Fatima LAMBARRAA-LEHNHARDT*, Sandra UTHES*, Peter ZANDER* and Ahmed BENHAMMOU**

How improving the technical efficiency of Moroccan saffron farms can contribute to sustainable agriculture in the Anti-Atlas region

The saffron sector as a sustainable farming system plays a primordial agro-ecological and socio-economic role in the Anti-Atlas region in Morocco. Under the Green Morocco Policy, the saffron area has more than tripled; however, productivity is still very low. To evaluate the efficiency of Moroccan saffron farming and its determinants, we estimated a stochastic frontier model using survey data collected in the production area. The results show that saffron farms suffer from technical inefficiencies. More time dedicated to saffron field operations, a higher number of saffron plots and a greater distance to the urban centre increase farm efficiency, while the age of the farmer and the presence of off-farm activities decrease it. Building on our results, we argue that the new policy "Generation Green" should be focused on younger farmers as they are more likely to improve their skills and crop management techniques. To upscale the adoption of saffron as a sustainable farming system, an improvement in farmers' market access is necessary which would facilitate farm specialisation, convert saffron to a major source of income and reduce dependence on off-farm activities. Strengthening the role of saffron cooperatives could represent an important step in this direction, but this requires improved knowledge dissemination and technology access.

Keywords: saffron farms, sustainable agriculture, stochastic frontier model, technical efficiency, Anti-Atlas Mountains

JEL classification: Q12

* Farm Economics and Ecosystem Services Group, Leibniz Centre for Agricultural Landscape Research (ZALF), Eberswalder Str. 84, 15374 Müncheberg, Germany. Corresponding author: fatima.lehnhardt@zalf.de.

** International Labour Organization, Geneva, Switzerland.

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Introduction

The saffron crop (*Crocus sativus*) is traditionally grown in low input farming systems, and is characterised by specific agronomical and biological traits, such as low fertiliser requirements and high adaptation to poor soils (Gresta *et al.,* 2008). The cultivation of saffron in Morocco has increased considerably over the past few years. According to the Moroccan Ministry of Agriculture, the cultivated saffron area increased and reached 1,826 hectares in 2019 (MAPM, 2022), making Morocco the world's fourth-largest producer of saffron. Saffron production in Morocco is concentrated in the regions of Taliouine and Taznakht, which are located in the mountainous provinces of Ouarzazate and Taroudant in the Anti-Atlas mountain area. The climate of this area is continental, semi-arid to arid with low rainfall (220 mm to 300 mm) and temperature variation from -1°C in winter to +40°C in summer. The predominant soil types are light, shallow soils that are rich in limestone.

Farmers practice subsistence agriculture based on diversified farming systems with cereal production (barley, durum wheat and soft wheat), saffron cultivation and market gardening. As an endemic species in Morocco, the saffron crop is highly adapted to the pedoclimatic conditions of the region, and requires no specific phytosanitary measures, chemical fertilisation, or chemical weed treatments. These features highlight the fact that saffron plays an important agro-ecological role in preserving local biodiversity. The main field operations of this type of farming are carried out manually (particularly harvesting), a factor which contributes to the high price of saffron and hence increases the land value in the Anti-Atlas region. Women play a crucial role in saffron production, a situation that possibly contributes to rural women's empowerment. As a labour-intensive crop, saffron production demands around 258,000 working days per year (MAPM, 2022), thereby contributing to the alleviation of poverty and inequality in the region, while at the same time promoting local and socio-economic development.

Furthermore, the saffron sector plays an important cultural role which goes beyond agricultural production, extending to tourism and gastronomic activities, as well as social and cultural events. The Moroccan government has recognised these distinctive features that characterise the saffron sector and has introduced specific regulations along with support measures bundled together within the framework of the Green Morocco Policy (GMP), which include the creation of a new Protected Designation of Origin (PDO) Saffron of Taliouine quality scheme in 2010 with a view to supporting the saffron production system and the economy of the saffron territory. Since then, the saffron area has more than tripled in only 10 years, now exceeding the target set in the agricultural strategy by 35%. The current Moroccan annual average production has reached 6.5 tons, of which 1.2 tons are exported, mainly to Spain and Switzerland (MAPM, 2022). However, Morocco's productivity is still very low if it is compared to other countries, with yields of approximately 3.5 kg/ha compared to, for example, 8.4 kg/ha in Italy (MAPM, 2022; Kothari *et al.,* 2021). This low output implies that there is considerable unexploited potential to improve the productivity of the saffron sector in Morocco. It also raises the question of how to sustainably intensify production without compromising agroecological benefits.

Although there is a large body of literature dealing with productivity and technical efficiency analysis, the causes of the low saffron productivity, and thus potential entry points for its improvement, are still insufficiently studied. Recent studies have examined farm efficiency mostly in the context of developing countries, and have linked it to sustainable farming, climate change and precision agriculture (Adetoyinbo and Otter, 2022; Carrer *et al.,* 2022; Endalew *et al.,* 2022; Shahbaz *et al.,* 2022). However, most of the studies on the saffron crop have focused on plant physiology and biology (e.g. Abu-Izneid *el al.,* 2022; El Midaoui *et al.,* 2022; Rather *et al.,* 2022). A recent study examined the influence of dense planting on the technical efficiency of saffron production in Iran using data envelopment analysis (Ramezani *et al.,* 2022). Studies on Moroccan saffron have meanwhile tended to analyse crop cultivation techniques primarily from an agronomic point of view, or in terms of farm strategies for adapting to climate change (e.g. Aziz and Sadok, 2015; Lage, 2009). A recently published study carried out a strategic analysis of the Moroccan saffron sector and investigated marketing prospects as well as the perceptions of Moroccan consumers and their willingness to pay for this product (Lambarraa-Lehnhardt and Lmouden, 2022).

No previous studies have examined the technical efficiency of Moroccan saffron farms and its different determinants; this is therefore the main objective of the current study. As specific objectives, we estimate the technical efficiency of the main regions of saffron production in Morocco and analyse the impact of various farm and socioeconomic factors. Results from the analysis are expected to provide valuable insights into the causes of low saffron productivity in Morocco which could help policy makers designing policies aiming at the improvement of Moroccan saffron productivity and its upscaling as a sustainable farming system in the climatic and edaphic conditions of the Anti-Atlas area.

Methodology

Technical efficiency is defined as the capacity of an economic unit to produce the maximum attainable output from a given set of inputs and technology. Farrell (1957) provided a standard reference, enabling comparison of the efficiency of multiple firms using the concept of the frontier. According to the author, the measurement of firm efficiency is based on the comparison of a firm's performance with other similar firms belonging to the same sector, while the best ones define this frontier.

To apply this concept to saffron farms, we chose to build on the stochastic frontier model (SFM), which was originally introduced by Aigner *et al.* (1977) and Meeusen and van den Broeck (1977). SFM seeks to address the shortcomings of deterministic approaches (e.g. Data Envelopment Analysis, DEA) by distinguishing between exogenous shocks outside the farm's control, and inefficiency. The model assumes that, for a given combination of inputs, the maximum attainable production by a firm is delimited from above by a parametric function of known inputs involving unknown parameters and a measurement error. Based on this, a stochastic frontier production model can be expressed as follows:

$$y_i = f(x_i, \beta)e^{v_i - u_i} \tag{1}$$

where y_i is the output of the i-th firm (i=1,…,N), $f(x_i, \beta)$ represents the production technology, x_i is a $(1\times k)$ vector of inputs and other factors influencing production associated with the i-th firm β is a $(1\times k)$ vector of unknown parameters to be estimated. The disturbance term is composed of two parts: v_i is a symmetric component, which permits random variations of the frontier across firms and captures the effects of statistical noise outside the firm's control, is assumed to be normally distributed with the error term $N(0, \sigma_v^2)$, (i.e., statistical noise), and the term of inefficiency u_i is an independently and identically distributed one-sided random error term representing the stochastic shortfall of the i-th farm output from its production frontier due to the existence of technical inefficiency $N^+(0, \sigma_u^2)$ (i.e., farm-specific output-oriented technical inefficiency). It is further assumed that the two error terms are independently distributed from each other.

The specification that we are going to adopt is the model proposed by Battese and Coelli (1995), where technical efficiency is explained by specific factors. Thus, the term of technical inefficiency responds to the following pattern of behaviour:

$$u_i = \delta z_i + \eta_i \tag{2}$$

δ is an $(1\times m)$ vector of unknown coefficients of the firm-specific inefficiency variables. η_i random variable defined by the truncation of the normal distribution with zero mean and variance σ^2, such that the point of truncation is $-z_i\delta$. The explanatory variables z_i is a $(m\times 1)$ vector of firm-specific variables.

Maximum likelihood techniques are used for a simultaneous estimation of the stochastic frontier and the technical inefficiency model. This model is widely implemented using panel data and some studies exploited the nature of such data by assessing the dynamic technical efficiency of the farm (e.g. Lambarraa *et al.,* 2016; Tsionas *el al.,* 2019).

Technical efficiency is then used to predict conditional expectation, which allows calculating the individual efficiency of each producer. Then, the Technical efficiency (TE) ratio of the i-th producer firm is defined by equation (3):

$$TE_i = \frac{y_i}{f(x_i,\beta)} = \frac{f(x_i,\beta)e^{-u_i}}{f(x_i,\beta)} = e^{-u_i} \tag{3}$$

This ratio measures the proportion of actual production (output) to the maximum potential production if the farm used their resources efficiently. Finally, we used the generalised likelihood-ratio statistic to test several hypotheses related to the model:

- First, the functional form must accurately describe the production technology: if $\beta_{ij} = 0$ then the Cobb-Douglass is the convenient functional form for the model.
- Second, if $\delta = 0$ technical inefficiency effects are non-stochastic and the model (1) reduces to the average response function in which the explanatory variables in the technical inefficiency model are also included in the production function.
- Third, if $\sum_{ij} \beta_{ij} = 1$, then we have a constant return to scale.

The test statistic is calculated using this equation: $\lambda = -2\{ln\, L(H_0) - ln\, L(H_1)\}$, where $L(H_0)$ and $L(H_1)$ denote the values of the likelihood function under the null

(H_0) and the alternative (H_1) hypothesis, respectively. The LR has an asymptotic Chi-square distribution with degrees of freedom equal to the number of restrictions on the parameters if the null hypothesis is true (Coelli, 1995; Kodde and Palm, 1986).

Data collection

The database used in this study is based on a field survey on technical and socio-economic information conducted in 2018 among Moroccan saffron farmers (n = 125) in the regions of Taliouine and Taznakht (administrative district of Ouarzazate), which represent 95 % of the national farmers producing saffron. The data were collected in face-to-face interviews in Amazigh language. The area of study is difficult to access and involves complicated logistics. The methodology used to determine the number of farmers to be surveyed is based on stratified sampling method with two levels of stratification.

The first level of stratification is determined by the Agricultural Development Centre "ADC". These centres belong to the Moroccan ministry of agriculture and each centre is responsible for a specific area of production and farmers. Three ADCs operate in the study region:

- Agricultural Development Centre of Taliouine: It is the most important one in terms of farmers' number and the total surface of produced saffron. It includes six rural communes (RC), representing 51% of the total farmers, and 74.6% of the total surface of saffron;
- Agricultural Development Centre of Askaoune: This centre includes two RC and represents approximately 23.7% of saffron producers, and 9.7% of the total surface of saffron;
- Agricultural Development Centre of Taznakht: This centre includes four RC representing approximately 25.3% of saffron producers, and 15.7% of the total surface of the saffron.

The weighting basis used for the determination of the number of farmers to be surveyed per ADC corresponds to the ratio of the relative area per Agricultural Development Centre to the total area of saffron:

$$N_{zi} = N_t * (S_{zi}/S_t) \quad (4)$$

where
N_{zi}: is the number of farmers for the ADC_i
N_t: is the total number of farmers to be interviewed in the study area
S_{zi}: is the area of saffron in the ADC_i (ha)
S_t: is the total area of saffron in the study area (ha).

The second level of stratification corresponds to the rural communes producing saffron within each ADC (first level). Thus, for each ADC, the number of farmers to be interviewed per commune is determined on the basis of the weighting of the saffron area per commune to the total area at the ADC:

$$N_{cj} = N_{tzi} * (S_{cj}/S_{tzi}) \quad (5)$$

where:
N_{cj}: is the number of farmers for commune j
N_{tzi}: is the total number of farmers to be surveyed for the ADC_i
S_{cj}: is the area of saffron in commune j (ha)
S_{tzi}: is the total area of saffron in the ADC_i (ha)

Following this stratification technique, a total of 130 farmers needed to be interviewed, which represents 2.5% of the farms producing saffron. However, giving the time and logistics limitations, we were able to carry out 125 surveys from which we excluded a total of 8 incomplete questionnaires.

Empirical application

To analyse the efficiency of Moroccan saffron farms, we modelled the saffron production and efficiency using the collected farm-level data. To specify the model, we carried out different statistical tests using the generalised likelihood-ratio (L-R). Table 1 presents the results. The null hypotheses that the second order coefficients are zero ($\beta_{ij} = 0$) is accepted at the 5% significance level, which reduces the model to the Cobb-Douglass functional form. The second hypothesis tested $H'_0: \gamma = \delta_i = 0$ is rejected, which reveals that inefficiency effects are not absent from the model, confirming that Moroccan saffron farms suffer from inefficiencies. Both systematic and random technical inefficiency effects explain output variability. The third tested hypothesis of the presence of constant returns to scale ($\sum_{ij} \beta_{ij} = 1$) is accepted at the 5% significance level for the total sample, which means that there are constant returns to scale which speaks against expanding the saffron farms size as a possible strategy to increasing productivity.

Table 1: Model specification tests.

Hypothesis	LR test-statistic	Critical value (α = 0.05)	
Cobb-Douglas form, i.e.,: ($H_0: \beta_{ij} = 0$ for all j and i)	20.5	25	AH_0
Absence of inefficiency effects, i.e.,: ($H'_0: \gamma = \delta_i = 0$)	31.3	12.59	RH'_0
Constant returns-to-scale, i.e., : ($H''_0: \Sigma\beta_{ij} = 1$)	0.69	3.84	AH''_0

Source: Own composition

Thus, the production frontier function is specified as a Cobb-Douglas takes the form:

$$\ln(y_i) = \beta_0 + \sum_{k=1}^{p} \beta_k \ln(x_{ki}) + v_i - u_i \quad (6)$$

Production y_i is defined as the total saffron production in kilograms. Vector x_{ki} is defined as a (1x4) vector composed of four inputs. β is a ($K \times 1$) vector of unknown parameters to be estimated, and the disturbance term is composed of two parts: v_i and u_i. The following input variables were used:

- Labour (x_L), since the production of saffron is known to be very labour-intensive (e.g. hand-picked harvesting). This variable is introduced in the model as the total number of working hours.

- Plantation (x_p), which is the total quantity of bulbs (in tons) planted in the considered area.
- Land (x_L), which is the total area occupied by saffron (in ha). In the region of study, the area devoted by farms to saffron cultivation is very variable, and generally small.
- Expenditure on organic fertilisers (x_F), which is approximated using the cost of manure in Moroccan Dirhams since there is no use of mineral fertilisation.
- Other inputs (x_{OI}), which includes e.g. the cost of diesel, and farming overheads, all measured in Moroccan Dirhams.

The technical inefficiency effects function is specified as:

$$u_i = \delta_0 + \sum_{i=1}^{m} \delta_i z_i + w_i \quad (7)$$

Vector (z_i) in the technical inefficiency effects function is a (1x6) vector that specifies the Constant (Z_1), the Farmer age (Z_2), Management practices (Z_3) expressed by the number of days by year spent for saffron management practices, Distance to the urban centre (Z_4), Number of saffron plots (Z_5), and Off-farm activities (Z_6). Following the literature, older farmers are expected to be less efficient in comparison to younger ones, since younger farmers tend to be more willing or have greater ability to introduce changes in farm management techniques (Battese and Coelli, 1995; Lambarraa *et al.,* 2007). As suggested by previous studies (Bloom *el al.,* 2013; Shuhao, 2005), the number of plots and the time spent on management practices also could influence technical efficiency. Both variables could be considered as indicators of specialisation and full-time commitment to this farming activity which could improve farms' efficiency (Bloom *el al.,* 2013), while off-farm activities are expected to have a negative impact on technical efficiency.

Results and discussion

Characteristics of the farm sample

Summary statistics for the sample of saffron farms are given in Table 2, showing that the average annual saffron produce per farm is around 1.88 kg. The sample farms employ 4,322 labour hours per year, 60.2% of which are family labour. The sample farms use more than 4 tons of saffron bulb for the plantation per year and spent 943 Moroccan Dirhams on fertilisers and 659 Moroccan Dirhams on other specific costs. The land average is around 1.39 ha. The average farm distance to the urban centre is around 35 km with a maximum of 97 km and a minimum of 12 km. The average age of farmers is 52 years.

Table 3 shows the characteristics of saffron plots as reported by the Agricultural Development Centre. Generally, there are no major differences regarding the saffron area between the different centres. Taliouine farmers have on average a larger saffron area per farm, but the land is more fragmented with an average of 12 plots per farm compared to Askouan with only 7 plots per farm. The oldest saffron is observed among Askouan farmers with an average age of 9 years, while the Taznakht saffron with an average age of 4 years appears to be the youngest.

The majority of the interviewed saffron households (62%) have between 4 and 10 members, 31% have more than 10 members and only 7% have less than 4 persons in their families. The overall average number of family members per farm household in the sample is around 9 persons. The majority of farmers (44.5%) have no formal school education, 20% have a Koranic-level education, while only 1.7% of the farmers have a university degree. The saffron farmers are well experienced in agriculture: 19% have experience

Table 2: Description of the sample data.

Variable	Unit of measure	Mean	Std Dev	Minimum	Maximum
Production	Kg	1.88	2.68	0.1	16
Labour	h	4322.4	2108.61	496	18,640
Land	ha	1.39	1.23	0.05	8
Plantation (Saffron bulb)	t	4.43	5.65	0.34	40
Fertilisation	dirhams	943.50	793.19	240	6,000
Other costs	dirhams	658.92	978.10	1	7,680
Farmer age	years	52.48	15.02	25	85
Distance to the urban centre	km	35.38	12.84	18	97

Source: Own composition

Table 3: Characteristics of saffron plots.

Agricultural Development Centre (ADC)	Saffron area (ha)	Plots (number)	Age of saffron (years)
ADC-Taliouine	1.51	12.74	7.21
ADC-Askaoune	1.08	7.85	9.77
ADC-Taznakht	1	6.19	4.44
Total Average	1.39	11.30	7.11

Source: Own composition

in agriculture of more than 50 years, 76% have experience between 10 and 50 years, while only 5% have less than 10 years of experience. Most of the interviewed farmers (60%) are not involved in off-farm activities. The remainder carry out parallel activities, such as trade, masonry, and others. The distribution by ADC shows that most farmers having off-farm activities are primarily located in Askaoune (61.5%), followed by the farmers of Taliouine (37.5%), while the farmers of Taznakht are most dedicated to farming, with only 12.5% being involved in off-farm activities. The Membership rate in cooperatives is around 57%; the farmers of Taznakht are the most to adhere to cooperatives (87%), followed by the farmers of Taliouine (54.6%), and finally the farmers of Askaoune (38.5%).

Regarding the farming technical itinerary; most farms grow barley (61.5%) or maize (36.8%) as previous crop to saffron and only 1.7% use market gardening. A quasi-totality of the farmers (82 %) plant their saffron in September, 8.6 % in August and the remainder between May and April. The average depth of plantation is 21.25 cm and the average space between bulbs is 14.74 cm. The majority of farmers (55.6%) use between 4 to 10 tons of bulbs per hectare, 27.4% use less than 4 tons per hectare, and 17.1% use more than 10 tons per hectare. The largest dose of planting is used in Taznakht with an average of 11.13 t/ha, followed by Askaoune with an average of 6.85 t/ha, and finally Taliouine where farmers use only 5.4 t/ha of bulbs on average. The sample farmers irrigate their saffron 10 times on average and the majority (60.7%) control weeds mechanically in March, 20.5% in April and 13.7% in May. Almost all farmers (90.6 %) report no disease occurrence related to the saffron, while 9.4 % declare bulbs rot called "Bayoud". Half of the farms declare having rats or hare attacks, but they consider such damage not be significant. More than half of the interviewed farmers (58%) dry their saffron produce in the shade, 34% do so in the sun and only 8% use electric dryers. The vast majority of the farmers in the entire region (93.2 %) have limited access to the major markets since they sell their saffron to local markets ("souks"); the remainder sells it to other Moroccan cities aiming to take advantage of a higher price. The average contribution of family labour is around 60%; farmers of Taznakht seem to make the most use of family labour (82% of the total work), followed by Askaoune (70%) and Taliouine (55%).

Technical efficiency assessment

Results derived from the estimated Cobb-Douglas stochastic frontier model are presented in Table 4.

First-order parameters, β_k are all positive and statistically significant. This result indicates that the Moroccan saffron production increases with all inputs: plantation, labour, land, fertilisers, and other inputs. These estimations also suggest that the quantity of planted bulbs and the allocated working time are the most relevant factors affecting saffron production with coefficients of the order of 0.317 and 0.310 respectively, followed by Land (0.163) and Fertilisers (0.109). The sum of the partial production elasticities of these factors is equal to 1. This result is compatible with the likelihood-ratio test (see Table 1), confirming the presence of constant returns to scale which make an increase in the saffron farms' size unattractive (as this would require increasing returns to scale).

The second part of the model regarding the estimated determinants of technical inefficiency helps revealing which factors affect farm efficiency. The goal is to explore

Table 4: Maximum Likelihood Estimates of Production stochastic frontier model for Moroccan saffron farms.

Variables	Parameters	Estimate	Standard Error
Production Frontier Model			
Constant	β_0	3.1348	(0.6822)***
Plantation	β_P	0.3170	(0.0690)***
Labour	β_{LB}	0.3104	(0.0722)***
Land	β_{LND}	0.1634	(0.0773)**
Fertilisers	β_F	0.1093	(0.0674)*
Other variable inputs	B_{OI}	0.0382	(0.0135)***
Inefficiency effects model			
Constant	δ_0	-0.6270	(1.7235)
Number of saffron plots	δ_{NP}	-0.2481	(0.1336)*
Off-farm activities	δ_{OF}	1.6557	(0.8365)**
Management practices	δ_{MT}	-0.4247	(0.2508)*
Age	δ_A	0.0201	(0.0223)
Distance to urban centre	δ_{DU}	-0.0089	(0.0361)
sigma-squared	σ^2	0.3413	(0.0284)***
gamma	γ	0.7304	
log ML = -50.6057			

Notes:***,** and * indicate that the parameter is significant at the 1, 5 and 10%, respectively.
Source: Own composition

the impact of a variety of factors on the efficiency of saffron farms, as specified in the section empirical application. The number of saffron plots, management practices and the distance to the urban centre are associated with a higher saffron farm efficiency, while the age of the farmer and having off-farm activities decrease it. Management practices, maintenance, and technical control effort such as corn planting, flower harvest and irrigation are expressed by the number of days that the farmer dedicated to these activities. The efficiency of saffron farms improves when farmers are more engaged in controlling different management practices. This result could be explained by the specialisation-effect; which argues that the more time is dedicated by the farmers to their farming activity, the better is the accumulated learning experience, which improves the efficiency of saffron production.

The negative sign of this variable shows that the number of plots has a negative impact on saffron farm inefficiency, which could be explained by the fact that saffron farmers who own more plots are more specialised in this farming activity, and hence more efficient, which is in line with other studies (e.g. Jha *et al.,* 2005).

The negative effect of distance to the urban centre on the level of technical inefficiency is statistically significant. Farmers with the greatest distance to the urban centre are the most efficient compared to farms in close peri-urban areas. This result can be explained by the fact that the farmers located in closest distance to the urban centre tend to be more often engaged in off-farm activities (e.g. masonry, electricity) and spend less time on saffron farming. Since saffron farming is labour-intensive, this situation leads to an increase in the inefficiency of the farms.

The effect of off-farm activities on technical inefficiency is statistically significant. The positive sign of this variable shows that farmers' engagement in off-farm activities increases technical inefficiency. This result is consistent with other studies (e.g. Sabasi *et al.,* 2019) and demonstrates that producers having other off-farm activities have an extra opportunity-cost expressed as the lost time on managing their saffron farm. This time reallocation leads to changes in management practices resulting in reduced effectiveness (Bloom *el al.,* 2013). Spending less time on the farm means that the production decisions may then be based on less information, which could lead to technical inefficiencies (Mayen *et al.,* 2010; Kumbhakar *et al.,* 1989). Other studies have found that off-farm income has a negative impact on farm technical efficiency due to the changes that take place in the farm household's work ethic and performance (Chang and Mishra, 2013). Farms managed by older farmers are less efficient than those managed by younger ones, which suggests that younger farmers may be more likely to introduce efficiency-enhancing management techniques on their farms. Another factor could be the inability of older farmers to concentrate on the labour-intensive saffron crop farming activity. This result is consistent with Lambarraa *et al.* (2007, 2009) who also found that age had a negative effect on technical efficiency.

Figure 1 and 2 show the predicted technical efficiency rates distributed by interval and Agricultural Development Centre (ADC). The technical efficiency in the farm sample takes an average value of 51%, implying that the production of Moroccan saffron farms could increase considerably, if technical inefficiencies were eliminated through more efficient use of inputs. Figure 2 shows that the majority of saffron farms (59%) have a TE rate less than 50% and only 20% of saffron producers have a TE -rate of greater than 80%.

The distribution of technical efficiencies by development centre, as shown in Figure 1, indicates that the most efficient farms are located in Taznakhte (TE= 67%), followed by Talioune (TE= 49%) and finally Askaoune (TE= 44%). These results could be explained by the fact that the Taliouine region has the highest rate of younger farmers adhering to the cooperatives with full engagement to the farming activity with lowest off-farm activities and highest family labour input.

A recent strategic analysis of the Moroccan Saffron sector shows that it has good potential to grow and expand further, particularly as regards the Moroccan and international markets (Lambarraa-Lehnhardt and Lmouden, 2022). However, on the production side, our study demonstrates that Moroccan saffron farms are inefficient. There is a need to improve

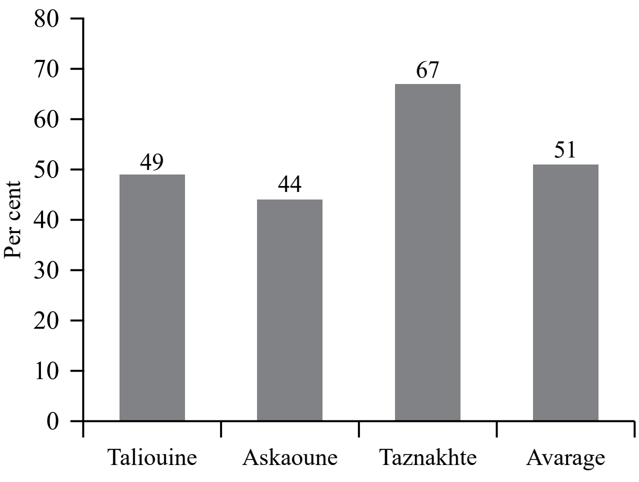

Figure 1: The distribution of the technical efficiency (TE) level by ADC.

Source: Own composition

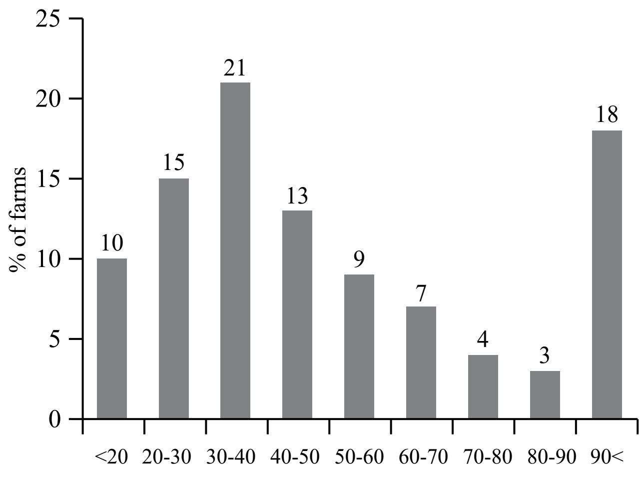

Figure 2: Distribution of the technical efficiency (TE) level by farms.

Source: Own composition

the farmer's efficiency and productivity to meet the increasing demands from the domestic market and to profit from the opportunities existing in the international export market. The new agricultural policy "Generation Green" launched in 2020 needs to achieve a sustainable intensification of saffron farming by improving farmers' specialisation. The saffron cooperatives could play a crucial role in reaching this objective by attracting more farmers to dedicate themselves fully to this farming activity and by providing them with the training programmes necessary to improve their skills and technical conduct. Moreover, more regulation is needed at the local market level to establish formal market channels under the Protected Designation of Origin (PDO) "Saffron of Talouine", which would serve to guarantee saffron farming as farmers' main source of income as well as to reduce off-farm activities.

The main limitation of this study relates to its use of cross-sectional data to analyse farmers' technical efficiency. The use of panel data can detect and measure the technical inefficiency over time. It also makes it possible to apply a more sophisticated modelling approach, such as the dynamic technical efficiency model and the decomposition of the farms' productivity and its evolution over time. Thus, we recommend that future studies collect data over a period of time. This could be facilitated by the establishment of a techno-economic observatory for monitoring the evolution of saffron production by the Moroccan Ministry of Agriculture and Fisheries. Such an observatory could provide researchers and policy makers with the necessary data to obtain better insights into the evolution of the Moroccan saffron sector.

As we anticipate future research, we need to consider analysing farmer technical and economic efficiency and productivity over time. The analysis of economic efficiency will reveal more information regarding the efficiency of saffron farms in relation to the market. The consideration of behavioural factors will complement the economic analysis to help explain farmers' decision-making in relation to the adoption of saffron farming.

Conclusions

Saffron farming plays an important agro-ecological and socioeconomic role in the marginal area of the Anti-Atlas mountain area. In this study, we assessed the technical efficiency of Moroccan saffron farms using a stochastic frontier model. A survey to 125 saffron producers was conducted in the production region of Taliouine and Taznakht according to a stratified sampling method. The main results of the estimated Stochastic Frontier Model and hypothesis tests are that the production of saffron is characterised by constant returns to scale and the main factors affecting the production are the corms planting dose, labour, land, and fertilisers. The estimated average efficiency level for the farm sample was about 50%, which means that there is ample scope to double the production of saffron without the need to increase required inputs or alter the production technology. The Taznakht region was found to perform more efficiently relative to Taliouine or Askaoune. Only 41% of the producers had a technical efficiency rate above 50 %, and among them, 18 % achieved a rate that was greater than 90 %. This large gap in efficiency levels shows that there is considerable potential to increase saffron production based on the factors affecting farm inefficiency. Among these factors, we find that the number of saffron plots, the frequency of use of different management practices and the distance to the urban centre increase saffron farms' efficiency, whereas the age of the farmer and the existence of off-farm activities decrease it.

In view of these results, we see a need to set up an appropriate strategy in the framework of the new agricultural policy "Generation Green" oriented towards improving the efficiency of the saffron sector. This strategy needs to be focused on activating the role of the cooperatives by attracting more farmers, especially younger ones, as they are more prone to introducing changes in crop management techniques. These farmers can improve their set of skills and technical conduct through knowledge dissemination by cooperatives (e.g. through trainings and other support measures, such as getting access to high quality saffron bulbs). However, more regulation is also needed in relation to farmers' access to the market. This would ensure that saffron production becomes the main source of income for farmers, thereby reducing off-farm activities and increasing specialisation through full-time commitment.

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