

Study of the technical efficiency of the sweet chili (*Capsicum chinense*) in the producing regions of the Colombian Caribbean

Estudio de la eficiencia técnica del ají dulce (*Capsicum chinense*) en las regiones productoras del Caribe Colombiano



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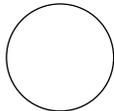
Sweet chili fruits.

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ABSTRACT

Sweet pepper cultivation is one of the more important activities in the Caribbean region, cultivated by approximately 4,284 farmers with the family farming system, in areas ranging from 0.25 to 2.0 ha. In the literature for this region, there is no evidence of a study that has investigated the technical efficiency of this production system. For this reason, this study aimed to evaluate the technical efficiency of the use of resources by sweet chili farmers in the Caribbean producing areas of Colombia. The sample was 62 farmers, surveyed via simple random sampling from the use of statistics from the Ministry of Agriculture of Colombia. A Cobb Douglas-type functional model was formulated. The contribution of the variables seed, labor, fertilizer, weeds and yields in the productive units was determined. The results showed that labor and weed management had a positive effect on production increases. There was inefficiency with production gaps of 0.18% and efficiency of 82%; a production deficit of 1 t ha⁻¹ was observed. There were returns on an increasing scale that was explained by the direct relationship between the inputs of labor and weed management.

Additional keywords: technology; response technologies; physical returns; productivity; inputs; products; agriculture.



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RESUMEN

El cultivo del ají dulce es una de las hortalizas más importantes de la región Caribe, cultivada aproximadamente por 4.284 agricultores bajo el sistema de agricultura familiar en áreas que van desde 0,25 hasta 2,0 ha. En la literatura de esta región, no se evidencia un estudio que indague sobre la eficiencia técnica de este sistema de producción. Por esta razón, este estudio tuvo como objetivo evaluar la eficiencia técnica del uso de los recursos por parte del agricultor de ají dulce en las zonas productoras del Caribe de Colombia. La muestra fueron 62 agricultores encuestados seleccionados mediante muestreo aleatorio simple a partir del uso de estadísticas del Ministerio de Agricultura de Colombia. Se formuló un modelo funcional tipo Cobb Douglas. Se determinó la contribución de las variables semilla, mano de obra, fertilizante, malezas y los rendimientos en las unidades productivas. Los resultados muestran que la mano de obra y manejo de malezas inciden positivamente en los aumentos de la producción. Se concluye hay presencia de ineficiencia con brechas de producción de 0,18% y la eficiencia de 82%, se genera un déficit de producción de 1 t ha⁻¹. Hay presencia de rendimientos a escala creciente que se explica por la relación directa de los insumos mano de obra y manejo de malezas.

Palabras clave adicionales: tecnologías; respuestas tecnológicas; retornos físicos; productividad; insumos; productos.

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INTRODUCTION

The sweet chili is a widely diffused vegetable in many regions, especially in tropical climates such as Colombia and the producing areas of Venezuela (Carvalho *et al.*, 2017). It belongs to the *Capsicum* genus, Solanaceous family, of which there are several cultivated species with variations in the fruit characteristics. The more representative species are *C. annuum* L., *C. baccatum* L., *C. chinense* Jacq., *C. frutescens* L., and *C. pubescens* R. & P. (Carvalho and Bianchetti, 2008). Its origins are in the Amazon River basin, and Venezuela is the center of diversity (Moses and Umaharan, 2012). It is used in different culinary recipes because of characteristics that make it attractive to consumers (Quevedo and Laurentin, 2020).

In 2019, global production was 38 million tons from 1.99 million hectares, with average yields of 19 t ha⁻¹. In Colombia, 8,704 ha were sown, which an average of 15.5 t ha⁻¹ (FAO, 2021). The Caribbean region of Colombia had a planting area of 2,925 ha of sweet chili cultivation, which had around 10,000 productive units with an average of 0.25 ha (Agronet, 2018; Correa-Álvarez *et al.*, 2019). The Caribbean Region provides 51% of the domestic harvested area, and the largest chili producer is the Magdalena Department, with 12,288 (Agronet, 2019).

It is very important because it is incorporated into diets and has culinary characteristics such as flavor, aroma, and color that make it attractive to consumers

and the regional gastronomy. In addition, the productive tradition in the region is relevant to the rural economy (Correa-Álvarez *et al.*, 2019; Quevedo and Laurentin, 2020).

It has great growth potential because of its high consumption worldwide and industrial uses (Duran 2013; Srivastava and Mangal, 2019; Costa *et al.*, 2019). Estimates by Rugeles (2011) indicated that this crop demands an average of 650 wages per hectare – cycle. Therefore, this crop generates around 1.9 million wages in the region, showing its importance to employment and the rural economy.

For the sweet chili production system in the Caribbean region, no economic studies have been carried out that reveal aspects such as the rationality of the producer in decision-making, allocation of resources for production, technical production efficiency, and technological gaps.

Studies on technical efficiency in production systems have been developed by Márquez *et al.* (2015) in beans, Colque (2019) in onion, Asravor *et al.* (2016) in chili peppers in the Volta region of Ghana with modified function models of stochastic frontier cost and production, and Martínez-Reina *et al.* (2021).

The use of the stochastic frontier technique is recurrent, with estimates using models of functional

relationships between inputs and outputs using translogarithmic estimates and Cobb Douglas functions. The stochastic frontier technique has been used in studies on coffee in Nicaragua (Saravia, 2007; Urbina, 2017) and Mexico (Cárdenas *et al.*, 2005), along with modeling of the technical efficiency of rice producers in Bangladesh (Rahman *et al.*, 2012).

Abate *et al.* (2019) surveyed 385 farmers selected with random sampling and calculated a Cobb Douglas-type stochastic frontier function. The efficiency was 78.80%. It was found that the cultivated area, the seed, the agrochemicals, the animal traction, and the labor explained the production of chili. Likewise, the possibilities of increasing efficiency are conditioned by socioeconomic variables such as age, educational level, land size, distribution of land use, rural extension services, access to credit and market information. These socioeconomic variables affect the technical efficiency of chili production.

When consulting the bibliographic sources, it was evident that, for the allocation of resources for the sweet chili production system, there is no study for Colombia that investigated and explained the rationale of producers when making decisions and allocating resources for production in the Caribbean Region, analyzing the rationality of producers with technical efficiency and identifying technological gaps.

The working hypothesis is that the rational farmer maximizes production with the proper use of resources, that is, he does not spend more or less than the inputs necessary to carry out production and always seeks to maximize their use (De los Ríos, 2006).

This article is structured as follows: it begins with a general presentation of the sweet chili production system in the region, the estimation of technical efficiency identifying the factors responsible for the inefficiency, and finally ideas are presented as conclusions. The results of this research contribute to researchers and sweet chili farmers in the Colombian Caribbean region because they can be used to improve aspects that make the system inefficient, increasing productivity and efficiency.

MATERIALS AND METHODS

This research was carried out in the Colombian Caribbean Region in the municipalities of San Juan del

Cesar and Ponedera, located in the Departments of La Guajira and Atlantico, respectively.

The information collection instrument was a survey with 30 questions divided into three components: technical, socioeconomic and market elements of sweet chili. For the purposes of this research, emphasis was placed on the technological variables that determined the efficiency and on the socioeconomic variables to measure the factors that inhibit it.

The sample size of this study was 62 farmers, classified as small farmers who cultivate with the family farming model, which were obtained from the two surveyed localities using statistics from the *Secretaría Económica y Desarrollo Agroindustrial*, with 845 from the Caribbean Region. The simple random sampling method was applied using the cultivated area, where 62% corresponded to productive units of less than 1 ha, while 39% had more than 1 ha. The calculations were made according to Rodríguez (2005) by applying the following Equation (1):

$$n = \frac{Z^2pqN}{[(e^2(N-1)) + Z^2pq]} \quad (1)$$

Where, n was total number of surveys or sample; Z corresponding to the confidence level chosen in this case, 95%; p proportion of the population that cultivate less than 1 ha, 524 farmers; q the difference between the total population and the proportion of the population that does not meet the characteristic (in this case, units larger than 1 ha), 321 farmers; e maximum permissible error 15%; N population size of 845 productive units.

The total number of surveys calculated was 62 productive units applied to expert farmers in the crop.

Once the surveys were carried out, the second stage of the investigation started, which consisted of a phase of cleaning and processing the data and tabulation through the construction of a database in the SPSS program (IBM SPSS). Data analyses were done by applying descriptive statistics, correlation analysis and the formulation of the Cobb-Douglas function (Douglas, 1976) (Eq. 2)

$$Y = F(K, L) = AK^\alpha L^\beta \quad (2)$$

Where, Y was the total production of sweet chili, kg ha⁻¹; K capital factor; L work; α change in Y when

capital factor changes; β change in Y when the labor factor changes.

The original data were transformed into a natural logarithm to express the value of the parameters as elasticities, that is, the change in the quantity produced by the change in one unit of the variable input. These parameters in the case of α symbols are the cut-off point or zeros of the function, that is, production when the use of inputs does not change; the value of the β parameters are the elasticities of the product in relation to the change of each input. Under these circumstances, in how many units does chili chili production change due to the change in one unit of the input, when this value is greater than 1, yields are presented on an increasing scale.

The field data after defining the variables and the classification into dependent variable and explanatory variables, the parameters were estimated using the Ordinary Least Squares (OLS) method. The linearization of the function was done according to Toro *et al.* (2010) using natural logarithms.

The proposed Equation (3) was the following:

$$y = \beta_0 + \beta_1 \ln x_1 + \beta_2 \ln x_2 + \beta_3 \ln x_3 + \beta_4 \ln x_4 + \beta_5 \ln x_5 + \varepsilon_1 \quad (3)$$

Where, \ln was natural logarithm; Y amount of chili produced, kg; X_1 seed, kg ha⁻¹; X_2 labor per ha; X_3 control weeds used per ha⁻¹; X_4 fertilizer, kg ha⁻¹; X_5 yield, t ha⁻¹; $\beta_0 - \beta_5$ parameters to be estimated (regression coefficients), and ε_i compound error term defined as $V_i - U_i$.

The measurement of inefficiency was understood as the factors that act negatively on efficiency or those that inhibit technical efficiency, socioeconomic variables such as age, education, experience, and the size of the area used in the cultivation of the crop were considered.

$$y = \alpha_0 + \alpha_1 \ln x_1 + \alpha_2 \ln x_2 + \alpha_3 \ln x_3 + \varepsilon_1 \quad (4)$$

Where, y was technical inefficiency; α_1 age (years); α_2 experience in cultivation (years); α_3 area cultivated in hectares; ε_i error term, and $\alpha_0 - \alpha_3$ parameters to be estimated

As in equation 4, the Ordinary Least Squares method was used to estimate the parameters in the Eviews 8

econometric program. The information was obtained from the 62 surveys applied to farmers who are experts in the cultivation of chili in the target area.

The technical efficiency calculations used the variables of real production and potential production, in this case the yield average in tons of sweet chili from the 62 productive units surveyed. Potential production is the result of calculating the elasticities or changes that production undergoes as the result of the change in a unit of input and is obtained by replacing the values of the parameters in the general Equation (5):

$$Production = C(1) + C(2)Seed + C(3)Labor + C(4)Fertilizer + C(5)Weeds + C(6)Yield \quad (5)$$

There are two values: real production and potential production, and the difference between these two variables gives the technological gap, the difference between real production and potential production, the greater the technological gap (Eq. 6)

$$ET = \frac{Production\ real}{Production\ production} \quad (6)$$

The smaller the difference between actual production and power, the higher the efficiency is.

RESULTS AND DISCUSSION

Socioeconomic characteristics of the sample

Farmers who grow sweet chili in the Caribbean Region are small with an average of 0.6 ha and a family model that uses few inputs compared to the market; the majority of activities are done manually with the help of all members of the family.

The average age is 51 years, and the average experience is 11 years. 90% of production is destined for the market in the same locality or in the closest consumption centers and the closest markets, such as Barranquilla and Cartagena in the case of farmers in the Departments of Bolivar and Atlantico.

The Cobb Douglas model parameter estimation for sweet chili with least squares regression is in table 1.

Table 1. Estimation of Cobb Douglas model parameters for sweet chili in the Colombian Caribbean Region, 2020.

Variable	Coefficient	Standard error	t-Statistic	P value
C	-0.901696	1.438868	-0.626671	0.5334
Seed	-1.096501	0.375617	-2.903716	0.0053
Labor	0.394575	0.553753	0.794790	0.4301
Fertilizer	-0.090041	0.527581	-0.062280	0.9506
Weeds	0.860351	0.504737	1.349500	0.1826
Yield (t ha ⁻¹)	1.104786	0.135733	8.221480	0.0000

The coefficient related to labor, understood as the number of wages per productive unit in each crop cycle, was 0.394575, suggesting that an increase in the use of labor will increase production. This productive system is part of a rural economy and is intensive in the use of labor, which, in many cases, is an implicit cost since it does not imply disbursements of money by the producer.

The other component or factor that was considered in the model was fertilization. It is not a very common practice. The value of the parameter was -0.090041 and indicated an inverse relationship between increases in production and increases in fertilization. When fertilization is done without a soil analysis and without considering the nutritional requirements of the crop, this factor can be underutilized, which is the presumed case for sweet chili.

Weed management presented a coefficient of 0.860351, indicating a direct relationship between production increases and weed management, which is mostly done manually and is environmentally friendly. In addition, there is a rational management of chemical inputs.

Yield is the factor that makes a productive unit have favorable production levels for the producer. A value for this parameter of 1.104786 with a positive sign indicates great influence and contribution to total production to the extent that a biophysical response given all the inputs that were involved in production. With the yields obtained here, the expenditure of both energy and the same inputs were compensated, explaining the direct relationship.

As defined above, technical efficiency results from relating real production to potential production. Where the potential production is less than real production,

technological gaps are generated in sweet chili production, as can be seen in figure 1.

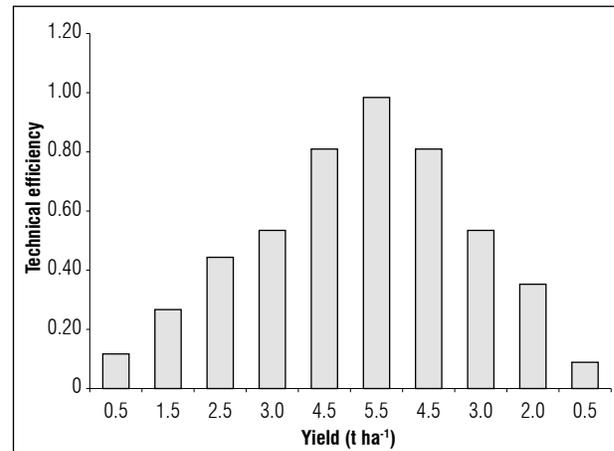


Figure 1. Analysis of technical efficiency in the cultivation of sweet chili in the producing regions of the Colombian Caribbean.

The real production was 4.5 t ha⁻¹ of chili, while the potential production was 5.5, which indicates that, to reach production efficiency, this value must be equal to 1. With yields of 4.5 t ha⁻¹, the efficiency was 0.81, which means 0.19 more was needed to reach an efficient yield of 5.5 t ha⁻¹, generating a production gap of 1 t ha⁻¹. Thus, despite being close to 1, the efficiency value, even with real yields, cannot be reached, which is explained by factors such as seed and fertilizer, where the use of these factors is presumed to be underutilized.

Determinants of technical inefficiency

Socio-economic variables are used to determine the possibility of increasing or decreasing efficiency since they depend more on human will and the decisions made by the producer, as well as the environment in which the production is carried out.

In this case, variables such as age, experience, education, and the size of the productive unit represented in the cultivated area were considered. The output of the regression is in table 2.

The measurement of production inefficiency, understood as those variables that inhibit the process and that act negatively, were in table 2. In this case, a parameter value with a positive sign indicates that the variable has a negative effect on efficiency, and a

negative sign of the parameter indicates that the variable positively influences efficiency. Next, each of the variables selected for the model were analyzed.

Table 2. Variables that explain the inefficiency of the production system of the sweet chili production system in the Colombian Caribbean Region, 2020.

Variable	Coefficiente	Standard error	t-Statistic	P value
C	3.421659	2148258	1592760	0.1168
Age	-0.390733	0.509836	-0.766391	0.4467
Experience	-0.112180	0.156577	-0.716452	0.4767
Education	0.151720	0.436409	0.347655	0.7294
Area	1.077874	0.122439	8803341	0.0000

The age parameter had a value of -0.390733, meaning that age can positively influence production efficiency, perhaps the methods used and transmitted by family members make it more careful in the use of inputs, and the older the age is, the greater the possibility of increasing efficiency is.

Experience is closely related to age: the older the farmer is, the more experience and efficiency the farmer has. The parameter value of -0.112180 showed this relationship between experience and efficiency, as more experience is less likely to see mistakes when allocating resources, resulting in greater efficiency.

The cultivated area presented a coefficient of 1.077874, which indicates that increasing the cultivated area does not increase efficiency, the presence of economies of scale in agriculture as demonstrated by Martínez-Reina *et al.* (2021), in the case of yams or Perdomo and Hueth (2011), in the case of coffee in Colombia.

One characteristic of this production system is that it is done under the productive model of a peasant economy with traditional technology and a strong family incidence, responding to external factors such as lack of income, scarce technology, and adverse weather conditions (FAO, 2014). Family farming is characterized by a small and strongly diversified scale of production where the products are intended for self-consumption or sale and is the main source of employment and income for the rural population (Fonseca-Carreño *et al.*, 2019).

Socioeconomic variables, such as age, education, and experience, in this study included farmers with

an average age of 56 years, similar to characteristics found in other production systems in the Caribbean region (Martínez-Reina *et al.*, 2019; Martínez-Reina *et al.*, 2019). Results reported for cowpea beans in Nigeria showed that the average age of producers was 35 years, with a similar handling time of 15 years (Joshua *et al.*, 2019). On the other hand, 58% of the producers had up to basic primary schooling (Martínez-Reina *et al.*, 2019), while 78% of cowpea bean producers in Nigeria completed basic primary (Joshua *et al.*, 2019).

The average age of farmers was over 50 years, which can be a threat to the socioeconomic and technical sustainability of the cultivation of sweet chili. Some similar information was found by Orewa and Izekeor (2012) in the yam production system in Nigeria, who reported an average age of 59 years. In this same production system (yam), Martínez-Reina *et al.* (2021) found an average age of 57 years, indicating a general aging trend in agriculture.

There was a negative relationship between technical efficiency and the age of the farmers, which can be interpreted as being directly associated with the experience of the farmers; these results coincide with those of Tef in Ethiopia (Abate *et al.*, 2019). However, there are other studies that contradict the results, reporting a positive relationship with respect to the age of farmers and technical efficiency, that is, the older the farmer is, the less efficient the productive system is (Asravor *et al.*, 2016).

The behavior of the seed coefficient, which also presented a negative effect (-1.096501), had a t value of -2.9037160, suggesting a decrease in this factor would result in a decrease in yield, contrary to the findings of Wahid *et al.* (2017) in a study estimating the technical efficiency of tomato producers in Malakand, Pakistan, which showed that seedlings have a very significant effect on production with a coefficient of 1.02, meaning that increasing the number of seedlings by 1% there will increase production by 1.02%.

When analyzing the results of the yields and technical efficiency (0.81) in this study, it could be inferred that it is possible to improve the production system of sweet chili by intervening in factors such as seeds and fertilizers, as well as improving pest management, disease control and other agronomic practices that were not included in this study. Authors such as Wahid *et al.* (2017) and Abate *et al.* (2019) in studies on tomatoes in Pakistan and peppers in Ethiopia

respectively indicated that technical efficiency in the short term could increase by reducing the inputs used in production and using technically efficient practices.

The seed coefficient also presented a negative effect (-1.096501) and had a t value of -2.9037160, meaning a decrease in this factor would result in a decrease in yield, contrary to the findings of Wahid *et al.* (2017) in a study estimating the technical efficiency of tomato producers in Malakand, Pakistan that showed that seedlings have a very significant effect on production, registering a coefficient of 1.02, meaning that increasing the number of seedlings by 1% there will increase production by 1.02%.

For the fertilization variable, an increase in this variable decreases yields, as seen in studies carried out by Ismail (2010), who confirmed that excess fertilization and water deficits, among other factors, reflected a decline performance. However, production is not only related to soil fertility but also to a plant's genetics and relationships with the environment.

In this study, there were no economies of scale but there were increasing returns to scale explained by labor and weeds. The absence of returns on a decreasing scale was evidenced in empirical studies by Orewa and Izeke (2012). In this same study, yields on an increasing scale were seen, as reported in studies by Márquez *et al.* (2015), with a value of 0.81, Martínez-Reina *et al.* (2021), on the yam production system with a value of 0.9, and Rahman *et al.* (2012), on the cultivation of rice in Bangladesh (0.88).

The results of technical efficiency in the cultivation of sweet chili showed a very low technological gap, close to one (0.81), which corresponds to a difference of one ton. This situation is very similar to that found by Márquez *et al.* (2015) in the case of beans in the State of Portuguesa in Venezuela, with a similar technology gap.

CONCLUSION

There was rationality in the sweet chili farmers when assigning production factors, as reflected in the technological gap of 0.82, very close to the ideal of 1, because the real production was very close to potential production.

The direct relationship between labor inputs, weeds, and yields made the technological gap close to zero, meaning the work is efficient. An inverse relationship between seeds and fertilizer was evidenced, which indicates the underutilization of these production factors.

With the modal yields of 4.5 t ha⁻¹, it is possible to generate economic surpluses, in addition to the presence of yields on an increasing scale due to the positive relationship between the use of inputs and increases in production, a difference is also appreciated minimum between actual production and potential production.

Conflict of interests: The manuscript was prepared and reviewed with the participation of the authors, who declare that there exists no conflict of interest that puts at risk the validity of the results.

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