRSTE - Variable Return to Scale			Projected efficiency		Gap on inputs (R$)				Cost per kg		Unit Dif.
Municipalities	P kg/ha	Efficiency *Score*	P. kg/ha	%	MJS	SMFA	MDE	RF	Current	Projected	%
Jaboticabal	3.580	0.630	5.680	58,66	22	49,00	364,	36,00	2,23	1,32	41
Tupã	4.450	0.831	5.358	20,40	0	0,00	214,	2.5	1,74	1,41	19
Lins	3.910	0.803	4.870	24,55	0	210.53	0	0	1,87	1,46	22
SJ Rio Preto	3.060	0.812	3.767	23,10	24.8	0	0	0	2,12	1,72	19
Assis	4.030	0.908	4.438	10,12	0	0	49.5	0	1,74	1,57	10
Barretos	3.740	0.718	5.209	39,28	21.8	84.93	0	36.18	2,03	1,43	30
Araçatuba	3.500	0.771	4.538	29,66	19	76	0	0	1,96	1,46	25
R. Preto	3.360	0.713	4.713	40,27	0	0	0	0	2,07	1,37	34
P. Venceslau	2.790	0.994	2.807	0,61	151.	0	0	22.66	2,01	1,94	4
G. Salgado	3.710	0.905	4.101	10,54	0	337.05	0	0	1,89	1,62	14
Araraquara	3.270	0.787	4.153	27,00	102,	394,15	0	0	2,00	1,44	28
Jaú	3.600	0.755	4.767	32,42	127.	0	0	2.60	1,96	1,45	26
Bauru	3.660	0.782	4.692	28,20	121,	0	0	2,8	1,81	1,29	28
Andradina	4.190	0.954	4.393	4,84	39.3	0	0	0,66	1,61	1,50	6
Limeira	5.000	0.880	5.680	13,60	4.00	259.00	10,	6	1,56	1,32	15
Orlândia	3.670	0.722	5.086	38,58	0	127.93	0	4.17	1,99	1,41	29
Fernandópolis	1.820	0.879	2.069	13,68	0	465.76	0	0	2,97	2,39	20
Mean									1,97	0,44	21,74

Source: Research data, 2022.

1 - MJS: Machinery, interest and services; 2 - SMFA: Seeds/seedlings, fertilizers and pesticides; 3 - MDE: Maintenance, depreciation and social security charges; 4 - RF: Factor income.

The achievement of productive efficiency by the 17 inefficient ones implies adjustments mainly in SMFA and MDE inputs and increase in productivity. Such actions would reduce the cost per kg by 21.74% and increase productivity by 881 kg/ha. Municipalities like Andradina and Jaboticabal need to increase their productivity from 4.84% to 58%, respectively. However, the average increase in productivity for others is around 30%.

Unlike other oilseeds, these inefficient producers require greater adjustments in the variable inputs MJS (Machines, Interest and Services) and SMFA (Seeds/seedlings, fertilizers and pesticides).

In their studies on the efficiency of production capacity to make biodiesel in the 38 regions of São Paulo that produce soybean, cotton and peanut oils, Martins *et al.* (2017) presented the orientation of more investments in inputs that could induce efficiency in the production of those regions and inefficient crops.

THE TECHNICAL EFFICIENCY OF OIL PALM PRODUCTIVITY IN THE STATE OF PARÁ

Among the ten oil palm producing municipalities in the state of Pará, eight are efficient: Bonito, Açará, Tomé-Açu, Tailândia, Igarapé-Açu, Abaetetuba, and São Domingos do Capim. Only two require adjustments in their inputs to reach their efficiency levels (Table 9).

Table 9 | Technical efficiency of oil palm producing municipalities in the state of Pará, in 2021

VRSTE - Variable Return to Scale			Projected efficiency		Gap on inputs (R$)				Cost per kg		Unit Dif.
Municipalities	P kg/ha	Efficiency *Score*	P. kg/ha	%	MJS	SMFA	MDE	RF	Current	Projected	%
Moju	15.000	0.834	17.986	20	0	643	122	0	1,01	0,80	20,80
Concórdia Pará	29.250	0.861	33.972	16	0	612	340	0	0,93	0,77	16,91
Mean									0,97	0,79	18,86

Source: Research data, 2022.

1 - MJS: Machinery, interest and services; 2 - SMFA: Seeds/seedlings, fertilizers and pesticides; 3 - MDE: Maintenance, depreciation and social security charges; 4 - RF: Factor income.

These two (Table 9) need to increase their productivity by 20% (Moju) and 16% (Concórdia do Pará), and reduce SMFA inputs by 11% and MDE inputs by 8% (Moju), and SMFA inputs by 6% and 14% in MDE inputs (Concórdia do Pará). Such actions correspond to an 18% reduction in the cost of kg and an average increase of 7,708 kg/ha in productivity.

Damasceno *et al.* (2018) reported that, in recent years, public policies, such as PNPB and PPSOP (Sustainable Palm Oil Production Program), have favored the installation of enterprises interested in the production of oil palm in regions with agricultural aptitude in the microregion of Tomé-Açu, in order to meet the demand of biodiesel plants.

Among inefficient municipalities, the average unit cost per kg is R$ 0.97, with the adjustments in pursuit of efficiency, this cost can be reduced to R$ 0.79 (reduction of 18%).

THE TECHNICAL EFFICIENCY OF SUNFLOWER PRODUCTIVITY

Among the ten municipalities, seven are efficient and three, from different states, (São Luiz Gonzaga/RS, Araguari/MG and Caldas Novas/GO), 30% of the sample, require adjustments in their inputs to reach efficiency levels (Table 18).

Table 10 | Technical efficiency in sunflower producing municipalities

VRSTE - Variable Return to Scale			Projected efficiency		Gap on inputs (R$)				Cost per kg		Unit Dif.
Municipalities	P kg/ha	Efficiency *Score*	P. kg/ha	%	MJS	SMFA	MDE	RF	Current	Projected	%
SL Gonzaga- RS	1.560	0.914	1706	9,5	406.772	0	0	0	2,30	1,87	18,67
Araguari (MG)	1500	0.921	1700	13,3	442.019	0	0	0	2,50	1,94	22,44
C. Novas (GO)	1500	1.000	1688	12,5	0	225	0	0	1,88	1,54	18,23
Mean									2,23	1,78	19,78

Source: Research data, 2022.

1 - MJS: Machinery, interest and services; 2 - SMFA: Seeds/seedlings, fertilizers and pesticides; 3 - MDE: Maintenance, depreciation and social security charges; 4 - RF: Factor income.

The achievement of efficiency by the producers of the three inefficient municipalities implies a reduction of 41% and 49% in MJS inputs in the municipalities of São Luiz Gonzaga/RS and Araguari/MG, respectively, a reduction of 14% in SMFA inputs by producers in the municipality of Caldas Novas/GO, and the increase in productivity by 9.5%, 13.3% and 12.5%, respectively (Table 10). Such actions would generate an average reduction of 19.78% in the unit cost of production per kg, corresponding to an average increase of 534 kg/ha in productivity. Among inefficient municipalities, the average unit cost per kg is R$ 2.23. With the adjustments in search of efficiency, this cost can be reduced to R$ 1.78 (20%).

According to Embrapa Soja (2022), in Brazil, sunflower remains a secondary crop (after soybean), not much for a country that has more than 10m/ha of areas considered suitable for its cultivation. The main obstacle to the advancement of this crop is the lack of a solid market, which limits an eventual expansion of the cultivated area, agronomic research, generation of technologies and better management of the crop. This finding conditions the expansion of sunflower to the growth of the agroindustrial sector in Brazil, in which the biodiesel industry is linked.

THE TECHNICAL EFFICIENCY OF CANOLA PRODUCTIVITY

Embrapa Trigo (2020) reports that Rio Grande do Sul is the largest canola producer nationwide, as it has adequate thermal conditions for growth during autumn, winter and early spring. In addition, there is proximity to industries that process grains and promote production, which facilitates the technical conduct of cultivation and commercialization in the South region.

Table 11 | Technical efficiency of canola producing municipalities in the state of Rio Grande do Sul

VRSTE - Variable Return to Scale			Projected efficiency		Gap on inputs (R$)				Cost per kg		Unit Dif.
Municipalities	P kg/ha	Efficiency *Score*	P (kg/ha)	%	MJS	SMFA	MDE	RF	Current	Projected	%
Erechim	1.660	0.990	1.660	34,51	62	545	0	0	3,10	2,73	11,81
Frederico Westphalen	1.246	0.872	1676	2,36	21	970	0	0	3,78	2,22	41,32
Santa Rosa	1.324	0.858	1542	16,47	67	0	0	18	2,95	2,47	16,34
Mean									3,28	2,47	23,16

Source: Research data, 2022.

1 - MJS: Machinery, interest and services; 2 - SMFA: Seeds/seedlings, fertilizers and pesticides; 3 - MDE: Maintenance, depreciation and social security charges; 4 - RF: Factor income.

Of the ten municipalities, seven are efficient: São Luiz Gonzaga, Bagé, Caxias do Sul, Ijuí, Passo Fundo, Santa Maria and Soledade (excluded from Table 19), and the three above are inefficient. In terms of average productivity to achieve efficiency, municipalities need to increase their average productivity by 34.51%, 2.36% and 16.47%, and reduce 7.6% in MJS inputs and 16.7% in SMFA inputs (Erechim), 2.7% in MJS inputs and 32.4% in SMFA inputs (Frederico Westphalen), and 7.5% in MJS inputs and 16.7% in RF inputs (Santa Rosa). An average reduction of 23.16% in the average cost per kg would correspond to an average increase of 648 kg/ha in productivity.

In terms of average productivity, municipalities need to increase by 34.51%, 2.36% and 16.47%, respectively, to achieve efficiency. Among inefficient municipalities, the average unit cost of production (kg) is R$ 3.28, with adjustments in pursuit of efficiency, this cost can be reduced to R$ 2.47 (24%).

Embrapa Trigo (2020) also explains that the cultivation of canola is an economic alternative because it benefits from the same structure of machines and equipment used in other crops, such as corn, soybean, wheat and beans, with some adaptations and additions. Furthermore, it has a relatively low cost of pesticides compared to other species used in grain production.

OVERVIEW OF THE EFFICIENCY ANALYSIS IN THE PRODUCTIVITY OF OILSEEDS EXPLOITED FOR BIODIESEL IN BRAZIL IN 2022

Of the 111 municipalities analyzed, 55 (49% of the sample) are inefficient. There are 43% of soybean producing municipalities (10/23), 68% of corn producing municipalities (13/19), 58% of cotton producing municipalities (7/12), 20% of oil palm producing municipalities (2/10), 30% of sunflower producing municipalities (3/10), 30% of canola producing municipalities (3/10), and 63% of peanut producing municipalities (17/27) (Table 12).

Table 12 | Result of the efficiency analysis estimates

O	Total of Municipalities: 111			Efficient Municipalities: 60			Inefficient Municipalities: 51					
	Prod.	Input	Ef.	Productivity	Input	Ef.	Productivity	Input	Ef.	DEA	TC%	Scale
1	3270	3809	0,8	3238	3539	0,9	3312	4155	0,8	1,0	16	11
2	5761	3581	1,6	5850	3183	1,9	5719	3764	1,5	2,1	18	15
3	2766	7938	0,3	4289	3212	1,3	1679	1131	0,1	0,6	41	135
4	25780	21955	1,2	26693	22135	1,4	22125	21236	1,1	1,3	4	17
5	1822	3794	0,5	1951	3968	0,5	1520	3385	0,5	0,5	11	12
6	1530	4518	0,3	1582	4490	0,3	1410	4585	0,3	0,4	12	15
7	3624	4141	0,9	3653	6498	0,6	3608	6942	0,5	0,6	4	24

Source: Research data, 2022.

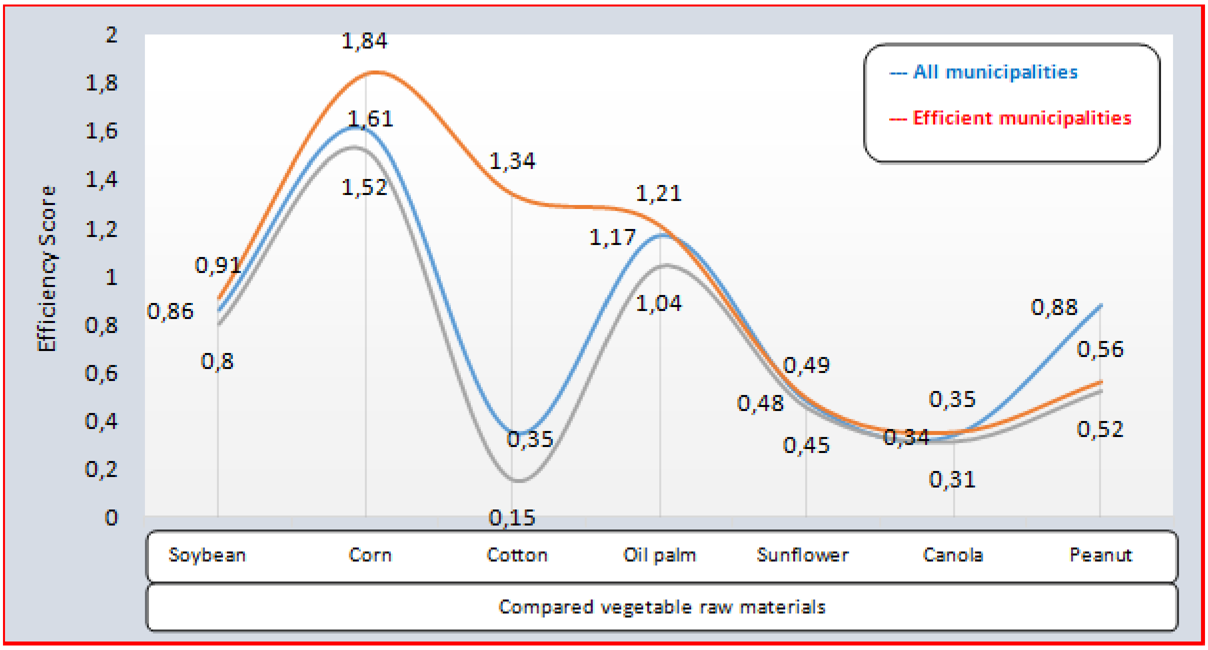
1: soybean; 2: corn; 3: cotton; 4: oil palm; 5: sunflower; 6: canola; 7: peanut.

Of the four groups of inputs, SMFA are the ones that require the greatest adjustments in the search for efficiency. Its average impact on inefficiency reaches 58% of total costs, from 21% in sunflower to 90% in canola. Inefficient municipalities need to adjust an average of 15% of their inputs to achieve efficiency. The greatest efforts to be made are in the production of cotton (41%), corn (18%) and soybean (16%), and the smallest efforts are in peanuts and oil palm (4%), which also have the best scalability (24% and 17%), after herbaceous cotton (135%). In efficient municipalities, the highest efficiency is that of corn (1.9), followed by oil palm (1.4). In the inefficient ones, corn maintains a high efficiency (1.5), oil palm the efficiency (1.1), and soybean have a relative efficiency: 0.9 among the efficient ones, and 0.8 among the inefficient ones.

The average productivity of oil palm exceeds peanuts by more than three times and by up to seven times other oilseeds, in addition to being the least costly in absolute terms.

In the efficiency analysis of oilseeds in all municipalities, the highest efficiencies are in the production of corn (1.61) and oil palm (1.17), followed by peanuts, which is relatively efficient (0.88) (Graph 1).

Graph 1 | Final result of estimates by Vegetable Raw Material and municipalities



Source: Research data, 2022.

In efficient municipalities, the efficiency of corn increases to 1.84 and that of oil palm to 1.21, and cotton appears with efficiency 1.34 (driven by seed cotton) and the efficiency of peanuts drops to 0.56 (inefficient). Among inefficient municipalities, corn maintains high efficiency (1.52), oil palm remains efficient (1.04), peanut efficiency drops more (0.52), and cotton drops sharply (0.15), driven by cotton plume (processed) (Graph 1).

In the three scenarios, soybean occupies an intermediate position, with relative efficiencies of 0.91 among the efficient ones, 0.86 among all municipalities and 0.80 among the inefficient ones, but with a lower level of efficiency than peanuts (0.88) in the analysis of all municipalities. Sunflower, canola and cotton plume (processed) are the least technically efficient in all classifications.

In all seven oilseeds of the 55 inefficient municipalities (49% of the sample), there is room for increasing efficiency that can provide an average reduction of 4% to 18% in the final cost that can be transferred to the cost of the oil offered to the biodiesel industry.

FINAL CONSIDERATIONS

From results, 56 municipalities are efficient (51%), and 55 (49%) do not have maximum efficiency in at least one of the oilseeds analyzed, mainly due to the SMFA inputs cost, with the exception of oil palm, where the cost of the prevailing input is with MJS (machines, interest and services), in a lower proportion than its own SMFA cost, and, in this, lower in relation to the other oilseeds.

The municipalities of the state of Paraná have the best soybean and corn productivity averages, however, they are not the most efficient in these. Their productivity averages do not necessarily guarantee efficiency.

Simultaneously, seven municipalities achieved maximum efficiency in the production of more than one oilseed: Pedro Afonso/TO, Sorriso/MT and Chapadão do Sul/MS (soybean and corn), São Luiz Gonzaga and Ijuí/RS (soybean and canola), Campo Novo do Parecis/MT and Brasília/DF (soybean and sunflower).

The soybean agroindustrial complex is one of the most modern in the world, nevertheless, there is room for improvement in almost half of the sample (10/23). The corn production structure has been modernized and achieved exponential growth in recent years. However, it also presents room for productivity improvements in most of the municipalities analyzed (13/19). The calculated values show corn with a more advantageous production cost. Both in efficient and inefficient municipalities, its average production cost per kg/ha is 50% lower than that of soybeans, and represents 0.08% of the average unit cost of cotton plume (processed), whose average cost per kg/ha in relation to seed cotton reaches 660%.

The exponential production of soybean and its competitive price do not necessarily make it the best choice for biodiesel production, considering that it has the lowest oil yield in kg/ha (51%) and the lowest energy balance (1.3:1). This also happens with corn (kg/ha yield: 14.17% and energy balance 1.42:1) and cotton (kg/ha yield: 45% and energy balance 1.77:1).

These three oilseeds are not the most effective from an environmental point of view, but they establish themselves in the biodiesel market because of their production scales. However, oil palm, which generates two oils (the palm of the mesocarp and the palm kernel of the endocarp), together, constitutes the second best yield in kg/ha (280) and the best energy balance (5.6:1), due to its low dependence on fertilizers. However, there are logistical limitations on the extraction and industrialization of its oil.

Efficiency in production reduces the final cost, can reduce final market prices and cause positive impacts on the biodiesel production chain, making it more competitive. For this, it is necessary to advance in the efficiency of the productivity of these oilseeds that allow greater offers and diversification for biodiesel.

Currently, two regulatory frameworks support production and commercialization of biodiesel in Brazil, PNPB and RENOVABIO. The first came into effect in 2005, with the aim of developing the biofuels production chain in its initial phase, the second came into effect in 2018, with the purpose of stimulating this production chain in its final stage. However, in this space of thirteen years (from PNPB/2005 to Reonvabio, 2018), both policies did not promote mechanisms to subsidize one of the main gaps in this chain, fertilizers – Nitrogen (N), Phosphorus (P) and Potassium (K) –, imported at increasing prices due to fluctuations in the international market, which have increased even more because of the pandemic and the consequences of the war in Ukraine.

Finally, it is considered that, given the increase in renewable fuel consumption in response to the mandatory reduction in fossil fuel consumption, there may be greater demand for the cultivation of oilseeds destined for biodiesel, with attention to productivity, oil yield and energy balance compatible with the sustainability of the Paris/2015 and COP/21 protocols.

The variations found in this research provoke the need to expand the analysis of efficiency in other crops and in mixed productions, a common strategy in Brazilian agriculture.

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