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Evaluation of Egyptian Fish Farms' Technical Efficiency: Using the Stochastic Frontier Method

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ABSTRACT

Aquaculture is a critical global sector for food security, supplying nutritious food and playing an essential role in fostering economic growth and job creation. Egypt is the leading producer of aquaculture in Africa. This sector constituted approximately 8.44% of the total national agricultural income. Egypt relies on this sector to satisfy the increasing demand for fish, which accounts for approximately 79% of total fish production. Nevertheless, the country continues to be a net importer of fish products to mitigate the food gap. Additionally, the production of Tilapia fish faces several challenges, which in turn lead to reduced profitability and production efficiency in Tilapia aquaculture. The study aimed to evaluate the technical efficiency of Tilapia farms in Kafr El-Sheikh from July to August 2022**,** employing the stochastic frontier methodology. The stochastic frontier function examines technical efficiency and distinguishes between random factors that are outside the fish farmers' control and the effects of inefficiency. The main findings indicated that fingerlings, labor, and machinery are the inputs that significantly affect Tilapia production in the study sample. Furthermore, 79.8% of the Tilapia farms exhibited technical inefficiencies. This led to a reduction in the farmers' ability to manage their fish farms effectively, ultimately decreasing fish production. This study recommended the implementation of extension programs at the farm level to aid Tilapia fish farmers in optimizing their resource utilization to enhance fish production on farms.

Keywords: Stochastic production frontier, Technical efficiency, Tilapia, Kafr El-Sheikh, Aquaculture

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INTRODUCTION

Aquatic food sources play a crucial role in ensuring the food security of millions of people worldwide by providing nutritious food. They also play a crucial role in sustaining economic growth, job creation, and income generation in various regions (Rossignoli et al., 2023). Aquaculture provides over 23 million direct and indirect full-time employment opportunities, predominantly in developing countries (Nasr-Allah et al., 2020).

Since the 1990s, natural fisheries have stabilized at approximately 90 million tons (Mehrim & Refaey, 2023). Therefore, aquaculture has the capacity to provide a sustainable aggregate fish supply to meet the rising global fish demand (Ikpoza et al., 2021). Furthermore, the global aquaculture sector will emerge as the principal provider of high-quality aquatic food in contemporary and future food systems (Mehrim & Refaey, 2023). Aquaculture represents the principal source of proteins and provides fatty acids, iron, zinc, omega-3 and vitamins (Boyd et al., 2022; Maaruf & Akbay, 2020; Tacon & Metian, 2013). In 2020, worldwide aquaculture production attained 122.6 million tons, with a valuation of $281.5 billion (FAO Report, 2023). By 2030, human consumption will account for 90% of total aquatic animal production, representing a rise of 15% from 2020. Projections indicate a marginal decline in per capita consumption in Africa, particularly in sub-Saharan Africa, by 2030, leading to concerns about food security (FAO, 2022).

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The projections indicate a 33% increase in the prices of globally traded aquatic products by 2030. Aquaculture production must rise to 30 million tons by 2030 to satisfy the growing global demand (Radhakrishnan et al., 2021).

The aquaculture sector is the fastest growing in food production, representing over 50% of global fish production. Developing countries, which contribute more than half of the world's aquaculture output, are significant fish producers (Mboya & Ouko, 2023; Samuel, 2023).

From 2000 to 2021, aquaculture in Africa grew at an annual rate of 8.8%, surpassing the global average growth rate of 5.0% for the same period, contributing 2.4 million tons, which accounts for 2% of total world aquaculture production (Menezes et al., 2024). Approximately 43.6% of African aquaculture production comprises Nile Tilapia. Egypt and Nigeria are the foremost producers of aquaculture in Africa. The primary fish species cultivated in Egypt and Nigeria are Tilapia and African catfish, respectively (Menezes et al., 2024).

The Actual State of Egyptian Fish Production

Egypt views fish production as a promising sector for enhancing food security and fostering economic development (Osman et al., 2018). This sector provides income and employment, as well as serving as a significant economic source of protein compared to other animal protein sources. The majority of Egyptian fish farms are situated in the Nile Delta region, specifically in the northern lakes such as Manzala, Edko, Borollos, and Mariuot lakes, with a total production of 208,699 tons in 2022 (MALR, 2022).

The fish production sector contributed approximately $2,389 million, representing 8.44% of the total national agricultural income in 2021 (Income, 2021). The primary sources of fish production in Egypt are natural fisheries and aquaculture. Fig. 1 illustrates the annual trend of fish production, which increased from 384 thousand tons in 2000 to 423 thousand tons in 2022, reflecting a 10.1% rise in natural fisheries (marine, lakes, and the Nile River and its branches). Egypt is experiencing considerable limitations in fishery production due to elevated prices of wild fish, highlighting the need for expansion in the aquaculture sector.

On the other hand, from 2000 to 2022, the annual growth rate of aquaculture fish production was approximately 7.8% (MALR, 2022). Aquaculture represents the majority of fish production in Egypt and is the only sector within fisheries capable of meeting the growing demand for fish. Aquaculture constitutes 79% of total fish production, predominantly sourced from private farms (Fig. 2). Small and medium-sized private farms produced over 85% of this output. In 2022, the cultivated area increased to 302 thousand feddan (MALR, 2022).

Egypt is the foremost aquaculture producer in Africa, producing 1.6 million tons of fish per year, with a market value of $3.5 billion in 2022 (MALR, 2022). Aquaculture, due to its significant current growth, has the potential to address the country's consistently high unemployment rates, especially among women and youth (Nasr-Allah et al., 2020).

In Egypt, numerous aquaculture systems involve the following:

1. The practice of extensive aquaculture encompasses the cultivation of earthen ponds, the replenishment of lakes with fry and fingerlings, and the introduction of grass carp in the Nile River, its tributaries, and enclosures.
2. Egypt's primary system, a semi-intensive culture system, accounts for 80% of its overall production. The majority of farms are situated in the northern and eastern regions of the Nile Delta, utilizing both brackish and freshwater resources. This type of aquaculture, which encompasses both governmental and private farms, utilizes a total cultivated area of approximately 301,938 feddan and produced approximately 1,386,268 tons of fish in 2022 (MALR, 2022).
3. Intensive aquaculture systems, including greenhouse culture, tank culture, concrete ponds, and cage culture, have gained popularity recently (Mehrim & Refaey, 2023). The recorded total fish production from cage culture was 196,355 tons, accounting for approximately 9.75% of the overall fish production in 2022 (Table 1). In 2022, the total output from intensive pond systems was 2,357 tons, or approximately 0.12% of the overall fish production (Table 1).

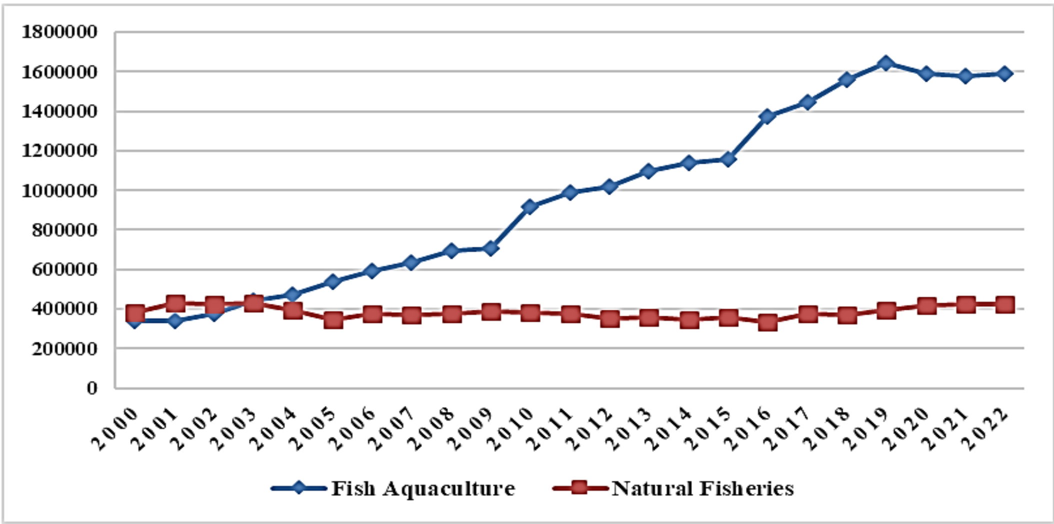

Fig. 1: Annual trend of fish production (ton) in Egypt during 2000 – 2022; Source: Statistical Bulletin on Fish Production from 2000 to 2022, Egyptian Ministry of Agriculture and Land Reclamation.

Table 1: Fish Aquaculture systems in Egypt in 2022

Systems	Production (Ton)	Aquaculture (%)	Total (%)
Governmental farms	17593	1.11	0.87
Private farms	1368676	86.1	68.0
Intensive Culture	2357	0.15	0.12
Floating Cages	196355	12.34	9.75
In-pond raceway system (IPRS)	70	0.004	0.003
Rice fields	5542	0.35	0.28
Total Aquaculture	1590593	100	79.0
Gross Total	2013563	-	100

Source: Statistical Bulletin on Fish Production in 2022, Egyptian Ministry of Agriculture and Land Reclamation.

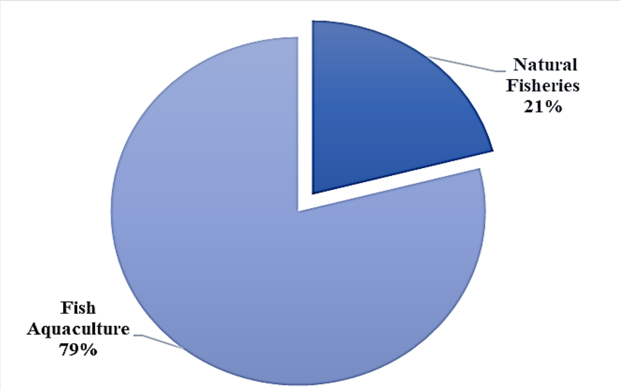

Fig. 2: Total fish production in Egypt in 2022; Source: Statistical Bulletin on Fish Production in 2022, Egyptian Ministry of Agriculture and Land Reclamation.

4. Furthermore, integrated aquaculture production systems incorporate plants (aquaponics). Aquaculture in rice fields varies with alterations in the land area allocated for rice cultivation. Total production amounted to 5,542 tons, constituting approximately 0.28% of the overall fish production in 2022 (Table 1).

Table 1 indicates that private farms are the predominant fish producers in Egypt, producing approximately 1,368,676 tons, which constitutes 86.1% of fish aquaculture and 68% of total fish production in 2022. Owned, leased, and temporary private farms span cultivated areas of 43,511, 61,489, and 147,289 feddan, respectively. In 2022, these farms produced approximately 255,556, 280,471, and 832,649 tons of owned, leased, and temporary farms, respectively, representing 18.7%, 20.5%, and 60.8% of total private farm production (MALR, 2022). Earth ponds are the dominant production system (accounting for 87.2% of total production in 2022), followed by cages (12.3%) (Table 1). The dominant species in terms of production is Tilapia.

Despite Egypt's notable increase in production (2 million tons), the country remains a net importer of fish products. In 2021, imports increased and reached 385,339 tons, reflecting the strong growth in annual per capita consumption, which was approximately 23.12kg annually (Yearbook, 2021).

Egypt ranks as the third largest producer of Tilapia worldwide, following China and Indonesia. Tilapia aquaculture significantly contributes to the national economy and food security, as all domestic production is sold locally (Rossignoli et al., 2023). Furthermore, the Tilapia markets in Egypt have become increasingly diverse, with different grades of products offered at varying prices based on size, quality, location, and market (Mohamed et al., 2022). Nonetheless, despite this achievement, the Egyptian Tilapia sector encounters diminishing profitability and production efficiency in Tilapia aquaculture. There are numerous obstacles that prevent its full exploitation, including high land rent, a shortage of fry, high feed costs, and management problems.

Therefore, the current study aims to evaluate the technical efficiency (TE) of freshwater Tilapia in the semi-intensive production system on private farms in Kafr El-Sheikh, Egypt, using the stochastic frontier method.

Previous Literature

Assessing technical efficiency is essential for pinpointing potential avenues for enhancing productivity with existing fish resources and technologies. In the stochastic frontier production framework, TE is characterized as the least inputs required to generate a particular output level or the highest output attainable with a specified input combination (Farrell, 1957).

Several studies employed stochastic frontier analysis to assess the TE of the aquaculture sector in multiple developing nations. Some of these studies, Adinya et al. (2011), Yin et al. (2014), Phiri & Yuan, (2018), Mussa et al. (2020), Radhakrishnan et al. (2020) and Ikpoza et al. (2021), employed the stochastic frontier production function to assess the technical efficiencies of different aquaculture products, including catfish, Tilapia, carp, clown, and shrimp. Similar studies were carried out on aquaculture farms in Ethiopia, Ghana, Nigeria and India (Crentsil & Essilfie, 2014; Ikpoza et al., 2021; Akram et al., 2023; Asmare & Aragaw, 2024). The main results of these studies indicated the existence of TE among the aquaculture farmers.

The TE of fish farms in Ghana, Nigeria and Zimbabwe was investigated by Onumah et al. (2010), Onumah & Acquah (2011), Itam et al. (2014), Ogundari & Akinbogun (2010), Isiaka & Damilola (2019) and Gwazani et al. (2022). Researchers discovered that the productivity of fish farms was low, but there is potential for increasing fish production by enhancing TE. The productivity of fish farming can be influenced by various factors, including family labor, hired labor, capital, feed, fertilizer, seed, land, and other costs. Furthermore, a study conducted by Aydoğan & Uysal (2021) revealed that the TE of sea bass farms in Turkey was affected by both fish loss rates and subsidies. Additionally, Islam et al. (2016) discovered that there are significant levels of technical inefficiency among cage culturists. Therefore, there is a significant opportunity to enhance fish production in Peninsular Malaysia by implementing more efficient management practices in cage culture.

In summary, previous studies have verified that the majority of fish farms exhibit technical inefficiency due to various factors that can impact fish production in multiple countries. Although developing countries are the foremost fish producers globally, they experience significant technical inefficiency among aquaculture farmers. At the same time, Egypt is the largest producer of aquaculture in Africa. Therefore, this study seeks to enhance the existing literature on the TE of fish farms in Egypt by employing the stochastic frontier method to assess their efficiency.

MATERIALS & METHODS

Data Sources and Study Sample

This study is based on two data sources: published data from various sources, such as the Egyptian Ministry of Agriculture and Land Reclamation (Statistical Bulletin on Fish Production from 2000 to 2022 and Bulletin of Estimates Agricultural Income 2021), the Lakes and Fish Resources Protection and Development Agency (LFRPDA), the Fish Statistics Yearbook 2021 and previous published research and studies. Furthermore, the collection of primary data was conducted by fish farmers of freshwater Tilapia in the semi-intensive production system on private farms located in Kafr El-Sheikh Governorate, Egypt. The Mediterranean Sea borders Kafr El-Sheikh to the north and the Rashid Branch of the Nile River to the west (Fig. 3). The governorate encompasses a segment of the Mediterranean Sea, Lake Burullus and aquaculture facilities, comprising fish hatcheries, fish nursery stations, three governmental fish farms, and several private fish farms (https://www.was.org/). Kafr El-Sheikh is the paramount governorate for aquaculture, contributing over 40% of Egypt's total fish production and comprising a variety of species, including Tilapia (https://www.bluelifehub.com).

Fig. 3: Map of Kafr El-Sheikh Governorate (https://commons.wikimedia.org).

Kafr El-Shaikh Governorate engages in intensive polyculture involving Nile Tilapia and mullet. Nevertheless, practicing intensive aquaculture in small rural water bodies poses significant challenges. Both small- and large-scale commercial farmers, who are progressively advancing aquaculture, favor the semi-intensive system. In this system, fish density typically exceeds that of extensive culture and farmers employ organic fertilization along with supplementary feeds derived from locally sourced agricultural byproducts (Soliman & Yacout, 2016).

Fish farmers were interviewed face-to-face with selected respondents using a pre-tested questionnaire. The questionnaire was designed to collect data on respondent characteristics, inputs, production costs, and the quantity and value of Tilapia production. This study collected data on various inputs, including fish fry (pieces), feed (tons), labor (pounds), rent (pounds), operational costs (pounds), and maintenance costs (pounds). From July to August 2022, a random sample of 60 respondents from fish farming leased farms in Kafr El-Sheikh governorate participated in the survey. The study focused on three districts based on the concentration of fish farms: El-Hamoul, El-Reyad, and Baltim. In these districts, the farm-cultivated areas ranged from 5 to 60 Fed.

Fig. 4 illustrates that the fish aquaculture production in Kafr El-Shiekh reached around 656 thousand tons in 2021 (Yearbook, 2021). The fish aquaculture production in Kafr El-Shiekh involves several systems, including government farms, private farms, cages, and an in-pond raceway system. The predominant source of production in Kafr El-Shiekh was private farms (owned, leased, and temporary), accounting for around 567 thousand tons, or 86.3% of the total fish aquaculture production. Following that, cages accounted for approximately 79.9 thousand tons, which represents 12.2% of the total production of fish aquaculture in Kafr El-Shiekh in 2021. Governmental farms contributed approximately 9.7 thousand tons, or 1.5%. The in-pond raceway system contributed around 0.003% to the total production.

Furthermore, Kafr El-Shiekh holds the rank of being the biggest producer of fish fingerlings in hatcheries, with a production of around 730.13 million units. This accounts for 81.1% of Egypt's total production in 2021 (Yearbook, 2021).

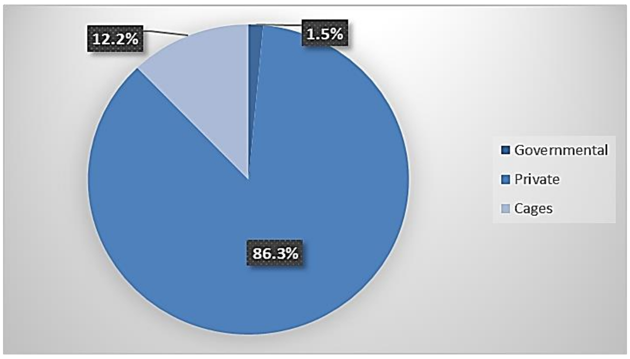

Fig. 4: Total production of fish aquaculture in Kafr El-Shiekh in 2021; Source: Fish Statistics Yearbook 2021, Lakes and Fish Resources Protection and Development Agency.

Empirical Models

Farrell (1957) explained efficiency as the capacity to achieve a specified amount of output at the lowest possible cost. Farrell (1957) classified efficiency as technical efficiency (TE), allocative efficiency (AE), and economic efficiency (EE), with the latter representing the synthesis of the former two. Technical efficiency, as articulated by Farrell (1957), denotes the ability to achieve a specific output level while utilizing the least number of inputs within a given production technology. Aigner et al. (1977) and Meeusen and van den Broeck (1977) devised the stochastic frontier production function to measure the TE of production. The stochastic frontier production function is appropriate for assessing TE, as it can overcome the constraints of the presumed error term in conventional production functions. These constraints relate to the statistical inference of parameters and the consequent efficiency estimates. The stochastic production frontier enables the differentiation between random output fluctuations and inefficiency impacts. Thus, it is distinct from the traditional production function, characterized by its two error components. The primary error term signifies technical inefficiency, whereas the following term pertains to random variables outside the fish farmers' influence (Asmare & Aragaw, 2024).

Furthermore, it is crucial to understand that measurement errors and various stochastic factors, such as disease and climate variables, frequently affect data in developing nations. Dey et al. (2005), Singh et al. (2009), and Mussa et al. (2020) observed that stochastic frontier analysis (SFA) is more suitable for assessing efficiency in these places (Phiri & Yuan, 2018).

Below, we articulate the stochastic frontier production model:

$$Y_i = X_i \beta + \varepsilon_i \quad (1)$$

Where Y_i represents the output for the farm (i = 1, 2,..., n); X_i represents a vector of farm inputs, while β denotes a vector of parameters to be estimated. ε_i represents the error term, which comprises two components, specifically:

$$\varepsilon_i = V_i - U_i \quad (2)$$

where V_i is a random error that accounts for statistical noise, it has an independent distribution and can be either positive or negative. The U_i is a non-negative random variable that represents pure technical inefficiencies in production, and it has an independent distribution (Aigner et al., 1977; Battese & Coelli, 1995). The presumption of an independent distribution between U_i and V_i enables the model to distinguish between stochastic and inefficiency effects. (Coelli et al., 2005) defined the technical inefficiency effects of U_i in the following way:

$$U_i = Z_i\ \delta + W_i \quad (3)$$

where Z_i represents a vector of variables affecting farm efficiency; δ is a vector of parameters that need to be estimated, and Wi's are random variables that are defined by cutting a normal distribution with mean 0 and variance $\sigma^2 u$ so that the point of cutting is $-Zi\delta$, i.e., $Wi \geq -Zi\delta$.

The maximum likelihood estimation (MLE) technique is employed to concurrently estimate the model parameters in equations (1) and (3). The parameters in Eq. (1) include β's and the variance parameters $\sigma^2 = \sigma^2_u + \sigma^2_v$ and $\gamma = \sigma^2_u / \sigma^2$.

Where σ^2 is the sum of the error variance; γ has a value ranging from 0 to 1 and measures the total variation of output from the frontier that is attributed to the existence of random noise or inefficiency. Inefficiency is not present when γ = 0, which means that all deviations from the frontier are due to random noise; however, if γ = 1, then the deviations are completely caused by inefficiency effects.

(Battese & Coelli, 1995), as referenced by (Mussa et al., 2020), asserted that the generalized likelihood-ratio test statistic can be derived from the logarithms of the likelihood function linked to the restricted MLE in the specific scenario where the relevant parameter equals zero.

The most common form for assessing the relationship between inputs and outputs is the Cobb-Douglas (CD). We applied a logarithm transformation to the quantitative variables, a prerequisite for fitting a Cobb-Douglas function (Singh et al., 2009). Consequently, we evaluated the Cobb-Douglas stochastic production frontier model for Tilapia aquaculture in Kafr El-Sheikh. The model will be utilized in formulation (1), as outlined below:

$$Ln\ Y_i = \beta_0 + \beta_1 Ln\ X_1 + \beta_2 Ln\ X_2 + \beta_3 Ln\ X_3 + \beta_4 Ln\ X_4 + \beta_5 Ln\ X_5 + \beta_6 Ln\ X_6 + \beta_7 Ln\ X_7 + V_i - U_i \quad (4)$$

Where Ln is the natural logarithm, Y is the fish output (ton); β_1, β_2, β_3, β_4, β_5, β_6, and β_7 are the regression coefficients of inputs; X_1 represents fish fry (pieces), X_2 represents feed (ton), X_3 represents labor (pound), X_4 represents rent (pound), X_5 represents machines (pound), X_6 represents energy (pound), and X_7 represents maintenance (pound), and Vi and Ui stand for noise and inefficiency, respectively.

Here's how we present the technical inefficiency model:

$$U_{it} = \delta_0 + \delta_1 Z_{i1} + \delta_2 Z_{i2} + \delta_3 Z_{i3} + \delta_4 Z_{i4} + \varepsilon \quad (5)$$

Where U_{it} is technical inefficiency. Z_1 stands for cultivated area (fed.), Z_2 for age (year), Z_3 for education level (year), and Z_4 for experience (year).

Consequently, the technical efficiency value for the farm in the sample (TEi) is defined as the ratio of actual output to the relevant frontier output (Coelli et al., 2005).

$$TE_i = exp\ (-\ u_i) \quad (6)$$

Where TEi is the farm's technical efficiency (0 < TE < 1). When Ui = 0, the farm is considered technically efficient as it lies on the stochastic frontier. If Ui > 0, the farm lies below the frontier, indicating that it is inefficient. We estimated the model using Frontier 4.1 software (Drinkwater & Harris, 1999).

RESULTS & DISCUSSION

Farmers' Characteristics

The study sample revealed that all farmers were male who leased farms for the purpose of fish farming. This finding aligns with Maaruf and Akbay (2020) and Ikpoza et al. (2021), who discovered that all farmers in the research area were male. Additionally, Adeniyi et al. (2015), Samuel (2023) and Rossignoli et al. (2023) found that approximately 94%, 92%, and 99% of farmers were male, respectively. The arduous tasks involved in the fish production process may account for this.

Additionally, the sample was based on some characteristics of fish farmers, such as age, education level, and years of experience.

In Fig. 5, the majority (46.7%) of the farmers were more than 50 years old. The increased years of experience in fish production may reflect this. The age range of 30-40 years' accounts for about 23.3%, while the productive age range of 41-50 years' accounts for about 21.7%. This means that fish farmers are in their prime and active age of production. We expect them to be productive in the next decade, and their strength and physical ability to manage the fish pond will likely increase the country's fish production (Williams et al., 2012). According to Sikiru et al. (2009) and Ikpoza et al. (2021), this is a productive age that predicts a better future for fish production.

The educational level of farmers showed that 25% were illiterate, 48.3% had diploma certification, 21.7% graduated from college, and 5% of farmers had a postgraduate degree (Fig. 5). This indicates that the majority (48.3%) of farmers had completed 10 years of basic education and were able to understand some basic fish farming techniques. This suggests a tendency for farmers to increase their level of technology adoption and skill acquisition. These results agree with findings by

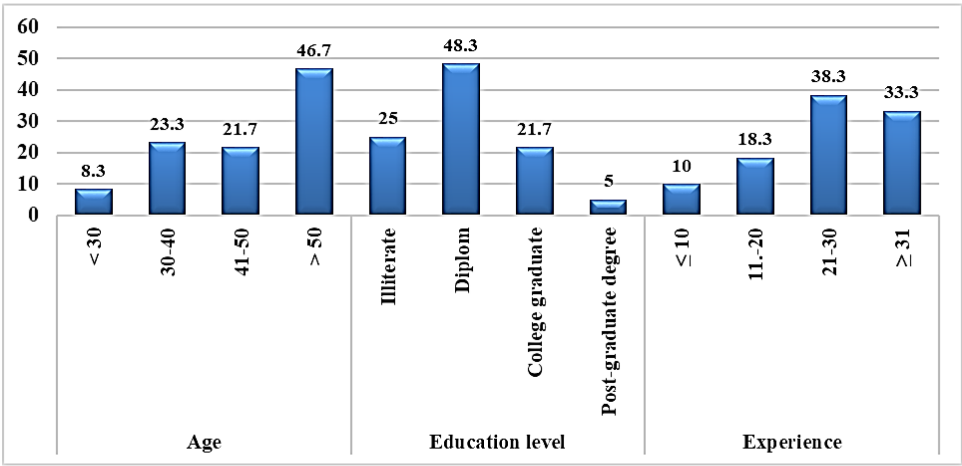

Fig. 5: Farmer's characteristics of the study sample.

Maaruf and Akbay (2020), in Iraq, as well as Ikpoza et al. (2021) and Gwazani et al. (2022), who found out that a greater percentage of farmers in Nigeria and Zimbabwe had basic education. Furthermore, Williams et al. (2012) report that nearly all Nigerian catfish farmers are literate. This implies that most catfish farmers will find it simple to comprehend management practices and readily implement the new innovations introduced by the State Agricultural Extension Agents, including improved fingerlings, feed formulation, water management strategy, etc.

In addition, results indicated that the average experience of farmers was 26 years, indicating substantial experience. The farmers with 21–30 years of experience occupied the highest shares (38.3%), followed by 33.3% of farmers with experience more than 31 years (Fig. 5). This may have occurred because approximately 46.7% of the farmers in the study sample were over 50 years old. This means that they had experience in fish production. This aligns with Williams et al.'s (2012) assertion that years of experience directly contribute to the efficient management of a fish farm and its overall productivity.

Statistical Descriptions of the Study's Variables

Table 2 displays a statistical summary for the study's variables. Prior studies identified the semi-intensive polyculture of Tilapia as the predominant method of Tilapia farming in Egypt (Macfadyen et al., 2012; Nasr-Allah et al., 2019; Rossignoli et al., 2023). This study found that earthen pond polyculture was the predominant aquaculture system, with all sampled farms cultivating Tilapia in polyculture with mullet. The mean fish production was 99 tons, with an average of 91 tons of Tilapia and 8 tons of mullets. The average cultivated area of fish farms was 21 acres in the study sample. Furthermore, Tilapia-mullet polyculture systems may influence fish yields, which average approximately 4.9 tons per acre. The findings of Nasr-Allah et al. (2019) and Rossignoli et al. (2023) indicated that fish yields are superior in monoculture compared to polyculture systems. Furthermore, Gwazani et al. (2022) found that Tilapia was the dominant fish in study areas in Zimbabwe.

The average cost of feed per production cycle was L.E. 1218 thousand. Fish farming requires intensive labor to feed the fish and clean the nets. The average labor cost per cycle was L.E. 66 thousand. All farmers acquired fingerlings from local hatcheries. The mean expenditure per fry was L.E. 95.4 thousand.

Table 2: Descriptive statistics for output and input variables of the study sample

Variables		Unit	Mean	Mini.	Max.	Std. Deviation
Fish production	Y	Ton	99	21	243	55
Fish fry	X_1	pieces	466883	75000	1700000	352663
Feed	X_2	Ton	137	20	561	92
Labor	X_3	Pound	66303	17500	208500	41427
Rent	X_4	Pound	14778	3000	20000	2510
Machines	X_5	Pound	20393	6000	70000	15676
Energy	X_6	Pound	26018	3900	120000	20111
Maintenance	X_7	Pound	17726	2000	65000	12053
Cultivated area		Fed.	21	5	60	13

Technical Efficiency of Farms in Kafr El-Shiekh

Table 3 presents that we estimated the Cobb-Douglas stochastic frontier production function parameters using MLE. Most of the estimated β coefficients have negative values, except for the coefficients for fingerlings, energy costs and maintenance costs. The impact of fingerlings at a 1% level indicates that this input has a substantial influence on fish production in Kafr El-Sheikh. This implies that a 1% increase in fingerling quantity will increase Tilapia production by 5.96, which indicates that there is a scope for increasing production of Tilapia by increasing the level of this input. Mussa et al. (2020) also reported this result.

Table 3: Maximum-likelihood estimates of stochastic production frontier parameters and technical inefficiency model

Parameter	Variable	Coefficients	Std. Error	t-Value
Stochastic production frontier				
β_0	C	-5.7343***	1.1212	-5.1143
β_1	Ln X_1	5.9564***	1.6798	3.5459
β_2	Ln X_2	-0.1071	0.4359	-0.2458
β_3	Ln X_3	-3.0691*	1.8795	-1.6329
β_4	Ln X_4	-0.1729	1.2745	-0.1357
β_5	Ln X_5	-3.7638***	0.9872	-3.8124
β_6	Ln X_6	0.8219	0.6100	1.3473
β_7	Ln X_7	0.4684	1.4260	0.3285
Technical inefficiency model				
δ_0	C	1.5602***	0.3422	4.5596
δ_1	Cultivated area	-0.0499***	0.0096	-5.2179
δ_2	Age	-0.0251***	0.0058	-4.3454
δ_3	Education level	-0.0233	0.0467	-0.4997
δ_4	Experience	0.0208***	0.0056	3.7114
Variance parameter				
Sigma-squared σ^2		0.0600***	0.0111	5.4242
Gamma γ		0.9811***	0.1099	8.9235
Log likelihood		40.594		
Mean TE		79.8%		

*** significant at 1 % and * significant at 5%.

The significant coefficients for labor and machines at 10% and 1% levels, respectively, indicate that these inputs also have an impact on fish production. This implies that a 1% reduction in labor and machine costs will increase the quantity of Tilapia production by 3.07 and 3.76, respectively. This is consistent with Islam et al. (2016), who reported that fingerlings and labor are the two inputs that significantly influence fish cage system production in Peninsular Malaysia. Phiri and Yuan (2018) and Mussa et al. (2020) also reported this result in Malawi and China. Ikpoza et al. (2021) discovered that an increase in the quantity of fingerlings will diminish the catfish output in Nigeria.

The findings also reveal a lack of significance and a negative coefficient for feed, suggesting an overuse of this resource. This means that the current production scale of Tilapia ponds in El-Hamoul, El-Reyad, and Baltim has reached its optimal levels of feed input, and each increase in feed input leads to a decrease in fish output. Rossignoli et al. (2023) discovered that being aware of the expenses and benefits of feed management practices in aquaculture will empower producers to improve feed management, thereby decreasing feed expenses, augmenting farm profits, and mitigating adverse environmental effects.

The FAO Report (2023) indicated that feeds constitute the most significant variable cost in aquaculture. In various aquaculture systems, feed can account for 60–80% of production costs, and both feed prices and feeding management efficiency influence its contribution to productive costs. The high cost of aquafeed or inadequate feeding management can render aquaculture economically unfeasible, underscoring the need to devise innovative, practical, and accessible technological solutions that can reduce costs, increase feed efficiency, and make production financially viable.

The correlation between fish production and the coefficients for other inputs is not statistically significant.

Table 3 displays the estimates for the technical inefficiency model's parameters. The coefficients for cultivated area, age, and education level are all negative and statistically significant at the 1% level. The education level is the only one that is not statistically significant. If the coefficient were negative, an increase in the issue variable would lead to a rise in technical efficiency and productivity, and vice versa. The findings indicate that a rise in the cultivated area, age, and education level of Tilapia fish farm owners will lead to a decrease in technical inefficiencies in fish farming.

The findings suggest that an expansion in the cultivated area of Tilapia farms will result in a reduction in technical inefficiencies in aquaculture in Kafr El-Sheikh farms. The impact of age on farm productivity suggests that increased age correlates with greater experience in fish production. This, along with the increasing level of education, indicates that fish farming necessitates a certain degree of technical expertise to effectively manage the intricate biological processes occurring in aquatic environments. This is consistent with Samuel (2023), who refers to older fishers as being more catch-efficient. Additionally, the experience of the fisher correlates with their age. Literate fishers demonstrate greater catch efficiency. Conversely, Mussa et al. (2020) found a positive correlation between the age of Tilapia producers and technical inefficiency. Younger farmers exhibit greater efficiency compared to their older counterparts due to their flexibility and adaptability to environmental changes.

The results also indicate that though years of experience have a statistically significant impact at a 1% level, they do not significantly decrease technical inefficiencies. This means experienced farmers were older. Conversely, most farmers in the study areas lack formal education, with approximately 25% being illiterate. This lack of education hampers their capacity to effectively manage and implement technology on their farms, leading to a decline in fish production. The study by Islam et al. (2016) supports these findings, revealing that Malaysian farmers' insufficient expertise in cage culture activities leads to cage farms' inefficiency. Phiri and Yuan (2018) and Mussa et al. (2020) also found that the number of years of experience a fish farmer has is insignificant due to producers' persistence in using antiquated, potentially less efficient methods and practices. Gwazani et al. (2022) also indicated that experienced farmers were older and exhibited a more conservative disposition, showing less receptiveness to change and new technology. They partially attributed the inefficiency associated with experience to a reduced level of commitment. In contrast, Achoja et al. (2020) and Ikpoza et al. (2021) demonstrate that fishers' age and educational achievement significantly influence the technical efficiency of fish aquaculture. As a result, increasing knowledge and skills in fish farm management will reduce inefficiency in Kafr El-Sheikh.

The estimated variance, $\sigma^2 = 0.0600$, which is an indication of goodness of fit, was statistically significant at the 1% level, which means that the model fits the Tilapia survey data from all districts well. This also means that the model's distribution assumption for the composite error term is correct (Rachmina et al., 2014). This value indicates that inefficiency is significant in Tilapia farmers' production activities. The estimated gamma (γ) coefficient is 0.981, which measures the variability of the two sources of error and was statistically significant at the 1% level (Table 3). This finding suggests that technical inefficiency, rather than random shocks, primarily causes fluctuations in fish farming production. This also implies that factors within the producers' control accounted for approximately 98% of the total variations in Tilapia output. The findings indicate that approximately 2% of the fluctuations in Tilapia production among the surveyed fish farmers are attributable to random shocks beyond the farmers' control. These unpredictable disturbances encompass unfavorable meteorological conditions, illnesses, and inaccuracies in data measurement. This is consistent with Phiri and Yuan (2018) and Mussa et al. (2020), who found that about 99% and 86%, respectively, of the total variations in Tilapia output for the producers were due to factors within their control in Malawi and China. Additionally, Asmare and Aragaw (2024) discovered that the technical inefficiency effect was responsible for 81.6% of the variation in fish caught from the frontier level of output in Ethiopia.

The anticipated average technical efficiencies (TE) of all the farms included in the sample is approximately 79.8%. This finding reveals substantial technical inefficiency

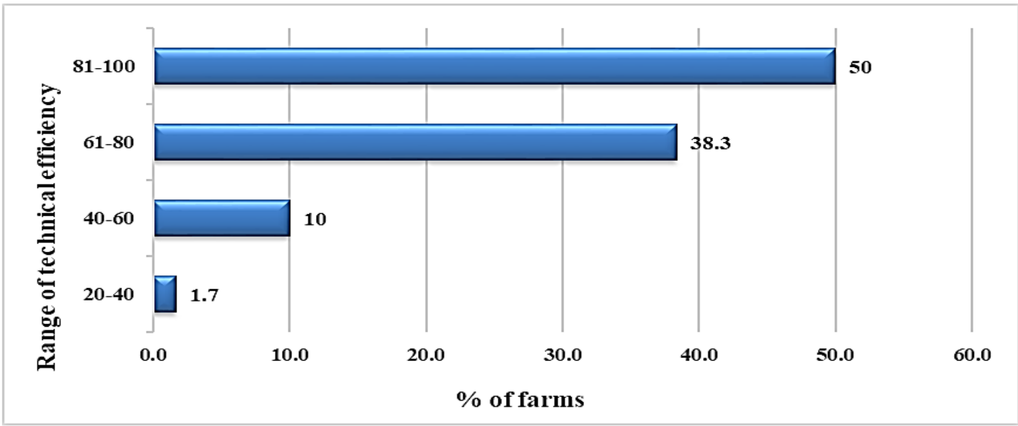

Fig. 6: Frequency distribution of technical efficiency for fish farms in Kafr El-Shiekh

among Tilapia farmers. The impact of inefficiency prevents approximately 20.2% from achieving their goals. This also means that there is significant potential to enhance Tilapia production by improving the efficiency of fish farm management in Kafr El-Sheikh. It is in line with the findings of Islam et al. (2016), who emphasize the need for enhanced efficiency in cage culture management in Peninsular Malaysia to boost fish production. Furthermore, Rossignoli et al. (2023) indicated that optimizing farm management is essential for augmenting the efficacy of Tilapia aquaculture systems in Egypt. Samuel (2023) indicated that this may relate to various aspects of fishing, including the types of inputs utilized, technology, and the managerial skills of fishers, which contribute to improved catch efficiency in Nigeria.

Furthermore, it notes that the mean technical efficiency level of fish farmers ranged from 53.5% to 79% in Ethiopia, Ghana, Zimbabwe, and Nigeria (Asmare & Aragaw, 2024; Crentsil & Essilfie, 2014; Gwazani et al., 2022; Ikpoza et al., 2021; Isiaka & Damilola, 2019). This means that the technical efficiency level of small-scale fish farmers is consistent across developing countries.

Fig. 6 shows the distribution of the technical efficiency estimates of the Tilapia farmers in Kafr El-Shiekh. It suggests that Tilapia farmers can enhance their output by 20.2% on average by optimizing their current input levels. Mussa et al. (2020) suggest that enhancing farm-specific factors such as training, access, and frequency of extension visits and the provision of high-quality feed and seed could enhance the existing Tilapia production in Malawi by 34%. Therefore, the findings indicate that there is a significant possibility to enhance Tilapia production in Kafr El-Sheikh farms by improving technical efficiency. The farm with the lowest level of technical efficiency could achieve a savings of 64.2% on inputs; that is, (1 − (35.3/98.6) × 100). The findings suggest that the existing technical inefficiency substantially impacts the quantities and variability of fish production in Kafr El-Sheikh farms. Fig. 6 illustrates the distribution of anticipated efficiency levels for aquaculture production in the study regions. The Fig. reveals that 50% of Tilapia farmers run their farms with an efficiency ranging from 81% to 100%. Furthermore, Isiaka & Damilola (2019) and Gwazani et al. (2022) proposed that concurrent technological advancement, a reduction in farm-level inefficiencies, and the implementation of user-friendly policies can achieve an increase in production through enhanced technical efficiency, independent of increases in input quantity.

Conclusion and Recommendations

The study's findings indicate that Tilapia farms in the examined areas exhibited technical inefficiency, resulting in fluctuations in fish farming production. Approximately 98% of the factors contributing to technical inefficiency are within the producers' control, including the age, experience, and educational level of Tilapia fish farmers. This impacted the farms' capacity to operate at their maximum production potential, which in turn hindered the farmers' ability to manage their fish farms effectively, leading to a reduction in fish production. The study recommends the implementation of extension programs at the farm level to assist Tilapia fish farmers in optimizing their resource utilization and thereby significantly enhancing their fish production. Farmers should augment their expertise and understanding to promote optimal farm management practices, which are crucial for boosting their economic returns.

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