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Technical efficiency of pineapple production in Republic of Benin

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Assessing the technical efficiency of pineapple producers is essential to avoid waste of resources and above all to target advices for improving the productivity of the pineapple producers. For this, a survey was carried out among 365 randomly selected producers from five major pineapple-producing Communes. Using the meta-border stochastic production model, technical efficiency scores of pineapple producers are estimated. It is found that the average technical efficiency index of pineapple production is 55.92 and 70% of pineapple producers have a technical efficiency index less than 60%. This proves the poor control of pineapple production techniques in Benin and the need to reorganize pineapple production system.

Key words: Efficiency potential, meta-border stochastic production function, pineapple varieties, technical efficiency.

INTRODUCTION

As a coastal country of West Africa located between Nigeria and Togo, Benin is a country whose economy is essentially agricultural. However, despite the agricultural potential offered by its morphology, its exports have always been based on a single crop: the oil palm between 1960 and the late 70s and cotton since the early 80s. To reduce the hardships of the mono-export and get out from the dependence of its cotton economy, Benin opted for the diversification of its agriculture (MAEP, 2011). Pineapple is one of the crops promoted for diversifying sources of foreign exchange. This crop not only contributes to the share of the agriculture in national income, but it possesses a great potential and comparative advantage to compete in the liberalized economy (Tidjani- Serpos, 2004).

Since 1990, pineapple is the most important cash crop for Atlantic Department's farmers who produce more than 98% of the national production (Yabi, 2014; MAEP, 2010). Its production has grown by an average of 12.77% per year (FAOSTAT, 2014) due to the expansion of areas. Tidjani-Serpos (2004) shows that the more the pineapple farm increases, the more the producer has the chance to get out of poverty. Unfortunately, farmers cultivating less than one hectare cannot get out from this situation of poverty. Thus, the increase in the area of pineapples allows producers to ensure their food security and to get out of poverty temporarily.

Coming from South America, pineapple is an

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intertropical and herbaceous crop which belongs to Bromeliaces family with several species that present more or least riser adaptation to drought (N'Guessan, 1985). The pineapple genus includes several species but the more cultivated is *Ananas comosus* which has numerous varieties classified into five groups: Cayenne, Queen, Spanish, Abacaxi and Perolera. Smooth cayenne is the most cultivated over the world but sugar loaf is more cultivated than smooth cayenne in Benin (Arinloyé, 2013).

Pineapple is a crop whose reproduction is ensured by the discharges which are the growths that come out at the base of the fruit (bulbils) or from the plant stem (suckers) or on the fruit (crown). Only bulbils and suckers are used for plantations. When sugar loaf can produce 8 to 15 releases, smooth cayenne does produce 3 or 4. The pineapple cycle length depends on several factors like the release nature and weight, the harvest homogeneity, and the average temperature and altitude (IRFA, 1984; Agence Française de Coopération and CIRAD, 2002). Pineapple must be cultivated on well aerated and with sufficient drainage soils (N'Guessan, 1985; Agence Française de Coopération and CIRAD, 2002) without fin gravel and stone because its roots are frail and superficial. Pineapple is a demanding crop in water which can be limiting factor (Py and Tisseau, 1965) and in some mineral elements (nitrogen and potassium) which must be supplied to its repeated culture. Optimum temperature for its culture is between 22 and 32°C (N'Guessan, 1985; Agee Française de Coopération and CIRAD, 2002; Py and Tisseau, 1965; Adegnandjou, 2014).

All the different parts of the pineapple are used for different purposes. For example, the leaves, which are very rich in cellulose, are used as fuel and in textile industries (FIRCA, 2012). Pineapple fruit can be processed into pineapple powder and pineapple juice into liquor, vinegar and other alcoholic beverages. The leaves used as a source of energy (bio-fuel) in nanoscale research (Zinatloo-Ajabshir et al., 2018, 2019a, b) produced excellent results.

Pineapple is characterized by high price fluctuations. It is the third most important tropical fruit in the world after banana (*Musa* spp.) and Citrus spp. (FAOSTAT, 2015). Nowadays, pineapple crop is cultivated in all tropical regions. Brazil, Thailand, Philippines and Costa Rica productions are respectively 2,491,970 tons; 2,278,570 tons; 2,209,340 tons and 1,678,130 tons in 2008 (FAO, 2011). Although Benin national pineapple production is insignificant at world level, pineapple constitutes a great cash crop for many farmers in Atlantic department of Benin Republic. The need for manpower for its farming and the various possibilities of its process make pineapple a job-creating crop (Gnimadi, 2008) and it offers investment opportunities for SMEs in relation to the supply of inputs, fruit pineapple processing, logistics for distribution in the sub region and inland countries (ABC/SNV, 2016). But despite this dazzling production, the government still does not benefit enough because of international markets conquest and the informal nature of sub-regional trade (Anasside and Aïvodji, 2009) which brews nearly 80% of the pineapple produced in Benin (Biaou, 2018). In order to get more beneficial from pineapple production, and in view of scarcity of resources, globalization of economies marked by competition between nations, the lack of technical support to producers and this new sector introduced in the producer farming system since the end of the 80s; it appears necessary to do the technical Efficiency Analysis of Pineapple Production in Republic of Benin.

Technical efficiency, which refers to certain microeconomic concepts (Farrell, 1957; Rainelli and Piot-Lepetit, 1996), is intended to judge the capacity of a production system to produce at best, through the implementation of all means of production (working capital, land and labor) (Borodak, 2005; Coelli et al., 1998). It measures the gap between the maximum achievable production and the level of production observed taking into account the technology used and inputs consumed (Rainelli and Piot-Lepetit, 1996; Issaka, 2002). The production function that describes the minimum amount of inputs required to produce maximum outputs is called the frontier production function (N'Gbo, 1991; El Arbi Chaffai, 1991; Blancard and Boussemart, 2006). Enterprises whose production level places them on the border are fully efficient in the use of resources (Battese and Coelli, 1992; N'Gbo, 1991).

Commonly, the technical efficiency is often determined using one of those two general approaches: the parametric approach and the non-parametric approach. However, the parametric approach is more used than nonparametric one for various reasons (Amara and Romain 2000; Coelli et al., 1998; Charnes et al., 1978). Parametric methods are based on the specification of a production function whose parameters are estimated by econometric tools. They include the deterministic parametric approach and the stochastic parametric approach (N'Gbo, 1991; Borodak, 2005). The stochastic approach allows the estimation of terms and the hypothesis tests allows the choice of the most suitable functional form (Coelli et al., 1998; Fontan, 2008).

However, as for any production system, not all enterprises are on the border, the analysis of agricultural production efficiency makes it possible to locate the system, to gauge the level of efficiency of the system and to target capacity building to be provided to producers. To satisfy the need to measure the level of efficiency of pineapple producers in Benin, this study is carried out. Because of its strengths and weaknesses the stochastic approach is used. Our target objectives in the present paper are to analyze the level of technical efficiency of pineapple production in Benin. Indeed, to maintain itself

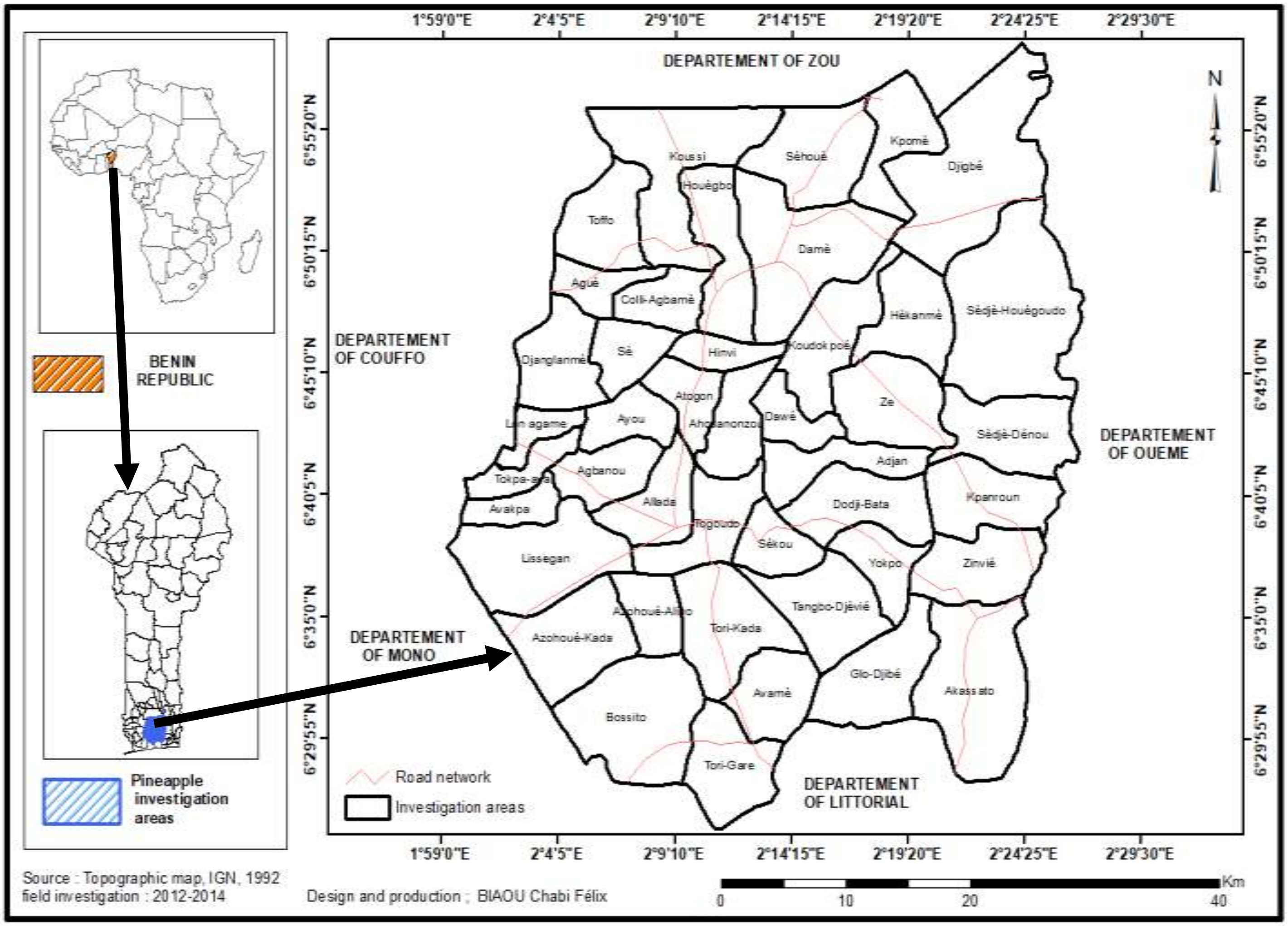

Figure 1. Study area in Benin.

sustainably in this new value chain, Benin must be among the countries with the highest productivity of this crop, despite the boom observed in Latin American and Asian countries (Loeillet, 2015) and climate change that have negative impacts on its production (Houssou et al*.,* 2014).

MATERIALS AND METHODS

Data collection

Study area

This research is conducted in the Atlantic Department, which produces the most 98**%** (MAEP, 2010) of pineapple in Benin. It is densely populated area close to major urban centers of the country, Cotonou, Porto-Novo, Abomey-Calavi, etc. Its estimated population of more than 800 000 inhabitants (INSAE, 2013), is distributed in 8 communities, of which five are the main of pineapple producers (Figure 1).

Sampling methods

Ten producers were randomly selected from the 40 villages selected in the five pineapple producing Communities of the Department. The Community and the village are the two strata we considered. The selected villages were distributed among the Communities in proportion to the number of pineapple producing villages in the Department, and the villages to be surveyed in each Community are determined according to the weight of the area of the pineapple of the village in that of the Community. Of the 400 targeted producers, 365 responded to our interview.

Techniques and data collection tools

The data were collected through individual interview using a

Table 1. Fertilizers supplied and their fractionation to pineapple.

Fertilizer and their fractionation	Modalities
Fertilizer (TYPENGR)	
All the three types of fertilizers	1
Otherwise	0
Fractionation of fertilizers	
All fertilizers supplied two times	0
Each fertilizer supplied more than one time	1 otherwise 0
All fertilizers supplied more than three times	1 otherwise 0

Source: Designed by the author (2015).

questionnaire. They covered the areas and quantities harvested and sold, the quantities of inputs used per hectare (fertilizer, carbide, seeds), the sex of the producer, his age, the labor used per hectare per farming operation, the costs of renting the land and labor, the equipment and materials used, their costs and lifetimes, equipment rental costs, etc.

Analytical methods

Theoretical model

The equation of the stochastic production frontier is defined by:

$$\ln(y_i) = X_i\beta + v_i - u_i \quad (1)$$

with i=1,2,…., N and where X_i denotes the matrix of n columns of the factors of production; B is the parameters to be estimated; Y_i is the dependent variable. v_i is a random component that is distributed on both sides of the production boundary. It measures the error of random factors such as climatic hazards and the combined effects of other variables not specified in the model. It follows a normal distribution of variance σ_v^2 and mean 0 and, u_i A component representing technical inefficiency that is distributed only on one side of the boundary and is a positive random variable of mean μ and variance σ_u^2.

The likelihood function is expressed in terms of the total variance of the composite error $\sigma_s^2 = \sigma_v^2 + \sigma_u^2$ and the share of the variance of u_i in the total variance is $\gamma = \sigma_u^2 / \sigma_s^2$ with $0 \leq \gamma \leq 1$ represents the relative share of the variance explained by the technical inefficiency. Thus, the closer the value of γ is to 1, the more this gap is mainly attributed to the inefficiency of the actors, and thus the smaller the effects of the random variables are reduced (the model would then be deterministic). This indicator has a key role to justify the statistical coherence of the model.

The improvement of the model resulted in the stochastic functions of inclusive frontier production functions developed by Battese and Coelli (1992). This method not only measures efficiency indices to determine the most efficient production points, but also assesses and compares technological differences between companies and regions (Nyemeck and Nkamleu, 2006; Singbo, 2007). The aggregate production function for all pineapple farms and for each identified production system is identical to Equation 1 but the size of each subgroup is such that:

$$N = \sum_{k=1}^{K} N_k \quad (2)$$

where N_k is the number of operators in each identified production subsystem

The β* coefficients estimated for each subgroup are such that

$$X_i\beta^* \geq X_i\beta \quad (3)$$

Empirical models

The stochastic production function was estimated for all producers and for smooth cayenne and sugarloaf by introducing dumb variables in the stochastic function of frontier production and for both functional shapes Cobb-Douglas and Translog (Mohamed et al., 2008; Coelli et al., 1998). The variables used are:

(i) the quantities per hectare of pineapple production (proanha) in kg,
(ii) the quantity of fertilizer applied (qengha) in kg;
(iii) the quantity of labor required in hj (qmoha),
(iv) the number of seeds or plants (qrejha),
(v) the quantity of floral induction product (qpif) in kg
(vi) depreciation of capital (ameq).

The dummy variables of the model relate to the types of fertilizer input and their fractionation and are defined in Table 1. Thus the two models Cobb-Douglas and Tranlog are written as follows:

Douglas Cobb Model

$$\mathrm{Ln}(Y_{mi}) = \beta_0 + \beta_{m1}\mathrm{Ln}(QAna_i) + \beta_{m2}\mathrm{Ln}(QMOC_i) + \beta_{m3}QMOP_i) + \beta_{4m}\mathrm{Ln}(qBout_i) + \beta_{m5}\mathrm{Ln}(qeau_i) + \beta_{m6}\mathrm{Ln}(CENIE_i) + +\beta_{m7}\mathrm{Ln}(Amort_i) + v_i - u_i$$

Translog model

$$\ln(proanha) = \beta_0 + \beta_1\ln(qengha) + \beta_2\ln(qmoha) + \beta_3\ln(qpif) + \beta_4\ln(ameq) + \beta_5\ln(qrejha) + 0,5\begin{bmatrix} \beta_6(qenha)^2 + \beta_7\ln(qmoha)^2 + \beta_8\ln(qpif)^2 + \beta_9\ln(ameq)^2 + \beta_{10}\ln(qrejha)^2 + \\ \beta_{11}\ln(qengha)*\ln(qmoha) + \beta_{12}\ln(qengha)*\ln(qpif) + \beta_{13}\ln(qengha)*\ln(qameq) \\ \beta_{14}\ln(qengha)*\ln(qrejha) + \beta_{15}\ln(qmoha)*\ln(qpif) + \beta_{16}\ln(qmoha)*\ln(ameq) + \\ \beta_{17}\ln(qmoha)*\ln(qrejha) + \beta_{18}\ln(qpif)*\ln(ameq) + \beta_{19}\ln(qpif)*\ln(qrejha) \\ +\beta_{20}\ln(ameq)*\ln(qrejha) \end{bmatrix} \beta_{21}typengr + \beta_{22}(1engp3f) + \beta_{23}(engp3f) + v_i - u_i \quad (4)$$

Table 2. Results of Cobb Douglas model.

Variable	Coefficients	Smooth Cayenne	Sugar loaf	Together
Constance	β_0	13.865*** (0.974)	13.884*** (1.569)	14.080*** (0.99)
Quantity of fertilizer	β_1	0.0761 (0.224)	0.079* (0.057)	0.061 (0.049)
Labor	β_2	-0.008 (0.256)	-0.292***(0.125)	-0.296*** (0.092)
PIF	β_3	-0.067*** (0.016)	-0.0324 (0.0555)	-0.004 (0.429)
Capital	β_4	0.008*** (0.003)	-0.0009 (0.011)	-0.002 (0.007)
Density	β_5	-0.2874 (0.2385)	-0.1335 (0.1267)	-0.155** (0.091)
Fertilizer supplied				
Two types of fertilizers		-	-	-
three types of fertilizers	β_6	0.0236 (0.2222)	0.038 (0.0849)	0.057 (0.055)
Fertilizer fractionation				
Fertilizer supplied two times		-	-	-
One of the fertilizers supplied more than three times	β_7	-0.026 (0.0311)	0.0512 (0.0965)	0.004 (0.057)
Fertilizers supplied more than three times	β_8	0.0481 (0.0517)	-0.0236 (0.0536)	-0.026 (0.037)
Efficiency parameters				
Sigma squared		0.260*** (0.055)	1.73*** (0.1408)	5.970*** (1.269)
Gamma	γ	0.999*** ($0.929.10^{-7}$)	0.9933*** (0.003)	0.9951*** (0.002)
LR		34.8602	203.372	405.764
Mean of technical efficiency (%)		73.509	48.135	59.362

* ;** and *** significant respectively at 10 ; 5 and1%. ( ) standard Error.
Source: Survey data (2013).

Based on the statistical tests of χ^2 and the likelihood ratio, the model that best meets the different pineapple production systems has been validated (Appendices 1 and 2).

RESULTS AND DISCUSSION

The results of the Cobb-Douglas and Translog functional forms (Table 2 and Appendix Table 1) show that the gamma values are highly significant at the 1% threshold for groups of producers. They are statistically different from zero at the 1% threshold and very close to 1 meaning that the technical inefficiency of pineapple production exists and it depends more on producers than on random effects.

Interpretations of the coefficients of the model

With the Cobb-Douglas model, the coefficients of the estimated parameters directly give the elasticities. As regards to fertilizers, the elasticities are positive and significant everywhere only at the level of sugar loaf producers at the 10% threshold. Therefore, an increase in the fertilizer dose of 1% increases the sugar loaf production by 0.079%. Thus, the input of fertilizers is still beneficial to the cultivation of pineapples, but this contribution by mimicry means that the applied doses vary greatly and the coefficients are insignificant for the most part. In relation to the labour force the elasticities are negative and significant everywhere at the level of sugar loaf producers and for the whole. Consequently, an increase in the labour force of 1% reduces pineapple production by 0.296% and sugar loaf production by 0.292% respectively (Table 2). These results are in line with those of Fontan (2008) for the permanent labour of rice farmers in Guinea. The negative sign of the elasticities of the labour force is explained by several reasons: the agricultural tools used do not allow to time the work actually carried out and the repetitive operations poorly executed (Weeding, spreading of fertilisers) not significantly increase production. The multi-activity of the operators does not determine the actual time spent to carry out each activity. This makes it impossible to accurately determine labour productivity. Only mechanization will help to determine the productivity of agricultural labour.The yield elasticities relative to the PIF (floral induction product) are everywhere negative but significant only for the producers of smooth Cayenne. Thus an increase in the dose of PIF by 1% would reduce the production of smooth Cayenne by 0.067% (Table 2). The PIF participates in the yield thus to the productivity through the number of feet having carried flowers after the treatment of the plants. The more flowering plants there are, the more fruit there is, and the higher the yield

Table 3. Maximum, mean and minimum technical efficiencies according to the cultivated varieties and for the whole (%).

	Smooth Cayenne	Sugar loaf	Together
Mean	73.509	48.135	55.922
Standard deviation	24.392	23.195	24.682
Minimum	15.448	13.023	14.689
Maximum	0.99984	96.134	96.253

Source: Survey data (2013).

will be. The negative sign would mean that the applied dose does not allow for sufficient flowering foot rates for good yield; either the period of application of the PIF does not allow for a sufficient flowering foot rate or the quality of the product used is not the best to allow for a sufficient number of flowering feet. Since the product used is calcium carbide used in other sectors, a study to specify the appropriate quality for the floral induction of pineapple is necessary The elasticities of production with respect to capital are positive and significant for smooth Cayenne producers but not significant everywhere else. These negative elasticities are explained by the unnecessary holding of certain equipment in kind and in number, which are sometimes used only for cultivation operations and are not used for the provision of services to be remunerated.

The yield elasticities in relation to crop density are everywhere negative and significant only at the overall level (Table 2); thus, the higher the density the lesser the production. Pineapple production is at densities ranging from about 10,000 to 90,000 plants per hectare and fertilizer inputs should be based on these densities. The lack of a framework means that producers imitate each other and the applied fertilizer doses not comply with the standard. As the producer seeks to save money, the amount of fertilizer per plant decreases with density; so the higher the density, the less fertilizer, and the lower the yield. Thus the insufficient amount of applied fertilizers explains the productions which are negatively proportional to the densities.

The intake of three types of fertilizer has positive signs everywhere but they are not significant. This indicates that the three types of fertilizer are better than the intake of the two types of fertilizer, but the application periods, the applied doses and even the nature of these fertilisers do not allow a significant increase in production compared to those, which provide only two types of fertilizer. The effect of fertilizer fractionation is variously appreciated. While the intake of one fertilizer more than three times has a positive sign for the production of sugar loaf and for the whole, it is the intake of all fertilizers more than three times that is better for smooth Cayenne. In short, fertilizer doses can be increased, but their fractionation will not benefit plants unless they respect the application periods.

Extension and research implications

These results show that the agricultural amateurism and the lack of supervision of pineapple producers and the implications concern both research and extension. Input doses vary from one producer to another and the standards prescribed for these doses are not respected (Biaou, 2018). Sometimes the quality of some of the inputs used is inappropriate. Pineapple growers need to be made aware and advised that input rates depend on crop densities. Extension and monitoring of farmers can ensure that the standards for the rates of various inputs are met. Extension will need to work in symbiosis with research to address the various problems of this crop. Extension workers will need to specialize in this crop in order to detect the slightest flaws in the fields and propose corrective measures.

Since 1990, the first introduced cultivars have been grown using self-supply of rejects. Not only must these cultivars be renewed for both varieties, but new ones must be developed that can be larger, juicier, and highly productive. These new varieties should be able to force the producer to buy the seedlings after one or two self-supplies. In addition, it must examine the quality of calcium carbide suitable for the floral induction treatment in order to increase the rate of flower-bearing plants after this operation. Indeed, some producers respect the technical itinerary of pineapple cultivation, but the quality of the floral induction product reduces the rate of flower-bearing plants to 60 or 70% instead of 95 to 100%.

Analysis of technical efficiencies

The results show that there are high-performing producers because they are very close to the production frontier as well as technically poor producers. Technical efficiencies vary from one producer to another and from one subgroup of producers to another between 13.023 and 99.984% (Table 3). The average technical efficiency is 55.922% for overall, 73.509% for smooth cayenne producers and

Table 4. Potentialities of Increasing level of technical efficiencies according to producers.

Producer	Smooth Cayenne	Sugar loaf	Together
The least	84.549	86.453	84.739
Average	26.480	49.929	41.901

Source: Survey data (2013).

48.135%for sugarloaf producers. This average technical efficiency index of pineapple producers is below that of cotton producers where Midingoyi (2008) found an average technical efficiency index of 71.16% and those of rice farmers in Benin center for whom Singbo (2007) finds a technical efficiency index of 85.8%. Savi (2009) found that *crincrin* producers have a technical average efficiency index of 66.4% and Houndétondji (2013) found an average technical efficiency index of 81% for maize producers in the municipality of Zogbodomè (Benin). This indicator of the effectiveness of pineapple producers is due to several factors such as the ageing of cultivars, poor management of producers and unavailability of inputs on time.

In fact, with the exception of the first time they produced pineapple, beninese pineapple producers are self-sufficient to produce rejections especially sugarloaf which supply them enough. This practice, which has been going on since the 90's, has finally aged the cultivars of this plant. Furthermore, the non-fully liberalized agricultural input distribution system in Benin penalizes areas where farmers are unorganized and they do not benefit from state subsidies. Thus, these average indices of pineapple producers show the need to change pineapple cultivars, to make available inputs, to supervise and to follow farmers who are mainly illiterate.

According to the average efficiencies, smooth cayenne producers are more effective than those producing sugarloaf. The efficiency of sugarloaf producers varies between 13.023% and 96.134%. Certainly there are successful producers but this proves that the production technique is not mastered, because this variety is more rustic compared to the smooth cayenne. This result indirectly reveals the poor organization of producers and the dysfunction of their management where only 10% of producers are monitored (Biaou*,* 2018).

Despite the fragility of smooth cayenne, the producers of this variety are more technically efficient than the producers of the sugarloaf variety. Indeed, knowing that they produce a very sensitive variety and for export, they put theirs and respect relatively its requirements. Moreover, producers who deliver to exporters are monitored by their technicians and thus improve their production technique. The few small producers who still cultivate it are meet mainly in the municipality of Toffo where their organization allows correcting the technical shortcomings of their members.

Potentials not yet exploited

These results demonstrate that the technical efficiency scores of pineapple producers could be increased under the same conditions of production. Compared with the whole and overall under the same conditions of use of inputs, the least technically efficient producer could increase its efficiency by 84.739% (1- (14.689 / 96.253)) to reach the efficiency level of the most efficient producer when the average producer will only have to increase it by 41.901% (Table 4). By considering the subgroups, the producer of smooth cayenne the least technically efficient must increase its efficiency by more than 84.549% to reach the level of efficiency of the most efficient producer while the average producer of this variety must increase it by 26.48% (Table 4). Thus, under the current conditions of factor use, it is possible to increase the efficiency of the pineapple producers of 41.90% on average by reinforcing the supervision, the support of the producers on the technical itineraries and the fertilizer inputs and splits.

Distribution of producers according to their efficiency levels

Smooth cayenne producers have right-handed distribution, and more than 30% producers of this variety have an efficiency index greater than 90% (Figure 2). That of sugar loaf producers is bimodal with the first peak reached with more than 22% of producers in the interval [30 40[% and the second peak in the range (80 and 90%) with almost 13% of producers. More than 59% of producers of this variety have a technical efficiency index less than 60%. The distribution of all producers according to the technical efficiency indices has a bimodal appearance. The first peak in the range (30 and 40%) with more than 18% of producers and the second peak in the range (80 and 90%) with more than 13% of producers. Thus, nearly 70% of pineapple producers have a technical efficiency index less than 60%. Overall,

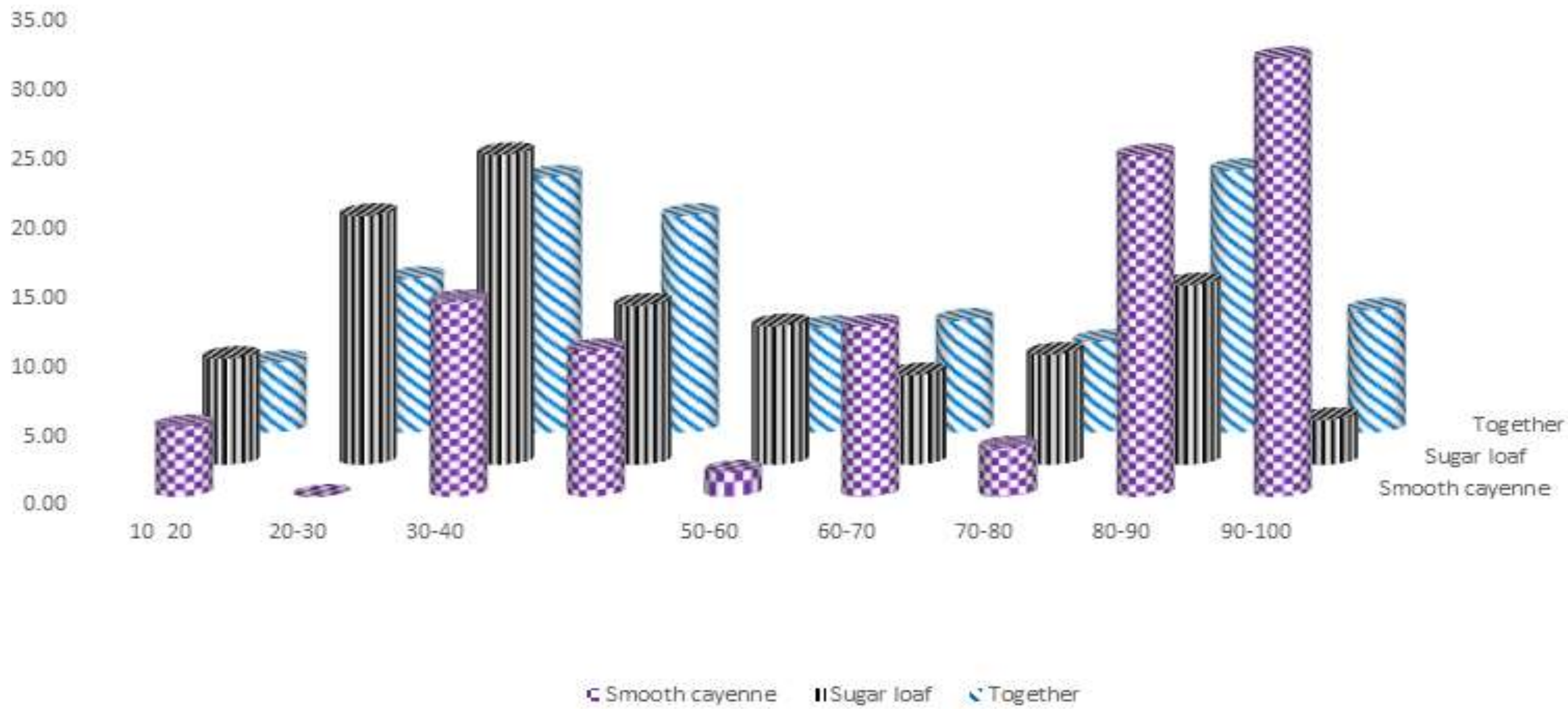

Figure 2. Distribution of pineapple producers according to their technical efficiency index and cultivated varieties.
Source: Survey data (2013).

all Beninese pineapple producers deserve capacity building to boost the production of this fruit.

Conclusion

This study shows the lack of extension workers who might follow advice of pineapple producers to increase their productivities for many factors. The low yields, negative elasticities in relation to fertilizers and their fractioning, to the floral induction treatment are a reflection of this absence. The technical efficiency levels of pineapple producers vary widely with an average of 55.922%.

Producers of smooth cayenne are technically more effective (73.509%) than those of sugarloaf (48.135%), although the latter variety is more rustic. More than 52% have an efficiency score of less than 52.5%, indicating poor mastery of production techniques by most producers and the existence of potential productivity gains with the current level of resource use.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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APPENDICES

Appendix 1. Trans log meta-border production model results.

Variables	Smooth Cayenne	Sugar loaf	Together
Constance	33.241*** (0.995)	12.074 (69.531)	58.682*** (1.00)
Fertilizer quantity	-50.143*** (0.929)	-3.1557 (4.4074)	-4.559*** (0.921)
Labor	-40.733*** (0.954)	1.1888 (10.3837)	-8.13*** (0.973)
Floral induction Product (FIP)	27.381*** (0.982)	1.7779 (3.2527)	-3.124** (1.372)
Capital	16.955***(0.836)	0.2052 (1.7873)	0.3818 (0.7593)
Density	26.551*** (0.838)	0.8905 (7.7473)	-2.516*** (0.813)
$[\ln(\text{Fertilizer})]^2$	-1.731*** (0.653)	-0.1535 (0.2237)	-0.1722 (0.1514)
$[\ln(\text{Labor})]^2$	-8.969*** (0.756)	-1.0005 (0.7864)	-0.7965 (0.6634)
$[\ln(\text{FIP})]^2$	0.3499 (0.388)	0.2523 (0.1566)	-0.182**(0.105)
$[\ln(\text{Capital})]^2$	0.110*** (0.028)	0.0012 (0.0085)	0.008* (0.006)
$[\ln(\text{density})]^2$	-8.071*** (0.368)	-4584 (0.4604)	-0.55*** (0.217)
Ln(Fertilizer)Ln(Labor)	1.352** (0.853)	0.3081 (0.4917)	0.4651 (0.3908)
Ln (Fertilizer)Ln(FIP)	0.071 (0.8129)	0.3661 (0.2194)	0.229* (0.169)
Ln (Fertilizer)Ln(Capital)	0.2918 (0.3233)	-0.0525 (0.064)	-0505 (0.0415)
Ln(Fertilizer)Ln(density)	10.469*** (0.773)	0.5689 (0.7853)	0.800*** (0.255)
Ln(labor)Ln(Ln (FIP)	-0.9091 (0.9032)	-0.5765 (0.4482)	-0531** (0.309)
Ln(Labor)Ln (Capital)	-0.2273 (0.5992)	-0.0153 (0.165)	-0.0541 (0.1065)
Ln(labor)Ln(density)	16.466*** (0.796)	0.7331 (1.7316)	2.153*** (0.681)
Ln(FIP)Ln(Capital)	-0.602*** (0.243)	-0.0364 (0.0421)	-0.054* (0.041)
Ln(FIP)LN(density)	-4.242*** (0.556)	-0.0946 (0.541)	-0.296 (0.264)
ln(Capital)Ln(density)	-3.221*** (0.398)	0.0096 (0.2677)	-0.0076 (0.1105)
Fertilizer supplied			
Two types of fertilizers			
Three types of fertilizers	0.0222 (0.1904)	0.075 (0.0907)	0.125** (0.069)
Fertilizer fractionation			
All fertilizer no more than two times			
On fertilizer, more than three times	-0.1143 (0.1481)	0.0981 (0.1019)	0.0304 (0.0759)
All fertilizers more than three times	-0.1338 (0.1746)	0.0101 (0.0644)	-0.0122(0.0574)
Efficiencies parameters			
Sigma squared	0.201*** (0.042)	1.682*** (0.145)	5.970*** (1.269)
Gamma	01*** (256.10^{-9})	0.9934*** (0.004)	**0.9951***** (0.002)
Mean of technical efficiencies	74.022	49.016	59.362

Source: Survey data (2013).
( ) Erreur standard Error; *; ** ; *** significant respectively at 10, 5 and 1%.

Appendix 2. Tests of the choice of the appropriate model

To choose the functional form in adequacy with the data thus collected, the LR test proposed by Coelli et al (1998) which follows the Khi 2 law with one degree of freedom was used (Table 1). Thus, the two functional forms Cobb-Douglas and Translog are well suited to the types of producers considered.

Table 1. LR test for both Cobb Douglas and Translog functional forms.

Producers subgroups	Cobb Douglas	Translog
	LR	LR
Together (meta frontier)	404.98	411.066
Smooth Cayenne	40.116	35,092
Sugar loaf	208.738	207,230

Source: Survey data, 2013; $\chi^2(1.5\%) = 2.71$.

To choose the most suitable functional form, the assumption that the second-degree coefficients of the Translog form are zero was tested. The final values of the likelihood function given directly by the model are used for this purpose and the LRG ratio is determined. So the test is as follows:

H0: β_ij = 0 against H1: β_ij ≠ 0

This test is based on the following statistic:

LRG = -2 {ln [L (H0) / L (H1)]} = -2 {ln [L (H0)] - ln [L (H1)]}, where

L (H0) and L (H1) correspond to the likelihood functions for the hypotheses H0 and H1 and therefore represent the values of the respective likelihood ratios of the Cobb-Douglas and Translog functions. This statistic follows a mixed Chi-square law whose number of degrees of freedom is equivalent to the number of restrictions imposed. Thus, H0 is accepted means that the coefficients are zero, so the Cobb-Douglas form function is the most suitable. H0 will then be rejected if LRG> χ^2 (n; 0.05) and n, being the degree of freedom.

From the results in Table 2, H0 is accepted. Thus the β_{ij} coefficients are statistically zero and the Cobb-Douglas model responds best for determining the technical efficiency of pineapple production for all producer groups (Table 2).

Table 2. Test for the choice of the most suitable model.

Log likelihood function	Varieties		Together
	Smooth Cayenne	Sugar loaf	
Of Cobb Douglas model (LR_C)	-9.371	-357.873	-317.731
Of translog model (LR_T)	-3.465	-352.859	-305.299
Generalized LR $LR_G = -2(LR_C - LR_T)$	11.8118	10.027	24.864
Degree of freedom	15	15	15
Decision	H_0 accepted	H_0 accepted	H_0 accepted

Source: Survey data, 2013. χ^2 (15.5%) =25.